Water Quality Pollutant Types and Sources Report: Black Ross Water Quality Improvement Plan

September 2009

Australian Government

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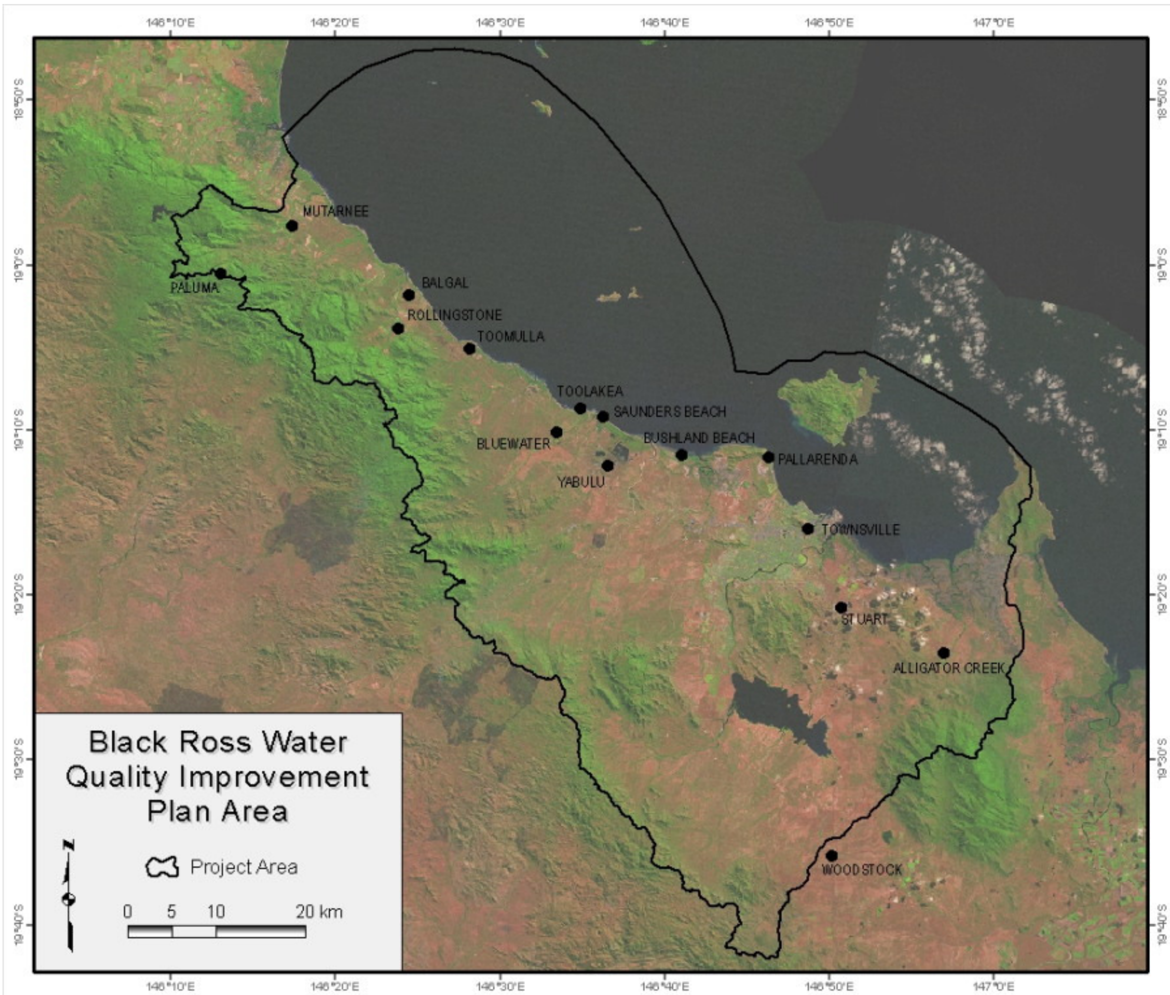
1. Introduction

1.1 Background

Creek to Coral managed the Townsville Coastal Catchments Initiative (CCI) project and along with its many partners prepared a Water Quality Improvement Plan (WQIP) for the Black and Ross River Basins. The Black Ross (Townsville) WQIP area extends from Crystal Creek in the north to Cape Cleveland in the south and encompasses all the waterways that flow to Cleveland Bay and Halifax Bay. The area also covers Magnetic Island and surrounding marine waters (see Figure 1.1).

Figure 1.1 Black Ross WQIP Area



One of the main tasks associated with the development of the WQIP was the identification of pollutants and their sources including; the location of major constructed discharge points for pollutants, the location of near shore facilities that are likely to contribute pollutant loads to receiving waters and the amount of diffuse source pollutants impacting waterways.

This document provides information on potential point source pollutant emitters including the location of discharge points in relation to waterways, pollutant types and known emissions. Diffuse pollutant types and potential sources are also identified and discussed in terms of both the urban and rural settings.

2. Point Sources

2.1 Point Source Discharge

Point source pollution is relatively easily identified as it involves intensive land use in a relatively small area. The pollutants, generally waste products, generated by the intensive activity are discharged from the facility at a specific point or points e.g. pipe or chimney, hence the name point source discharge.

2.2 Identifying Point Sources

Many of the potential point source activities are relatively well known in the Townsville region, as they are a conspicuous part of the landscape. The two main data sets used to identify less obvious point source discharges and to confirm discharge types are:

- Environmentally Relevant Activities (licensed through the Environmental Protection Agency); and
- The National Pollutant Inventory (http://www.npi.gov.au).

2.2.1 Environmentally Relevant Activities

A list of licensed Environmentally Relevant Activities (ERAs) in the Black Ross WQIP area were provided to Creek to Coral by the Environmental Protection Agency (EPA). A summary of the ERA information is listed in Table 2.1 including a qualitative assessment of the potential risk to surface water quality of the activity.

Table 2.1 ERAs in the Black Ross WQIP area

ERA No.	ERA description	Count	Potential Discharge	WQ Risk
1	Aquaculture	5	Water, Land	Moderate
6 [7]	Chemical manufacturing, processing or mixing	10	Air, Land	Low
7 [8]	Chemical storage	15	Air, Land	Low
9 [10]	Gas producing	1	Air	Low
10 [7]	Paint manufacturing	1	Air, Land	Low
11 [8]	Crude oil storing or petroleum product storing	21	Air, Land	Low
14 [x]	Crematorium	1	Air	Low
15 [63]	Sewage treatment	18	Water, Land, Air	High
16 [64]	Municipal water treatment plant	4	Water, Land	Moderate
17 [15]	Fuel burning	6	Air	Low
18 [14]	Power station	4	Air, Land, Water	Moderate/High
19 [16]	Dredging material	16	Water, Land	Moderate
20 [16]	Extracting rock or other material	20	Air, Land	Low
22 [16]	Screening etc. materials	13	Air, Land	Low
23 [17]	Abrasive blasting	7	Air, Land	Low
24 [18]	Boiler making or engineering	3	Air, Land	Low
25 [38]	Metal surface coating	11	Air, Land	Low
26 [19]	Metal forming	2	Air, Land	Low
28 [21]	Motor vehicle workshop	18	Air, Land	Low
32 [25]	Meat processing	1	Air, Land, Water	Moderate/High
35 [x]	Smoking, drying or curing works	1	Air	Low
40 [29]	Metal foundry	4	Air, Land, Water	Moderate/High
41 [30]	Metal works	2	Air, Land	Moderate
52 [37]	Printing	1	Air	Low
53	Soil conditioner manufacturing	2	Air, Land	Moderate
57 [13]	Tyre manufacturing or retreading	1	Air, Land	Low
62 [43]	Concrete batching	4	Air, Land	Low
67 [47]	Sawmilling or woodchipping	2	Air, Land	Moderate

71 [x]	Port	1	Air, Land, Water	High
72 [x]	Railway facility	1	Land, Air	Moderate
73 [x]	Marina or seaplane mooring	1	Water, Air	Moderate
74 [50]	Stockpiling, loading or unloading goods in bulk	17	Air, Land	Moderate
75 [60]	Waste disposal	2	Land, Air, Water	Moderate
76 [61]	Incinerating waste	3	Air, Land	Low
78 [55]	Chemical or oil recycling	3	Land	Low
79 [54]	Drum reconditioning	1	Air, Land	Low
81 [55]	Recycling or reprocessing regulated waste	1	Air, Land	Low
83 [57]	Regulated waste transport	32	Land	Low
84 [56]	Regulated waste storage	14	Land	Low
85 [58]	Regulated waste treatment	4	Land	Low
	Total ERAs	274		

Note: ERA numbers have been changed since EPA provided the listing. The new numbers (2008) from EP Regulations are provided in square brackets beside the old numbers, if they have changed. [x] indicates that the activity is no longer listed as an ERA.

[1]Certain types of agricultural activity were added to the list of ERAs in 2009 with the passing of the Great Barrier Reef Protection Amendment Act 2009 (Act No. 42 of 2009)

Risk levels

The low level of risk assigned to activities involving potentially toxic chemicals and hydrocarbons is based on the proximity of the activities to waterways and the assumption that the ERA licensing process ensures that the chemicals are stored in a safe and secure manner i.e. bunded. It is recognised that chemical contamination of waterways is a potentially serious issue however the risk level is not considered to be high given the low likelihood of uncontained spills entering waterways.

Where the principal discharge pathway of an activity is to air it was assumed that only high emission activities had the potential to have an impact on water quality so low emission activities were rated as low risk. Where the secondary discharge pathway of a low risk activity was to land it was assumed that ERA licensing conditions would also ensure that any potential discharge to land is managed appropriately and will not result in a subsequence discharge to water. No discharge data was available for the ERAs.

Moderate and high-risk activities involve either potential direct discharge to water or high levels of emissions to air. While emanating from a point source the emissions to air will be treated as diffuse sources as the plume containing the pollutants disperses and some of the pollutants will eventually settle on the land and water over a broader area. Dispersion modelling is required to more accurately determine the extent and concentration of the pollutants and potential implications for water quality.

Townsville ERAs

At the time of listing (early 2008), there were 168 ERA approvals in the Black Ross (Townsville) WQIP area, with many enterprises having more than one ERA attached. These are listed in Table 2.2. The assumed primary ERA activities associated with the licenses are listed in Table 2.3.

Table 2.2 Number of ERAs per approval/licence

ERAs	1	2	3	4	5	6	7	8	14
Count	121	25	9	7	0	3	0	2	1
Percentage	72	14.9	5.4	4.2	0.0	1.8	0.0	1.2	0.6

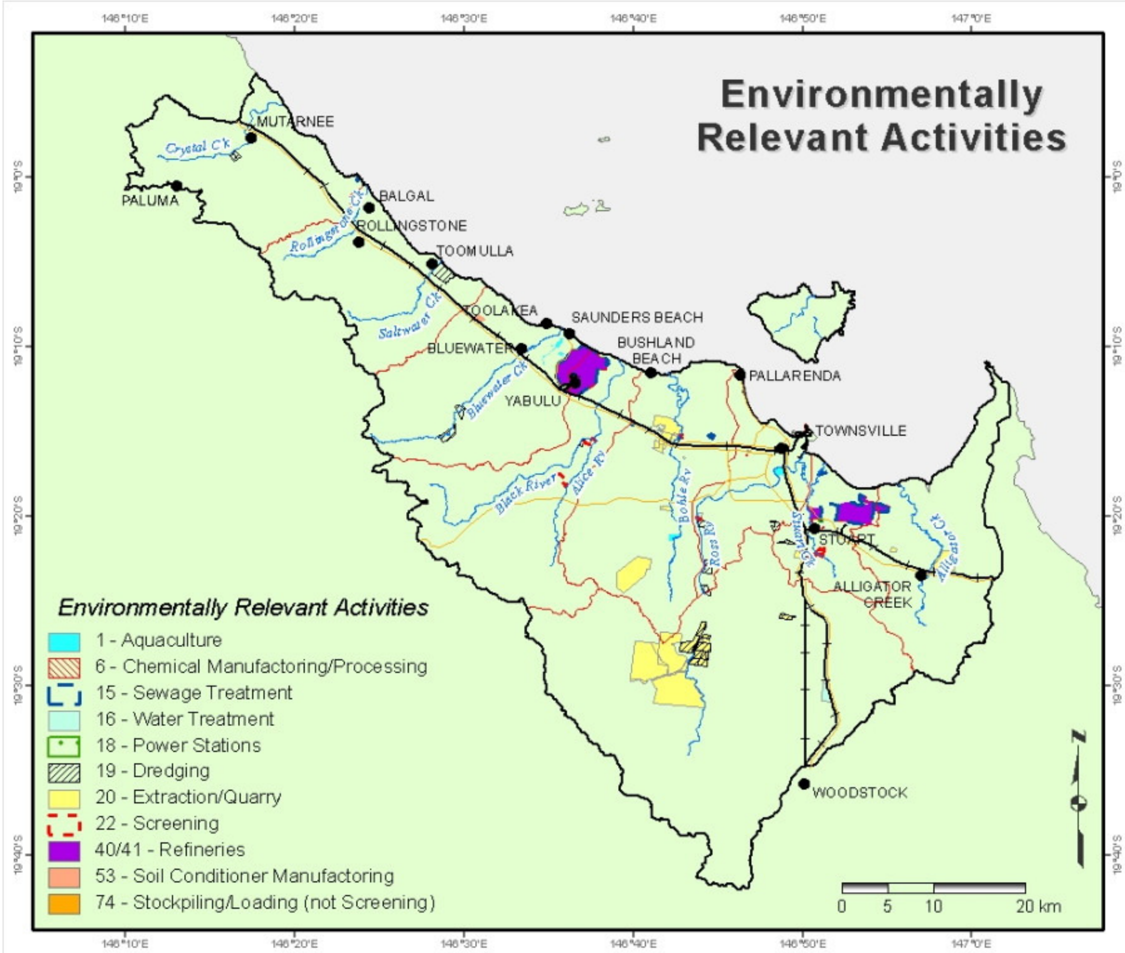
Table 2.3 Primary ERA Count

ERA No.	ERA description	Primary ERA (assumed)				
		1 Count	2 Count	3 Count	4 Count	6 Count
1	Aquaculture	5				
6 [7]	Chemical manufacturing, processing or mixing	3	3			
7 [8]	Chemical storage	3	2			
9 [10]	Gas producing	1				
10 [7]	Paint manufacturing	1				
11 [8]	Crude oil storing or petroleum product storing	4	1			
14 [x]	Crematorium	1				
15 [63]	Sewage treatment	14				
16 [64]	Municipal water treatment plant	3	1			
17 [15]	Fuel burning	2				
18 [14]	Power station		1	2		
19 [16]	Dredging material	10	3	1	2	
20 [16]	Extracting rock or other material	6	4		3	
22 [16]	Screening etc. materials	2	1			
23 [17]	Abrasive blasting	1	2	1		
24 [18]	Boiler making or engineering		1		1	
25 [38]	Metal surface coating		4			
28 [21]	Motor vehicle workshop	9				
32 [25]	Meat processing					1
35 [x]	Smoking, drying or curing works	1				
40 [29]	Metal foundry	2				
52 [37]	Printing			1		
53	Soil conditioner manufacturing	1				
57 [13]	Tyre manufacturing or retreading	1				
62 [43]	Concrete batching	2				
67 [47]	Sawmilling or woodchipping	2				
71 [x]	Port			1		
72 [x]	Railway facility	1				
73 [x]	Marina or seaplane mooring			1		
74 [50]	Stockpiling, loading or unloading goods in bulk	11	1	1		
75 [60]	Waste disposal			1		
76 [61]	Incinerating waste					1
78 [55]	Chemical or oil recycling	1			1	
84 [56]	Regulated waste storage	4	1			
85 [58]	Regulated waste treatment					1
	Total ERAs	91	25	9	7	3

Note: 30 of the ERA licences were for regulated waste transport and were not included as a potential point source discharge as it is an itinerant activity. From Table 2.2 the 2 metal foundries (Sunmetals and Xstrata) had 8 ERAs and the activity with 14 ERAs was a metal works (Yabulu) and power station.

ERA numbers have been changed since EPA provided the listing. The new numbers (2008) from EP Regulations are provided in square brackets beside the old numbers, if they have changed. [x] indicates that the activity is no longer listed as an ERA

Figure 2.1 ERA Locations in the Black Ross WQIP Area



Note: ERA numbers have changed since EPA provided the listing. See Table 2.3 for relevant new numbers

2.2.2 About the National Pollutant Inventory data

The National Pollutant Inventory (NPI) is the Australian Government central pollutant reporting and information system, which reports on pollutant emissions from industry and diffuse sources.

"*The NPI holds pollutant emissions data reported by industrial facilities, and diffuse data determined by state and territory environment agencies. Industrial facilities are required to annually report emissions to the NPI if they exceed NPI reporting thresholds for one or more NPI substances*". Reporting thresholds are listed in Appendix A.

"*The 90 NPI substances span a wide range of toxicities. A small amount of a highly toxic substance may be of more concern than a larger emission of a less toxic substance.*"

"*Commonwealth, state and territory environment agencies have approved the techniques used to estimate emissions for the NPI. It is important to note that the accuracy of these techniques varies. Industrial facilities estimate pollutant emissions using techniques described in an industry NPI manual, or else otherwise approved.*" (Source: http://www.npi.gov.au/database/data-explanation.html)

The ultimate fate of NPI substances emitted to the environment varies the impacts they have on human health and the environment. The pollution exposure to humans and the environment cannot be determined solely from the NPI point source data. Many additional factors determine whether a pollutant emission to air is felt as ground level pollution.

Examples of additional factors are the:

- Height of an emission above the ground (high stacks versus ground level vehicle exhausts);
- Nature of receiving environments;
- Chemical reactivity of the substance; and
- Prevailing weather conditions.

Since NPI does not attempt to collect information about these additional factors, NPI data can only reflect pollutant emissions at the emission source. The data for emissions to air from point source facilities will therefore be treated as diffuse source pollutants as they are dispersed and settle over a broader area. This is also the case for fugitive emissions i.e. emissions that 'escape' to the air rather than being released from a smoke stack.

Townsville facilities that report emissions through the NPI are listed in Table 2.4. Emissions to air may be either from a stack, fugitive or both.

Table 2.4 NPI Point Sources for Black Ross WQIP

Facility	Manager	Location	Emission type/s	Waterway
BP Australia - Townsville Terminal	BP Australia Pty Ltd	South Townsville	Air	
Cannington Port Facility	BHP Billington Mineral Pty Ltd	Townsville	Air	
QNI Townsville Port Bulk Fuel Facility	Queensland Nickel P/L	South Townsville	Air	
QNI Yabulu Refinery - Materials Handing Facility	Queensland Nickel P/L	Townsville	Air Water	Ross Creek / Cleveland Bay
Queensland Terminals	Queensland Terminals Pty Ltd	South Townsville	Air	
Southern Cross Fertilisers - Townsville Port Facility	Southern Cross Fertilisers Pty Ltd	Townsville	Air	
Townsville Port	Northern Shipping and Stevedoring P/L	Townsville	Air	
Townsville Terminal	The Shell Company of Aust. Ltd	Townsville	Air	
Xstrata Copper - Townsville Port Ops	Copper Refineries P/L	Townsville	Air Water	Ross Creek / Cleveland Bay
Townsville Port in general	All of the above	Townsville Port	As above	As above
Cleveland Bay STP	Townsville City Council	Townsville	Water	Sandfly Creek / Cleveland Bay
Copper Refinery	Copper Refineries Pty Ltd - Xstrata Copper	Stuart	Air	
Origin Power Station (Near Xstrata)	Origin Energy Aust Holding B.V.	Stuart	Air	Stack
New Railway Facility	Queensland Rail	Stuart	Air	
Stuart Railway Facility	Queensland Rail	Stuart	Air	
Zinc Refinery	Sunmetals Corp Pty Ltd	Stuart	Air Land	Stack
Townsville Abattoir	Australia Meat Holdings Pty Ltd	Stuart	Air	Stack
Douglas Water Treatment Plant	Townsville City Council	Douglas	Air	Ross River
Hanson Townsville Quarry	Hanson Construction Materials Pty Ltd	Townsville	Air	NW quarry

Condon Sewage Treatment Plant	Thuringowa City Council	Condon	Land Water	Bohle River
Townsville Airport Fuelling Service	The Shell Company of Aust. Ltd	Garbutt	Air	
Townsville Laundries	Ushers Investments Pty Ltd	Garbutt	Air	
AIR BP Townsville	BP Australia Pty Ltd	Townsville	Air	
Industrial Galvanizers Nth Qld	Industrial Galvanizers Corp P/L	Bohle	Air	
Bohle quarry	CSR Ltd	Bohle	Air	
Deeragun Sewage Treatment Plant	Thuringowa City Council	Deeragun	Land Water	Saunders Creek / Bohle River
Mount Low Sewage Treatment Plant	Thuringowa City Council	Mt Low	Land Water	Black River
Mt St John STP	Townsville City Council	Mt St John	Water	Bohle River
QNI - Yabulu Refinery	Queensland Nickel P/L	Yabulu	Air	Stack
Townsville Power Station	Transfield Townsville Pty Ltd	Yabulu	Air	Stack

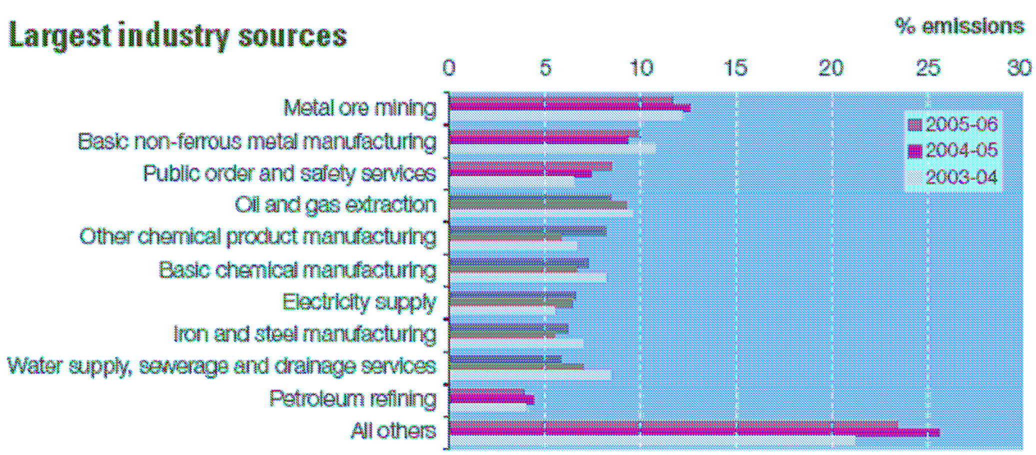
Source: http://www.npi.gov.au/overview/reports/qld-facility-location.html at 8 October 2007

Point source pollutant emissions, according to NPI records, from facilities listed in Table 2.4 are provided in Appendix A. Location of the main NPI emitters in Townsville are shown on Figure 2.3.

2.3 Industry Emission Sources

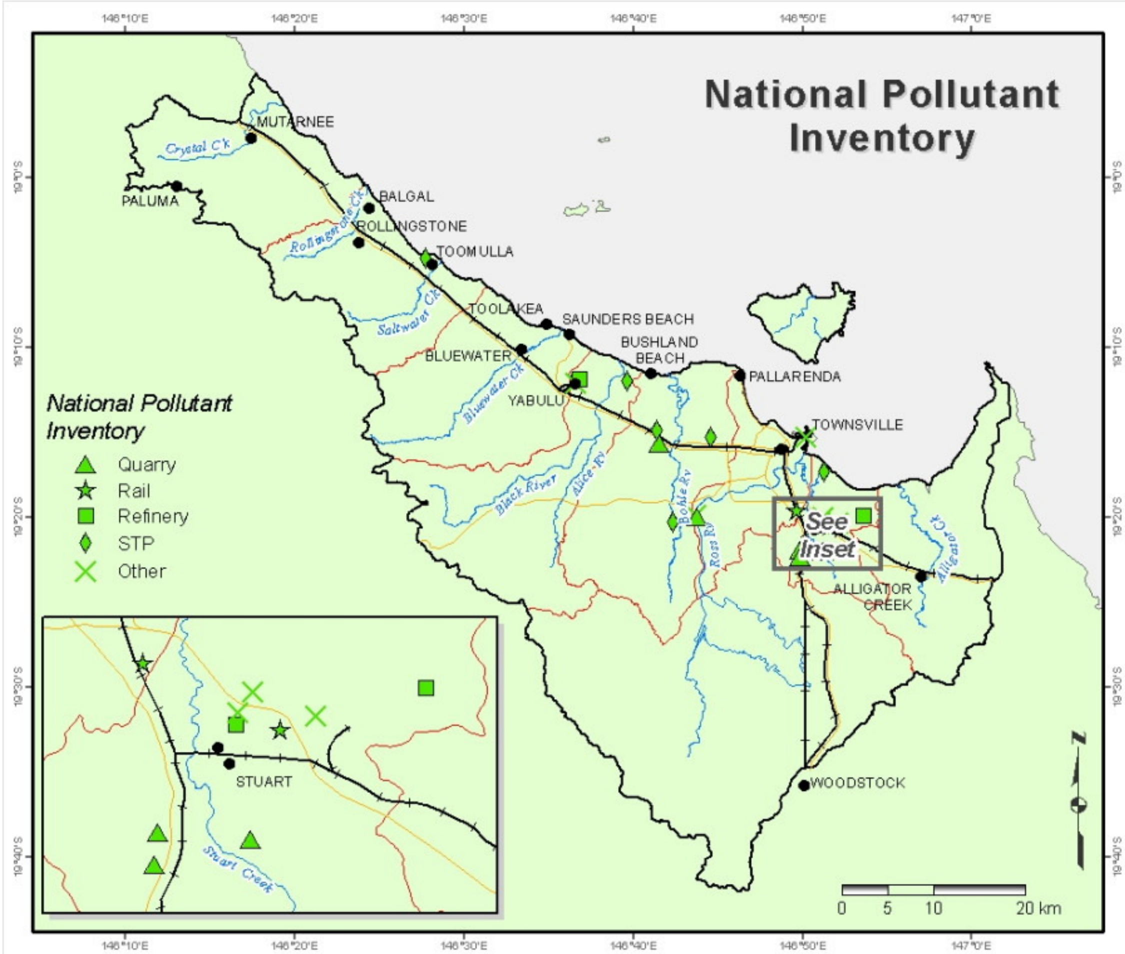
The main industry sources of emissions in Australia, reporting to the NPI, are shown in Figure 2.2 (NPI 2008, p.5). The two main industry sources in Townsville are "*Basic non-ferrous metal manufacturing*" and "*Water supply, sewerage and drainage services*".

Figure 2.2 Main Industry Emission Sources



Source: NPI 2008, p.5

Figure 2.3 NPI Point Source Discharge Locations Townsville City



2.4 Emissions to Water

According to the NPI "*the water, sewerage and drainage sector is the largest emitter of substances to water, followed by the basic chemical manufacturing and metal ore mining sectors*" (NPI 2008, p.13).

This is also the case for the Black Ross WQIP area where sewage, or wastewater treatment plants (WWTPs) are the main source of emissions to water. Details of emissions from these and other point sources are provided in Appendix A with additional information about each of the WWTP sites included in Appendix B.

The majority of the emissions are in the form of nutrients i.e. nitrogen, ammonia and phosphorus. According to the NPI, point source emissions of total nitrogen to water in 2005/06 was 35,000 tonnes compared to diffuse source emissions of 210,000. On the basis of these figures point source emissions account for 14% of total nitrogen emissions to water across Australia.

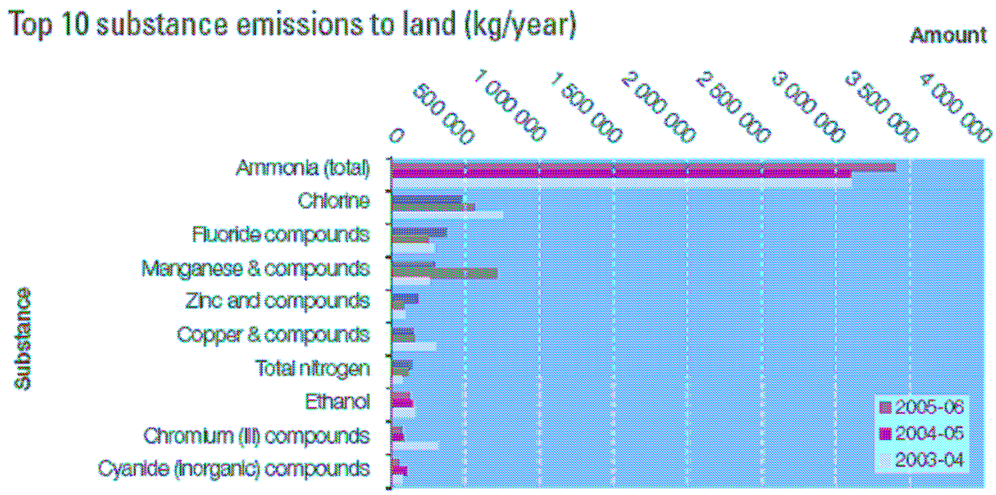
In 2005-06, eighteen facilities reported 76 tonnes of total phosphorus to water in the Murray Darling Basin compared to an estimated 12,000 tonnes of total phosphorus from diffuse sources. Point source emissions of total phosphorus accounted for less than 1% of total phosphorus emissions to water emphasising the relative importance of assumed fertiliser impacts on water quality.

Emissions to water also occur indirectly from the settling of industrial and vehicular atmospheric emissions to air as well as through runoff from land-based substances from industry, agriculture and roads. These indirect emissions to water are further considered in the section on diffuse sources (section 3).

2.5 Emissions to Land

Emissions to land can stem from a variety of sources including industry, vehicular emissions, fertiliser and chemical use in agricultural practices, and atmospheric deposition. While some of the deposition onto land may be secondarily transferred to water bodies through stormwater run-off, a high proportion is likely to remain insitu and have little subsequent impact on water quality; however there may be localised impacts on ecological processes and soil health.

Figure 2.4 Australian Top Ten Land Emissions



Source: NPI 2008, p.14

The main reported sources of emissions to land in the Black Ross WQIP area are wastewater treatment plants (WWTPs).

According to the NPI the main emissions to land are (see Figure 2.4):

- Ammonia - mainly from water supply, sewerage and drainage services and meat and meat product manufacturing;
- Chlorine - mostly from landfill (see waste disposal sector or the public order and safety services sector on the NPI database);
- Fluoride compounds - a range of sources mostly from salt production;
- Manganese and compounds;
- Zinc and compounds – the largest industry source of emissions of zinc and compounds to land is zinc smelting and refining.

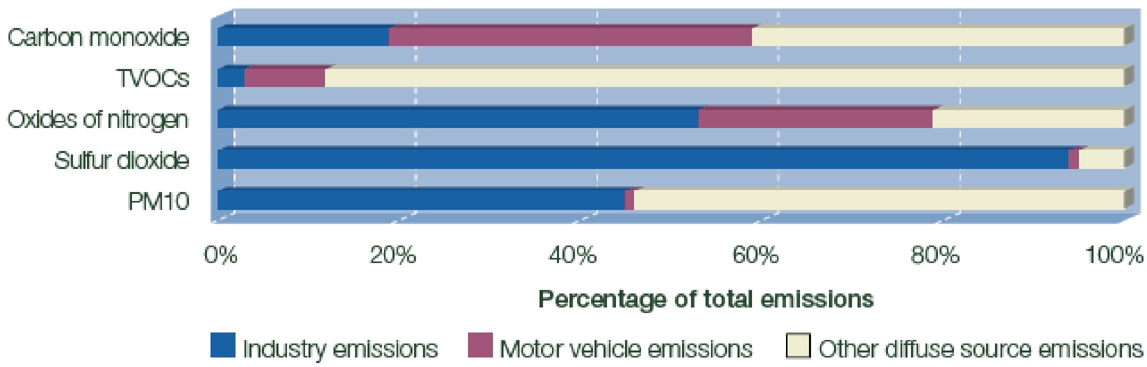
In the case of industry most emissions to land are substance emissions onto a facility's site, which include solid wastes, slurries and sediments, as well as accidental spills, and leaks from facilities. Emissions are usually contained in tailings dams which when decommissioned are capped to prevent water infiltration and subsequent seepage to groundwater.

Point source emissions to land are strictly regulated through the Environmental Protection Act and licensing of ERAs (see section 2.2.1) and are not considered further as a source of surface water quality pollution for this report.

2.6 Emissions to Air

There are a number of industrial activities in the Black Ross (Townsville) WQIP area that produce pollutants that are released into the atmosphere. The main point source emissions to air in the Townsville WQIP area (see Appendix A) include metal refineries such as the Sunmetals Zinc Refinery and the QNI Yabulu Nickel Refinery.

Figure 2.5 NPI Top Five Substances Emitted to Air in Australia 2005-06



Source: NPI 2008, p.12

Emissions to air take two different forms i.e. from chimneys/stacks and as fugitive emissions. Fugitive emissions are more disperse and are not a result of combustion or the burning of fuels in a contained environment where the exhaust emissions are channeled to a specific emission point. Fugitive emissions include vapour loss from tanks and ponds and dust from stockpiling operations.

The likely eventual fate of the non-fugitive industry emissions can be predicted using dispersion models. Inputs to dispersion models include; pollutant types and quantities, emission point above ground, settling rates and wind speed and direction. The fate of fugitive emissions can also be modeled however the results are less accurate due to the semi-diffuse starting point of the emissions. Tracking the fate of fugitive emissions would only be done where emissions are extremely high and the fate was likely to have significant localised impacts e.g. dust or ammonia.

Due to the dispersion of these pollutant emissions to air they are considered as diffuse sources in terms of water quality and are included in section 3 (Diffuse Sources).

2.7 Main Townsville Industry

The main point source pollutant emitters in Townsville have been identified through the Environmentally Relevant Activities (ERA) listing or by their reporting to the National Pollutant Inventory (NPI). The main industrial activities in Townsville are discussed below in terms of their potential to impact water quality. Industries identified as having low potential impact in previous sections are either discussed briefly or not included in the discussion.

2.7.1 Metal Refineries

There are three non-ferrous metal refineries in the Black Ross WQIP area, two in the Stuart industrial area and one at Yabulu (see Figure 2.2). The main emissions from the refineries are to air and as such are initially a potential air quality issue. If the volume of emissions is substantial and the settling rate of the emissions (dryfall atmospheric deposition) is high within a relatively small land and water area then there is also potential for water quality issues. Alternatively if the emissions are retained in the airshed in high quantities then there is potential for wet fall deposition via rainfall (see section 4.1).

Emissions from the refineries as reported to the NPI are included in Appendix A. Air quality monitoring associated with industry emissions from the metal refineries are discussed in sections 4.3 and 4.4, with additional information for the Yabulu nickel refinery in Appendix C.

From the available information it appears that the airborne emissions from the metal refineries are not a significant water quality issue. The emissions are within acceptable air quality standards and the dispersion of the pollutants throughout the airshed renders them innocuous in terms of water quality.

The main potential for water quality issues associated with the metal refineries relates to the land-based disposal of waste from the refining process, which is stored in 'tailings' dams. These are engineered stockpiles with requirements to ensure there is no leakage to the surrounding environment. Issues for water quality could arise if there was a failure in the waste management system either through failure of the physical infrastructure e.g. dam lining or walls, or the environmental management systems e.g. turning the wrong valve.

Given the number of ERAs associated with the refineries it is assumed that the necessary safeguards and systems are in place to prevent any such failures occurring. Results of water quality monitoring programs have not identified any water quality issues associated with the metal refineries in the Black Ross WQIP area.

2.7.2 Power Stations

There are two power stations listed in the NPI, one in the vicinity of the Yabulu nickel refinery and the other near the Xstrata copper refinery.

The Townsville Power Station at Yabulu was commissioned in 1996 after the Queensland Supply and Transmission Corporation sought competitive proposals to meet growing electricity demand utilising private power plants. The 160 megawatt peak-load power station was completed in 1999 by Transfield.

Transfield completed a $115 million redevelopment of the power station in 2005 increasing its capacity to a 240 MW gas fired, base loading plant. The upgrade was in conjunction with development of coal seam gas supplies in Moranbah and the construction by Enertrade of the 400km North Queensland Gas Pipeline. In the first 12 months of operation over 12 petajoules of gas was delivered to the Townsville Power Station by the gas pipeline, the equivalent of over 12,000 semi-trailer loads of LPG.

The Origin power station at Mt Stuart is a 288 MW gas turbine peaking plant which runs on kerosene. The plant can be readily converted to natural gas. In early 2008 Origin announced a $92 million expansion with the installation of a 126MW Frame 9E gas turbine generator set. This will result in a 45% increase in electricity output and is planned to come online in mid-2009. With the extra generator on site, Mt Stuart will have the capacity to generate power to around 255,000 homes.

As both power stations are either gas or kerosene fuelled, and relatively small compared to coal fired power stations (20% of the capacity of Tarong), their emissions are not as voluminous or 'dirty' and as coal-fired power stations. Emissions as reported to the NPI are listed in Appendix A and are not considered to be a significant water quality issue.

In 2006-07 Australia had 47,400 MW of installed electricity generation capacity. By comparison the combined capacity of Townsville's power stations is approximately 520 MW i.e. approximately 1% of Australia's capacity.

2.7.3 Townsville Port

The Townsville Port has a history dating back to the 1890s. A number of facilities in and around the port have been identified through the NPI and ERA licences. The main facilities. The main port facilities are shown in Figure 2.6, including those listed through the NPI or ERA licenses. The facilities are listed in Table 2.5 with reference to the numbering in Figure 2.6.

Figure 2.6 Potential Pollutant Sources at Townsville Port

Source: http://www.townsville-port.com.au/

The main berths are listed below with reference to the numbering in Figure 2.6.

Table 2.5 Townsville Port Facilities

No.	Facility	No.	Facility
13	Magnetic Island Car Ferry	29	Queensland Terminals
17 & 18	Queensland Sugar (Bulk sugar sheds)	31	Incitec Pivot
19	Northern Shipping and Stevedoring	32	Cement Australia
21	Xstrata	33	Shell
22	Australian Molasses Trading	37	Incitec Pivot
23	Chemtrans	38	Tropical Distributors
24	Origin Energy	39	Simsmetal
27	BHP Billiton Yabulu	40	BP Australia
28	BHP Billiton Cannington	47	Powerlink

Source: http://www.townsville-port.com.au/

Townsville Port handles a variety of imports and exports and involves bulk handling and storage of a number of materials including metal ores, fuel and chemicals. Products and materials handled at the Townsville Port are listed in Table 2.6.

Table 2.6 Townsville Port Imports and Exports

Imports
Zinc concentrates – for the Sunmetal refinery (244,000)
Nickel ore – for refining at Yabulu (2,928,000)
Oil products – for Shell, BP, Caltex and Ampol (1,140,000 includes 214,000 for Yabulu)
Cement – from Gladstone (582,000)
Fertiliser – principally nitrogen based for Incitec Pivot (96,000)
Sulphur – for use by Southern Cross Fertilisers (SCF) in fertiliser production (126,000)
Sulphuric acid - by Queensland Terminals for SCF to produce phosphate fertiliser
Motor vehicles – various makes (22,000)
General cargo (145,000)
Exports
Metallurgical coke – produced at Bowen and bound for European markets
Metal concentrates – to Europe and Asia (1,427,000)
Refined copper – from Xstrata refinery (177,000)
Nickel (413)
Zinc ingots (140,000)
Lead ingots (187,000)
Cattle – live trade to Phillipines, Brunei, Vietnam and Egypt (14,000)
Meat and meat by-products (8,000 tallow)
Fertiliser – Southern Cross Fertiliser export around 900,000 tonnes a year (778,000)
Sulphuric acid - Southern Cross Fertiliser excess produced at Phosphate Hill fertiliser plant (55,000)
Sugar (1,184,000)
Molasses – from Burdekin and Herbert sugar mills (223,000)
Feed pellets – for cattle on route to final destinations
Timber (115,000)
Sand and gravel – to Palm Island (35,000)
General cargo (176,000)

Source: http://www.townsville-port.com.au/ Note: Figures in brackets are imports/exports in tonnes for the 2007/08 financial year.

With the array of facilities, facility operators and potential for environmental harm associated with activities at the Port of Townsville it is essential to have adequate environmental safeguards in place. The Townsville Port Authority (TPA) is responsible for the overall coordination of environmental management within the limits of the port, which involves working with other port users and setting environmental standards for the operation of the port.

This has involved, amongst other things, the development of an Environmental Management Strategy for the Port of Townsville, in conjunction with the port community, and the preparation of Environmental Management Plans, Codes of Practice, Development Guidelines and the development of a research and monitoring program. Other port users are also responsible for preparing and implementing Environmental Management Plans and Emergency Response Plans specific to their own operations, and linked to the TPA Integrated Environmental Management System.

TPA and port users undertake a wide range of research and monitoring programs throughout the Port of Townsville including monitoring of; air (fugitive dust emissions), sediments (receiving environments), water (receiving waters), noise, stormwater (site specific), groundwater, trade waste and pests.

A water quality monitoring program was implemented in 2004 consisting of bi-annual (pre and post wet season) collection of samples at over 30 sites within Ross Creek, Ross River, Inner Harbour, Outer Harbour and the Sea Channel.

Fugitive dust emissions create nuisance deposits in the vicinity of the port and some of the dust would be washed into stormwater systems in rainfall run-off adding to the input from urban areas. While there are days where air quality is compromised by particulate matter (dust) from port operations the amount of particulate material is not large enough to have a significant direct impact on water quality. Air quality monitoring is discussed in section 4.4.

Figure 2.7 Townsville Port Loading/Unloading Facilities

Source: J Gunn (CCI\Images\20081216 port\wide angle crop)

2.7.4 Fuel and chemical storage

Fuel and chemical facilities are associated with the Townsville Port, Townsville Airport, the metal refineries and a number of other industries around Townsville. The main emissions are fugitive (see section 4.3) and are readily dispersed and volatalised. The main risk to water quality would be through leakage and spills. The activities are ERAs and subject to relatively strict licensing conditions, which covers bunding of storages and emergency back up responses. As this type of activity is a potential hazard rather than a known regular water quality pollutant it is not considered further in this report.

2.7.5 Meatworks

Abattoirs create nutrient rich effluent as a waste product, which is normally held in anaerobic fermentation ponds where a significant proportion of the nitrogen is converted to ammonia. The ammonia escapes as fugitive emissions and is reportable through the NPI. Meat processing is also an ERA and is subject to a variety of conditions associated with the disposal of the effluent i.e. conditions applied to the irrigation of effluent onto pasture etc.

Australian Meat Holdings (AMH) monitors their site, including air monitoring of particles at ground level, and it is assumed complies with its ERA licence conditions. Regardless of compliance with licence conditions the addition of nutrients to the Stuart Creek catchment through effluent irrigation may result in impacts on receiving waters through run-off and infiltration. The incremental accumulation of nutrients can be subtle and may only show up over time with regular monitoring.

2.7.6 Dredging

Dredging is an ERA often associated with sand and gravel extraction from watercourses, or at least environments where water is present. The disturbance to waterways in itself does not necessarily result in an increase in sediment or nutrients but may result in the resuspension and mobilisation of otherwise sedentary materials. As dredging is an ERA and conditions are imposed on the activity and it does not generally create ‘new’ pollutants it is not further considered in this report.

2.7.7 Quarrying

Quarrying is generally a hard rock, dry extraction process for construction materials. As such it has the potential to generate significant quantities of particulate matter (dust). Most of the dust settles in the vicinity of quarry operations and then has the potential to be carried in stormwater to add to the load of sediment in receiving waters. As an ERA the activity is subject to licensing conditions including dust suppression measures and stormwater management.

Regardless of the measures put in place it is assumed that some material will escape the bounds of quarry operations and have some impact on water quality. While the impact is not likely to be high in terms of overall load the actual contribution of sediment from quarrying operations cannot be quantified without targeted water quality monitoring in the vicinity of the operations. As with other industrial activities it is considered that there is an input to catchment loads from quarrying albeit not quantified.

2.7.8 Aquaculture

As an ERA aquaculture is heavily regulated and has additional development assessment criteria to meet as a result of legislation instigated by the Great Barrier Reef Marine Park Authority (GBRMPA). While technically being a point source industry aquaculture is considered to be a diffuse source by the NPI. Aquaculture is discussed in more detail in the section on diffuse sources (see section 3.7.3).

2.7.9 Soil conditioner manufacturing

Soil conditioner manufacturing is the process of turning organic material into compost. While there is potential for nutrient and sediment release from this activity the main issue may be the biochemical oxygen demand (BOD) associated with organic material from a composting operation entering receiving waters. There is only one ERA licence issued for this activity and it is assumed that the conditions attached to the ERA reduce the potential impacts of the activity on water quality.

2.7.10 Sawmilling and woodchipping

Sawmilling and woodchipping can be a precursor stage to soil conditioner manufacturing although the product is coarser and the organic breakdown and release of nutrients has not reached the same level as with compost. There is less potential impact in that respect and again the activity is regulated as an ERA and there is no evidence to suggest the activity has a significant impact on water quality.

2.8 Public Utilities

In addition to the main industrial activities public utilities and infrastructure also have the potential to impact water quality. The main public utilities with potential to impact water quality are discussed below.

2.8.1 Water Treatment

The Douglas Water Treatment Plant (DWTP) is the major water treatment and storage plant in Townsville. The water travels 9.2 kilometres from Ross River Dam to Douglas, in a 1.22m diameter concrete pipe. The DWTP treats on average 150 ML (megalitres) of water everyday. Note that 1ML is equal to 1 million litres.

The DWTP is operated in compliance with the International Quality Standards ISO 9001 and with the International Environmental Management Standards ISO 14001. Treated water meets the standards set out in the National Health and Medical Research Council (NHMRC) report "Australian Drinking Water Guidelines".
(Source: formerly available online at http://www.townsville.qld.gov.au/citiwater/douglas.asp)

Both the Mt Spec (Kinduro) water treatment plant and the DWTP are being upgraded to cope with the increased demand for potable water in Townsville. The Mt Spec plant upgrade involves the construction of a new 40ML per day water treatment plant on elevated land at Kinduro, north of Hencamp Creek ($23.58m from Qld Govt). Treatment modules at Douglas will be upgraded so the facility can better cope with the high level of treated water needed to be produced ($7.72 m from Qld Govt).

A decision on a subsidy for an additional treatment plant at Toonpan was deferred while the Townsville City Council re-assesses its need following a review of its local bulk water usage allowances and charges.
(Source: Media release 14 August 2008: Hon Warren Pitt MP - Minister for Main Roads and Local Government. http://statements.cabinet.qld.gov.au/MMS/StatementDisplaySingle.aspx?id=59695)

The reported emission through the NPI from the Douglas Water Treatment Plant is chlorine as a fugitive emission to air. The plant has in the past backwashed filters and released the backwash water to the Ross River however that activity ceased as a result of a change to licence conditions associated with the ERA. The plant is not considered to have an impact on water quality and is not considered further.

2.8.2 Sewage and Wastewater Treatment

Sewage and wastewater treatment is by its nature a risk to water quality due to the amount of nutrients in wastewater and the disposal method of the treated effluent i.e. generally to receiving waters. While subject to licence conditions as an ERA wastewater treatment facilities still have a significant direct impact on water quality. As the main point source pollutant activity wastewater treatment facilities are viewed in more detail in section 7.3 and Appendix B.

2.8.3 Railways

Railways are discussed in more detail in the diffuse source section (see section 3.7.9).

2.8.4 Roads

While there can be significant impacts associated with road infrastructure, especially during construction, it is the ongoing processes associated with roadways and the interactions with the stormwater network that makes roads an important consideration in water quality in urban areas. Roads and their role in stormwater processes are discussed in more detail in section 3.6.

2.8.5 Solid Waste Disposal

Solid waste disposal i.e. landfill, is discussed in more detail in the diffuse source section (see section 3.7.10).

3. Diffuse Sources

3.1 Identifying Diffuse Pollutant Sources

Diffuse pollutant sources were identified in the Worsley Parsons (WP) report for the wider Black and Ross River Basins and are summarised below. Additional information is provided from a literature search, with particular emphasis on urban diffuse pollutant sources including those identified through the National Pollutant Inventory (NPI) and by the Cooperate Research Centre for Catchment Hydrology (Catchment CRC).

3.2 Pollutant Source Report (WP)

An investigation was conducted by Worsley Parsons (WP) to identify the key pollutants in the study area and the broad land use classes likely to generate them. The summary results of this study are reproduced in Table 3.1.

Table 3.1 Pollutants by Land Use

Pollutant	Description	Associated Land Use Types
Suspended Solids	Generated when surface water flows collect and transport unstabilised soils and sediment. Can result in smothering of aquatic habitats and restriction of light penetration	Urban (particularly construction), Intensive Agriculture, Rural
Phosphorous	Generated from faecal material, and fertilizers, transported by surface rainfall runoff. Encourages algal growth and eutrophication.	Urban, Industrial, Intensive Agriculture
Nitrogen	Generated from fecal material, and fertilizers, transported by surface rainfall runoff. Encourages algal growth and eutrophication.	Urban, Industrial, Intensive Agriculture
Hydrocarbons	Liquid fuels (diesel, petroleum, oil). Can result in smothering of aquatic habitats. Morbidity and mortality in freshwater species, and impact upon reproductive cycle	Urban, Industrial, Commercial
Tri-butyl Tin	Tri-butyl Tin (TBT) is a common antifouling additive used in paints applied to ship hulls. It is a contaminant that is commonly associated with sediments around ports. Results in morbidity and mortality in freshwater species, and impact upon reproductive cycle	Industrial (Ports)
Herbicides	Applied to gardens and horticulture to control weeds, transported aerially or by surface rainwater runoff. Can result in morbidity and mortality in freshwater species.	Intensive Agriculture, Urban
Pesticides	Applied to gardens and horticulture typically to control pests such as insects, transported aerially or by surface rainwater runoff. Can result in morbidity and mortality in freshwater species.	Intensive Agriculture, Urban
Heavy Metals	Metals such as mercury, arsenic, lead, cadmium. Can result in morbidity and mortality in freshwater species (ecotoxicity).	Urban/Industrial

Source: Worley Parsons 2008, Table 2.2, pp.5-6

Additionally the report identified three non-toxic pollutant sources that could impact water quality:

- Hydrologic stress - results from increases in impervious cover in a catchment, causing higher flow velocities and frequencies than occur naturally;
- Gross pollutants - litter generated typically in commercial areas. This is an aesthetic water quality detractor; however plastic litter in waterways may result in ingestion and associated complications in aquatic animals; and
- Antibiotics and other pharmaceuticals (from treated sewage outflows, septic tanks, intensive animal production) may interfere with normal disease resistance and reproductive cycles of aquatic organisms.

The identified pollutants were then rated based on their properties of; persistence (P), potential to bioaccumulate (B), toxicity (T), and secondary effects (S). The pollutants were then classed as Low, Medium, High or Extreme potential impact [assumed as not stated]. The results of the classification are reproduced in Table 3.2.

Table 3.2 Pollutant Impact Classification

Pollutant	P	B	T	S	Overall score	Score /4	Rank
Total Phosphorous	1	1	1	3	6	1.5	Moderate
Total Nitrogen	1	1	1	3	6	1.5	Moderate
Pathogens	2	1	3	2	8	2	Moderate
Total Suspended Solids	2	1	2	3	8	2	Moderate
Gross Pollutants	3	1	1	3	8	2	Moderate
Hydrocarbons	3	1	2	4	10	2.5	High
Herbicides	3	3	3	2	11	2.75	High
Pesticides	3	3	3	2	11	2.75	High
TBT	3	1	4	3	11	2.75	High
Heavy Metals	4	3	3	3	13	3.25	Extreme

Source: Worley Parsons 2008, Table 3.3, pp.10-1. Note: P is persistence, B is potential to bioaccumulate, T is toxicity, and S is secondary effects. TBT is no longer used for anti fouling of ship hulls in Australia.

On the basis of the [assumed] impact classifications and expected pollutant generation from various secondary land uses the six principal land use classes were then assigned a notional pollutant generation rating (see Table 3.3).

Table 3.3 Pollutant Generation by Land Use

Secondary Land Use Category	Land Use Grouping by Usage Intensity	Notional Pollutant Generation Rating
Nature conservation	Minimal Use (Natural)	Low
Other minimal use		
Marsh/wetland		
Reservoir/dam		
River		
Residential	Urban (residential)/ Rural	Moderate
Grazing natural vegetation		
Intensive animal production	Commercial / Intensive Agricultural	High
Services		
Transport and communication		
Utilities		
Plantation forestry		
Production forestry		
Intensive animal production		
Services		
Transport and communication		
Perennial horticulture		
Irrigated cropping		
Irrigated perennial horticulture		
Irrigated seasonal horticulture		
Manufacturing and industrial	Industry (including ports and railway yards)	Extreme
Mining		
Waste treatment and disposal		

Source: Worley Parsons 2008, Table 3.4, pp.11-12

In essence the QLUMP (1999) land use mapping was transformed into a notional pollutant generation layer based on grouped land uses, associated pollutants and rated pollutant impacts.

The report then assumed that various environmental parameters i.e. slope, vegetation cover, soil erosion potential, rainfall and proximity to waterways, will affect pollutant transport into waterways. These factors were represented as GIS layers and combined with the landuse/pollutant generation layer to produce a pollutant 'hotspot' layer.

"*Pollution hotspots were determined by conducting a raster analysis using 25m cell size grids generated from GIS layers representing environmental pathways. Grids values were non-dimensionalised from 0 to 100 using the ranges described in Table 3.4. The analysis was then conducted by overlaying the grids and summing the values obtained for each. In this way, the effect of the cumulative impacts on waterway health can be investigated holistically and in an objective manner*" (WP 2008, p.14).

Table 3.4 Ranges Used for Hotspot Analysis

Value (0-100)	Variables					
	Landuse	Slope	Vegetation cover	Erosion Potential	Rainfall (mm/yr)	Proximity to Watercourse
0 (No impact)	Minimal use	<2%	Remnant / Bushland	Non erosive	<800	>150m
	Rural / Urban			Moderately erosive		
	Agriculture/ Commercial					
100 (Very High Impact)	Industry	>10%	Cleared	Highly erosive	>2000	0m

Source: Worley Parsons 2008, Table 4.4, p.14

As the hotspot analysis was based on a number of broad assumptions, qualitative assessments, limited data sets and aggregations of data it is difficult for it to accurately reflect the potential for pollutant transport to waterways. As such the hotspot analysis will not be used, as it has the potential to confuse the situation rather than inform it. Some of the background information from the report has been used to further inform this report and is acknowledged where used.

3.3 Other Water Quality Improvement Plans

Water Quality Improvement Plans (WQIPs) have been developed for the (former) Douglas Shire, Mackay Whitsunday NRM region, the Tully catchment and the rural component of Burdekin Dry Tropics NRM region. The Black and Ross WQIP area is part of the Burdekin Dry Tropics NRM region containing the main urban and industrial landuse areas in north Queensland. Some of the key findings from the Mackay Whitsunday and Burdekin WQIPs are presented below.

3.3.1 Mackay Whitsundays WQIP

The WQIP developed for the Mackay Whitsunday NRM region focuses predominantly on grazing and intensive agricultural land uses (sugar cane production) which account for 75% of the area of the region. Point source pollutants were also taken into account through consideration of discharge from sewage treatment plants (STPs) when diffuse source calculations were undertaken. Other minor sources and types of pollution were not considered in determination of pollutant impacts although they were recognised as being present. Relative contributions of the main diffuse source pollutants impacting water quality in the Mackay Whitsunday region were calculated through a combination of modelling and water quality event monitoring. Results are reproduced in Table 3.5.

Areal diffuse source sediment and nutrient generation rates (kg/ha) estimated from local river load data were found to be similar for urban areas and sugar cane growing areas, and the highest of the land use categories. Bushland had the lowest contribution with grazing being intermediate and closer to bushland than the intensive uses.

Table 3.5 MWNRM Land Use Relative Pollutant Contributions

Land use	% land use	% DIN	% PN	% FRP	% PP	% TSS	% Pest1	% Pest2
Conservation	17	1	6	0	2	39	0	0
Grazing	56	12	34	5	28	29	0	100
Horticulture	<1	1	1	1	1	<1	<1	0
Cane	19	77	53	84	62	98	98	0
Intensive uses	1	4	3	5	4	<1	<1	0
Urban	1	4	3	5	4	<1	<1	0
Dams/reservoirs	1							
Wetlands	6							

Source: MWNRM 2008, p.12. Notes: DIN is dissolved inorganic nitrogen, PN is particulate nitrogen, FRP is filterable reactive phosphorus, PP is particulate phosphorus, and TSS is total suspended solids. Pest1 is ametryn, atrazine, diuron and hexazinone (grouping of pesticides predominantly used in sugar cane) and Pest2 is tebuthiuron (predominantly used in grazing).

3.3.2 Burdekin WQIP

The Burdekin WQIP area covers the majority of the Burdekin NRM region including the Burdekin and Haughton River Basins. The volume of pollutants delivered to the marine environment by the Burdekin River far outweighs the amount of material delivered by the other four river basins (Don, Haughton, Ross and Black) in the Burdekin NRM region. On average the Burdekin River contributes around 80% of the total annual discharge of the region.

A summary of the river basins/catchments of the Burdekin region (from north to south) is provided in Table 3.6.

Table 3.6 Burdekin Region River Basins

Parameter	Black	Ross	Haughton	Burdekin	Don
Catchment size (km sq)	907	1,296	3,983	130,035	3,347
Grazing (km sq)	502	923	2,529	123,758	2,948
Sugar (km sq)	8.1	0	678	128	16.8
Horticulture/cereals (km sq)	7.4	9.4	37	742	114
Total land use (%)	57.06	71.94	81.45	95.84	91.99
Annual run-off volume (km cu)	0.38	0.49	0.74	10.29	0.75
Mean annual run-off (ML)	0.18*	0.15**	0.5	8.64	0.31
Annual sediment export (tonnes)	140,000	180,000	270,000	3,770,000	270,000
Average suspended sediment event (mg/L)	N/A	22	110	394	N/A
Range of suspended sediment event (mg/L)	N/A	3-69	41-200	74-3,559	N/A
DIN export (tonnes)	75	97	1467	2,027	148
DON export (tonnes)	53	68	103	1,430	104
PN export (tonnes)	191	246	372	5,176	377
TN export (tonnes)	319	411	621	8,633	629
DIP export (tonnes)	10	13	19	265	19
DOP export (tonnes)	3	4	7	92	7
PP export (tonnes)	49	64	96	1,338	98
TP export (tonnes)	63	81	122	1,695	124

Extracted from Lewis et al 2006, p.1 (Table 1)

Note: * includes Bohle River and Bluewater Creek ** includes Alligator Creek

"*During very large to extreme Burdekin discharge events (total event discharge >12 million ML), the Burdekin flood plume may reach as far north as Cooktown (~500 km north of the river mouth). During 'average floods' (total discharge of 3.0-7.0 million ML), the northward extent of the Burdekin plume is probably Hinchinbrook Island (~200 km north of the river mouth). Burdekin flood plumes are usually confined to within 30 km from shore but can occasionally extend further offshore and impinge on mid-shelf reefs, up to 120 km from shore*."

"*Discharge from other coastal rivers and creeks in the Burdekin Region (e.g. Black, Ross, Haughton and Don Rivers) are minor when compared to the Burdekin River. The extent of the plumes generated by these coastal rivers has not been studied, although these plumes are probably restricted to the embayments which host the mouth of these particular rivers*." (Lewis et al 2006, p.iii)

"*While flood plumes from rivers of the Burdekin Region may extend as far north as Cooktown, the northward extent of most sediments and particulate nutrients is the Townsville/Cleveland Bay area. The northward limit of the dissolved nutrient phases from the Burdekin Region probably extends as far as the Palm Island Group. The full extent of pesticides in the marine environment is unknown*." (Lewis et al 2006, p.v)

"*The Burdekin Community Water Quality Event Monitoring Project was established in late 2002 by the Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University for the Burdekin Dry Tropics Natural Resource Management (BDTNRM) regional body to investigate sediment and nutrient concentrations in waterways throughout the Burdekin Dry Tropics Region*" (Bainbridge et al 2007. p.i).

[2006/2007 was] "*Consistent with previous wet seasons, the lower Burdekin coastal catchments had considerably lower sediment and particulate nutrient concentrations than the grazed Burdekin sub-catchments. These coastal catchments with more intensive land uses (sugarcane cultivation and horticulture) had disproportionately high nitrate (and nitrite) (NO_x) and phosphate (FRP) event mean concentrations compared to the other larger Burdekin sub-catchments*."

"*Suspended sediment is the key parameter of concern for the Burdekin River catchment (rangeland grazing), with considerable variation in TSS concentrations and loads between the five major sub-catchments (upper Burdekin, Cape, Belyando, Suttor and Bowen Rivers*)" (Bainbridge et al 2007, p.ii).

"*Within the grazed Burdekin catchments particulate nutrients largely follow the pattern of suspended sediments, indicating that managing for sediment reductions will also achieve a reduction in particulate nutrient concentrations. This is particularly so for phosphorus, where particulate phosphorus dominates (70-95%) total phosphorus at most sites throughout the flow hydrograph. The relationship between suspended sediment and particulate nitrogen is not as strong, with the particulate proportion of total nitrogen often varying between 40-70% across sites and throughout the flow hydrograph. In contrast, nitrogen and phosphorus in the lower Burdekin coastal catchments are dominated by the dissolved fractions. The elevated inorganic nutrients (primarily nitrate) reflect the intensive land uses (sugarcane and horticulture) within these coastal catchments. The lower Haughton River and Barratta Creek have consistently produced disproportionately high NO_x loads for small coastal catchments, and as such are priority catchments for nutrient management*."

"*A suite of herbicide residues (diuron, atrazine and ametryn) were commonly detected in the waterways of the lower Burdekin during event and low flow conditions over the previous two wet seasons (Lewis et al., 2007)*" (Bainbridge et al 2007, p.iii).

"*Tebuthiuron residues were detected in four of the major Burdekin sub-catchments (Belyando, Suttor, Cape and Bowen Rivers) during limited sampling in the 2005/06 and 2006/07 wet seasons. This finding is concerning given the size of flow generated by these rivers and warrants further investigation into the presence and potential loads of tebuthiuron being generated within the Burdekin Rangelands during wet season flows. Tebuthiuron has a relatively long half life (around one year) and this herbicide may persist in catchment waterbodies and the larger reservoirs, such as the BFD throughout the year*." (Bainbridge et al 2007, p.iv)

A report on water quality issues in the Burdekin region was prepared for the BDT NRM WQIP in 2007 by the Australian Centre for Tropical Freshwater Research (ACTFR) (Mitchell et al 2007). Findings from the *Burdekin Community Water Quality Event Monitoring Project*, established in late 2002, along with other studies and reports were included in the ACTFR report.

Potential pollutants in the Burdekin region were identified for various broad land uses. An impact rating was applied to each pollutant based on their volumetric importance and their likely in-stream and down-stream impacts (0 no impact to 5 high impact). Nutrient and sediment pollutants are listed in Table 3.7.

Table 3.7 Potential Pollutants in the Burdekin - Nutrients and Sediment

Pollutant	Source	Rating	Notes
Nutrients			
Nitrate (NO_3)	Fertiliser	5	Low natural levels
Ammonia (NH_4)	Fertiliser	2	Low natural levels
DON	Fertiliser	2	Moderate natural levels, slow turnover
PN	Fertiliser and erosion	4	Moderate natural levels, loss to sediments
Phosphate (PO_4)	Fertiliser, salt licks	2	Low natural levels
DOP	Fertiliser	1	Moderate natural levels, slow turnover
PP	Fertiliser and erosion	3	Moderate natural levels, loss to sediments
Silicate ($Si(OH)_4$)	Erosion	0	
Sewage	STP discharge, septics	5	Contains all N, P forms at high levels
Suspended sediment (Varies between sub-catchments, greatly increased by grazing)			
Coarse (>63 µm)	Erosion	0	No likely impact, forms delta fan
Medium (2-63 µm)	Erosion	2	Carried only short distance
Fine (< 2µm)	Erosion	4	Carried widely over shelf, especially following dry year

Source: Mitchell et al 2007, p.7

A range of other pollutant groupings were identified and are listed in Table 3.8.

Table 3.8 Additional Potential Pollutants in the Burdekin

Pollutant Group	Specific Pollutant and Comments
DO reducing materials (organic material)	Sucrose, dunder, mill effluent – are products of sugarcane production and are limited to the Lower Burdekin. Manure principally from cattle grazing. Sewage from urban areas. Plant litter occurs naturally and is increased as by products of intensive agriculture and urban park and garden maintenance
Herbicides	Diuron, AAtrazine, Ametryn, Hexazinone and 2,4-D are principally used in the sugar industry. Simazine used in forestry. Tebuthiuron used in grazing industry. Glyphosate and paraquat used broadly in sugar cane, horticulture and urban areas
Insecticides	Organochlorines e.g. endosulfan, and a variety of others are used principally in horticulture and to a lessor extent sugar cane and the urban setting. Chlorpyrifos used in sugar cane for can grubs
Fungicides	Methoyetholmercuric chloride (MEMC) used in the sugar industry
Non insecticide organochlorines	PCB's from industry (reduced use but residues may persist) and Dioxins from agriculture and industry PAH's (polcyclic aromatic hydrocarbons) from cane firing, forest fires and oil spills
Heavy metals	Cadmium and potassium from fertiliser and mercury from fungicide. Other trace elements
Oil or hydrocarbons	Primarily from liquid fossil fuels and oil spills
Salinity	Both dryland and irrigation salinity resulting from land clearing (dryland) and irrigation activities
Antifoulants	Used primarily in the fishing industry at mooring sites (TBT now banned)
Acid	Principally associated with disturbance of acid sulphate soils

Source: Mitchell et al 2007, pp.7-8

Along with the pollutants and their diffuse sources the report also identified and prioritised the key water quality threats for GBR ecosystems from the main agricultural land uses. These are listed in Table 3.9.

Table 3.9 Priority Pollutants for GBR Ecosystems

Priority	Burdekin Rangelands (Grazing)	Lower Burdekin Area (Sugar)
1	Fine suspended sediment, PN, PP	Nitrate, atrazine, diuron and 2,4-D
2	Nitrate	Ametryn, Hexazinone and Simazine
3	DON	Insecticides and fungicides
4	Tebuthiuron	
5	Phosphate (particularly in the basaltic terrains)	

Threats for freshwater bodies in the Burdekin region were also identified as: turbidity, weeds, dissolved oxygen reducing substances (DORS e.g. sugar, mill mud, dundar), riparian vegetation (lack of), eutrophication (via nitrate), and pesticides (toxicity on freshwater systems) (Mitchell et al 2007, p.2).

Burdekin Dry Tropics NRM commissioned a report to determine "*the results of scenario analysis identifying potential impacts of change on sources, fluxes, and/or storage of sediment and nutrients' in the Burdekin catchment*." (Kinsey-Henderson et al 2007)

The erosion management strategies investigated for priority catchments included:

- Increasing minimum ground cover;
- Reducing gully erosion; and
- Riparian zone rehabilitation.

The study showed that significant gains could be made in reducing suspended sediment loads at the mouth of the Burdekin River if the strategies were implemented.

In general terms the assumptions made for the Burdekin WQIP area apply to the rural catchments of the Black Ross WQIP area, particularly with regard to grazing, and will be considered as default assumptions for the Black Ross WQIP in the absence of any more specific studies and data. Management actions developed for the Burdekin WQIP will also be adopted for the Black Ross WQIP.

3.4 BDT Townsville Catchments – Black and Ross Basins

The Burdekin Region was divided into fifty-one manageable sub-catchments, including the Black Ross WQIP area (referred to as Townsville Catchments) for SedNet and ANNEX modelling (Mitchell et al 2007, p.19). The following information relevant to the Black Ross WQIP area has been extracted from the Mitchell et al report.

3.4.1 Sediment

Flow weighted mean concentration (mg/L) for total suspended sediments for the Townsville Catchments were calculated to be between 271 mg/L and 375 mg/L (Mitchell et al 2007, from Figure 3, p.22) while erosion levels of total suspended sediments normalised over the total catchment area were calculated to be between 144 kg/ha and 250 kg/ha (Mitchell et al 2007, from Figure 4, p.23).

In terms of sediment exported from the Burdekin River, Bowling Green Bay is estimated to trap approximately 80-90% of the fine sediment while Cleveland and Upstart Bays each hold around 5-10% of the Burdekin sediments (Mitchell et al 2007, p.45). It was also considered that that a typical sediment resuspension event in the bays carries significantly more sediment than a river plume and that "*the extremely low sediment accumulation rates calculated for Cleveland Bay (~ 0.25 mm/year) are further evidence that this particular embayment acts more as a sediment transport system, rather than as a sediment trap (Carter et al., 1993)*" (Mitchell et al 2007, p.46).

"*Despite reports of increased turbidity at inshore coral reefs since European settlement, it is difficult to separate the effects of natural and human-induced change. Since no sediment is resuspended in waters deeper than 22 m (during rare cyclonic events; Orpin et al., 1999), the threat of terrigenous sediments to the GBR is almost entirely restricted to the inner shelf with the exception of the extremely fine and colloidal particles which may travel to the mid shelf"* (Mitchell et al 2007, p.47).

The relatively low volumes of sediment issuing from the Black and Ross Basins, compared to the Burdekin, are unlikely to have a significant impact on any marine areas apart from those in the near vicinity of the river and creek mouths. The marine extent of river influence estimated by CSIRO (Greiner et al 2003) has been adopted for the Black Ross WQIP, with modifications to include Magnetic Island and its influence.

3.4.2 Nutrients

Modelled estimates for DIN and DIP in the 'Townsville catchments' area (the coastal strip from Cape Cleveland north to around Crystal Creek) were considered to be "*almost certainly in gross error*". The small amount of data for the area "*show consistently low levels of DIN and DIP*" and from "*a land-use basis, there is no reason to believe that creeks to the north and south of Townsville will have elevated N or P concentrations*".

The possible land use exceptions noted were; some new cane and fruit tree farms in the north, fruit trees in the Alligator Creek area, the Yabulu Nickel Refinery (ammonia), the Copper Refinery and Sun Metals refinery. These are limited in extent (for intensive agriculture) and emission volume (for industry) and were not considered to be significant pollutant sources. Additionally "*elevated N and P inputs may derive from the Townsville Sewerage Plant discharging into Sandfly creek, but these would only occur in the estuarine, lower reaches. Hence, in a few small areas, some elevated nutrients may occur, but would seem unlikely to reach the same levels as seen in the Lower Burdekin Area*."

It was concluded that the very high modelled DIN load (1235 tonnes; Appendix 1) "*is as mysterious as it is wrong and misleading*" (Mitchell et al 2007, p.26).

Given the comments above the estimates of flow weighted DIN concentrations (>751µg/L) and DIN levels normalised over catchment area (>1.26 kg/Ha to 7.38 kg/Ha) will not be considered as relevant for this report (Mitchell et al 2007, from Figure 6, pp.27-28).

Figure 3.1 Potential Nutrient Source Crystal Creek Sub Basin

3.5 Other Studies

A number of reviews and studies have been undertaken to estimate the amount of additional pollutants impacting the marine environment as a result of land use and management practices on mainland Australia. Estimates of pre-development suspended sediment exports to the Great Barrier Reef are often developed by taking the sediment load of largely undeveloped rivers as the best available baseline reference. In this way, it is possible to estimate the change in nutrient and sediment exports to the Great Barrier Reef since anthropogenic activity began along the coast. Conversely, nutrient modeling allows the generation of similar data.

3.5.1 Catchments and Corals

A comprehensive review of the catchments of the Great Barrier Reef, their associated run-off to the reef and the influence of the run-off on coastal and reef ecosystems was presented in Catchments and Corals (Furnas 2003). Note: In Catchments and Corals the Ross Basin is not the AWR basin but includes part of the Haughton Basin draining to Bowling Green Bay.

Furnas (2003) reviewed a substantial volume of research information associated with the relationship between land-based activities in the Great Barrier Reef (GBR) catchments and the GBR. Some of the salient points are summarised below in relation to suspended sediments (Furnas 2003, pp.165-176) and nutrients (Furnas 2003, p.177-202).

- Fine silts and clays only accumulate in dams and weirs, still backwaters or shallow wetlands on floodplains where flow rates are low and water residence times are long relative to particle sinking velocities;
- Once clay and silt-sized particles reach the stream network, most will be rapidly transported out of the catchment into the GBR;
- Sediment transport in all rivers of the GBRC is dominated by fine sediments [80-95%] i.e. silt and clay;
- Most of the nutrients exported from catchments in particulate form are bound to fine sediments (<2μm);
- Particulate nitrogen (PN) and particulate phosphorus (PP) loads in GBRC rivers follow suspended sediment concentrations;
- GBRC soils, whether fertilised or not, naturally contain substantial stocks of nitrogen (N) and phosphorus (P);
- The average N and P content of particulate matter in rivers draining wet and dry catchments parallel the composition of catchment soils (Black and Ross are classed as mixed catchments);
- Regardless of catchment type, the good correlation between particulate nutrient and suspended sediment concentrations means that useful estimates of PN and PP exports from rivers can be derived from estimates of fine sediment exports from catchments;
- While PN and PP concentrations are correlated with suspended sediment load, they are not well correlated with discharge, due to rapid changes in suspended load in both large and small flood events;
- Rivers transport nutrients in several forms;
    - as free dissolved ions (e.g. ammonium NH_4^+, nitrate NO_3^-, nitrite NO_2^-, phosphate PO_4^{3-}),
    - as part of dissolved organic compounds (urea, amino acids), and
    - in suspended particulate matter.
- Nutrient concentrations in river waters depend on;
    - biological and chemical processes in catchment soils,
    - runoff and erosion which transport water, soil and nutrients to the rivers, and
    - water flows which move dissolved and particulate materials.
- Nitrate (NO_3^-) is the most abundant form of dissolved inorganic nitrogen (DIN) in GBRC rivers largely derived from bacterial oxidation of ammonia (NH_4^+) in oxygenated catchment soils, surface waters and groundwaters;
- Fertilisers are an additional source of nitrate either directly or through breakdown of urea/ammonia etc;
- Nitrate concentrations exhibit only small changes during floods in the two largest dry-catchment rivers i.e. nitrate inputs to the river in surface runoff are diluted by large volumes of water in floods;
- Over half of the nitrogen exports from the Burdekin and Fitzroy catchments (dry catchments) are particulate;
- In wet tropic rivers nitrate concentrations increase significantly during the wet season;

- There is little variation in dissolved organic nitrogen (DON) concentrations relative to river flow in both wet and dry catchment rivers;
- DON is the principle (up to 80%) form of N exported from pristine river catchments;
- The relative contribution of nitrate and DON to river N levels and exports may therefore indicate the degree of human disturbance and associated nitrate inputs;
- Dissolved phosphorus ($PO_4^{3-}$and DOP) concentrations in wet and dry catchment rivers respond differently to floods and seasonal changes in flow;
- Dissolved P concentrations in the large dry catchment rivers exhibit pronounced increases during wet season flood events with peak concentrations in excess of 110µg per litre while wet catchments have relatively stable P levels (20 µg/L);
- PP is the principal form of P export from both wet and dry catchments (66-77%);
- Total annual nutrient exports to the GBR lagoon closely follow the total volume of water discharged.

"*Annual inputs of terrestrial sediment to the GBR can be estimated by multiplying volume-specific sediment export coefficients appropriate for wet, dry and mixed catchments by the mean annual freshwater discharges from the catchments* (basins)" (Furnas 2003, p.208). Volume-specific sediment export coefficients are:

- Wet catchments - 39,000 tonne sediment per km^3 discharge,
- Mixed catchments 135,000 tonne sediment per km^3 discharge, and
- Dry catchments 366,000 tonne sediment per km^3 discharge.

Estimates of exports from the Black and Ross Basins are shown in Table 3.10.

Table 3.10 Estimated Average Annual Exports of Sediment and Nutrients

Element	Black River (117)	Ross River (118)	GBRC
Basin area km^2	1,057	1,707	42,3070
Adjusted runoff volume km^3	0.38	0.49	70.8
DIN export (tonnes)	75	97	12,982
DON export (tonnes)	53	68	7,627
PN export (tonnes)	191	246	22,298
Total N (tonnes)	319	411	42,907
DIP (tonnes)	10	13	1,022
DOP (tonnes)	3	4	517
PP (tonnes)	49	64	5,551
Total P (tonnes)	63	81	7,090
Fine sediment (tonnes)	140,000	180,000	14,400,000

(Furnas 2003, p.209)

Along with nutrient inputs from terrestrial sources the GBR also receives nutrients from:
- Upwelling from the Coral Sea;
- Rainfall;
- Sewage discharge; and
- Nitrogen fixation by cyanobacteria.

Estimates of nutrient inputs from the measured and estimated sources are shown in Table 3.11.

Table 3.11 Nutrient Inputs to the GBR from Various Sources

	Nitrogen tonnes year		Phosphorus tonnes year	
	Range	Average	Range	Average
Current land runoff -total	10,000-120,000	43,000	1,300-22,000	7,000
Current land runoff - soluble	6,000-60,000	20,000	300-4,700	1,500
Pre 1850 land runoff -total	4,000-66,000	23,000 (54%)	360-7,000	2,400 (34%)

Pre 1850 land runoff - soluble	2,900-38,000	12,000 (60%)	160-1,800	600 (40%)
Upwelling	4,400 to 44,000		630 to 6,300	
Rainfall	14,000 to 44,000		1,000 to 3,000	
Sewage		2,250 (5%)		600 (9%)
Prawn aquaculture		200 (0.4%)		20 (0.3%)

Notes: Source data from Table 36 (Furnas 2003, p.229) with notes interpreted from text (Furnas 2003, pp.225-26). All figures are per year and in tonnes. Percentages associated with pre 1850 figures are expressed as a percentage of current exports. Rainfall between 140 and 440 km3 per year at 100µg per L of N (100 t per km3) and 7 µg per L of P (7 t per km3). Sewage percentage is relative to river exports and based on sewage being discharged via ocean outlets or into coastal waterways. Sewage estimate does not take into account tertiary treatment and land based disposal so is an overestimate (based on 5kg N and 1.5kg P per person per year with modern secondary treatment). Aquaculture estimates based on daily discharge of 1kg N and 0.1 kg P per hectare of pond using 500 hectares of ponds. Aquaculture percentages are expressed as a proportion of river exports. More effluent is now being treated on site so figures may be higher than actual emissions. Proportionally higher increase in P reflects the increase in erosion and fine sediment losses from catchments.

3.5.2 Preliminary Assessment of Sediment and Nutrient Exports

In the early 1990s the issue of sediment and nutrient inputs to the coastal zone from agricultural lands was recognised and a quantitative assessment was undertaken jointly by the Queensland Department of Primary Industries (DPI) and the Department of Environment and Heritage (DEH). The resulting report titled *A Preliminary Assessment of Sediment and Nutrient Exports from Queensland Coastal Catchments* (Moss et al 1992) has some initial modelled estimates of the sediment and nutrient exports from the combined Ross and Black AWR River Basins. Point source inputs were calculated from DEH licence conditions for discharges. Inputs from urban diffuse sources and rural diffuse sources were calculated separately using different techniques and then combined to provide aggregate totals. Two models were used in the study. Results from the study for the combined Ross and Black Basins are summarised in the tables below.

Table 3.12 Ross-Black land use areas and other statistics

Land use areas (km^2)							Mean annual flow	Mean annual run-off
Pristine	Grazing			Cropping	Urban	Total		
	DPI estimate	Unallocated	Total grazing					
530	850	1,400	2,250	10	100	2,890	1,100	0.38

Source: Moss et al 1992 (p.12) Note: Mean annual flow (1000ML), Mean annual run-off (ML/km2)

Table 3.13 Ross-Black sediment export estimates

Export	Pristine	Grazing	Cropping	Urban	Total	Model 1	Belperio
Load (kilo tonnes)	13	223	2	4	242	265	550
Kilograms/hectare	247	990	2,474	[400]	838		

Source: Moss et al 1992 (pp.15-16) Note: Belperio (1983) estimates (Late Quaternary terrigenous sedimentation in the GBR lagoon in proceedings of the inaugural GBR Conference, Townsville (eds) Baker, J.T., Carter, R.M., Sammarco, P.W., and Stark, K.P. pp.71-76, JCU Press). Urban kg/ha estimate [in brackets] was not included in the report

Table 3.14 Ross-Black nutrient export estimates

Annual export		Pristine	Grazing	Cropping	Urban	Total	Model 1
Load (tonnes)	**N**	63	1,079	17	74	1,233	1,487
	P	9	154	3	7	173	212
Kilograms/hectare	**N**	1.2	4.8	17.3	[7.4]	4.3	
	P	0.17	0.69	2.57	[0.7]	0.6	

Source: Moss et al 1992 (pp.17-19)

Note: Urban kg/ha estimates [in brackets] were not included in the report

Overall, point sources of nutrients were found to be minor relative to diffuse sources, except in heavily urbanised catchments such as the Ross-Black (Townsville) and Barron (Cairns). Grazing land provided the greatest loads of sediment and nutrients based on the large areas devoted to this land use while cropping had the greatest export rate per unit area. Urban sediment and run-off rates used in the models have been included in the tables for comparison purposes but are an input to the study and not a result.

3.5.3 Sources of Sediment and Nutrient Exports to the GBR WHA

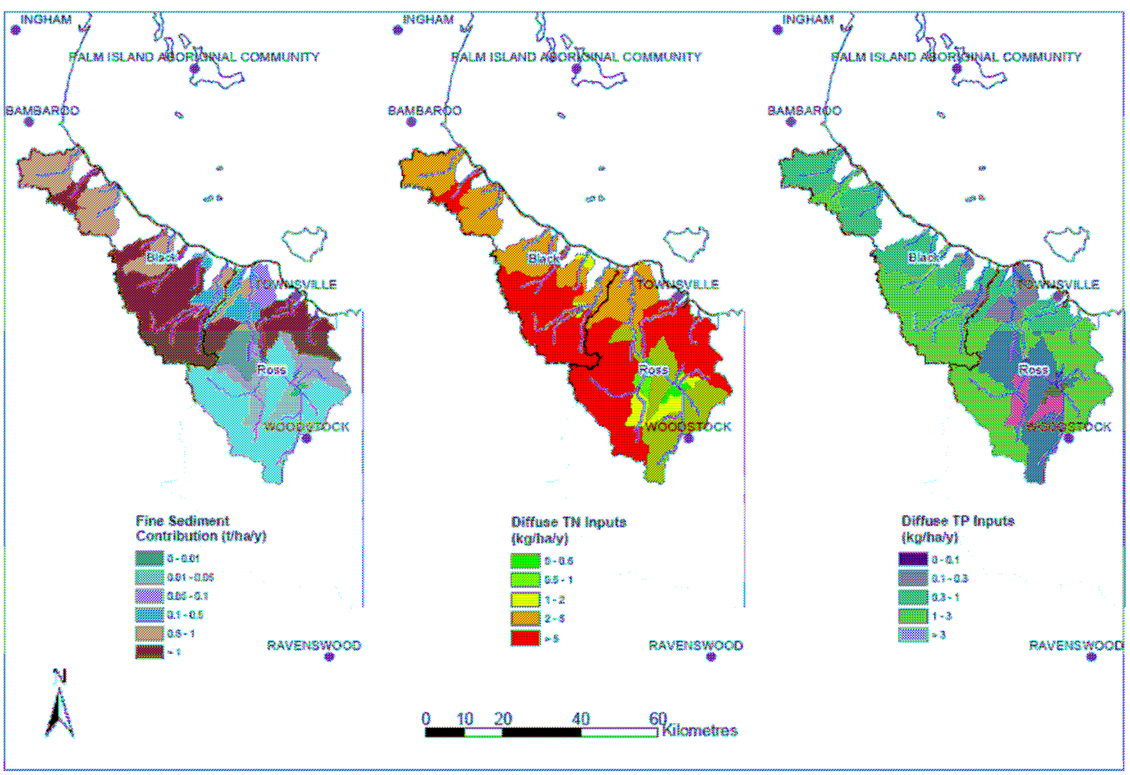
In their 2003 report Brodie et al estimated the current sediment and nutrient exports from the Black River and Ross River AWR Basins along with the pre-European export levels. The results are reproduced in Table 3.15.

Table 3.15 Current and natural exports from the Black and Ross River Basins

Export to coast	Black River Basin		Ross River Basin	
	Current	Natural	Current	Natural
SS (kt/yr)	161	30	80	20
DIN (t/yr)	53		63	
DON (t/yr)	65		32	
PN (t/yr)	452		212	
Total N (t/yr)	570	77	307	39
DOP (t/yr)	4		5	
FRP (t/yr)	3		1	
PP (t/yr)	92		38	
Total P (t/yr)	99	11	44	5

Estimated contributions of suspended sediment (SS) exported to the coast and diffuse total nitrogen (TN) and total phosphorus (TP) inputs to the Black and Ross River basins are shown in Figure 3.2.

Figure 3.2 Estimated pollutant contributions Black and Ross River Basins



Note: White areas were not modelled

The results were also compared to the results of previous studies. The comparison is provided in Table 3.16

Table 3.16 Comparison of modelled results to previous results

Study	Black River Basin			Ross River Basin		
	SS (kt/yr)	TN (t/yr)	TP (t/yr)	SS (kt/yr)	TN (t/yr)	TP (t/yr)
Current	161	571	99	80	307	44
Furnas (2003)	140	319	62	180	411	81
Belperio (1983)	250			250		
Horn et al (1998)	67					
NLWRA (2001)	80			60		

Contributions to the load of sediment and nutrients from different land uses was also calculated. The results of the land use calculations appear in Table 3.17 for the Black Basin and Table 3.18 for the Ross Basin.

Table 3.17 Contribution of pollutants from land uses in the Black Basin

Parameter	Forest	Grazing	Sugar	Crops	Other	Total	Export
Area (ha)	36,340	50,220	810	740	2,570	90,680	
Area (%)	40	55	1	1	3		
SS (t/yr)	51,000	106,000	1,000	1,000	3,000	162,000	162,000
DIN (t/yr)	25	25	1	1	3	55	53
DON (t/yr)	33	28	1	1	2	65	65
PN (t/yr)	144	374	2	2	10	532	452
Total N (t/yr)	202	427	4	4	15	652	570
DOP (t/yr)	2	2	0	0	0	4	4
FRP (t/yr)	4	5	0	0	0	9	3
PP (t/yr)	35	61	1	1	1	99	92
Total P (t/yr)	41	68	1	1	1	112	99

Notes: SS is delivery to the coast and nutrients is delivery to streams/waterways. Export is export from the basin. Forest includes savanna woodland

Table 3.18 Contribution of pollutants from land uses in the Ross Basin

	Forest	Grazing	Sugar	Crops	Other	Total	Export
Area (ha)	20,990	92,330	0	940	15,300	129,560	
Area (%)	16	71	0	1	12		
SS (t/yr)	12,000	57,000	0	1,000	11,000	81,000	81,000
DIN (t/yr)	11	34	0	0	18	63	63
DON (t/yr)	6	30	0	0	9	45	32
PN (t/yr)	91	548	0	5	37	681	212
Total N (t/yr)	108	612	0	5	64	789	307
DOP (t/yr)	0	2	0	0	0	2	5
FRP (t/yr)	2	6	0	0	2	10	1
PP (t/yr)	16	78	0	1	7	102	38
Total P (t/yr)	18	86	0	1	9	114	44

Note: Total Exports include point sources

In deriving the results for the export of sediment and nutrients from the Black and Ross Basins Brodie et al used mean annual flow figures of 352 GL/year for the Black Basin and 224 GL/year for the Ross Basin. Natural flow figures for the Black Basin were considered to be the same as the current figure while the natural flow figure for the Ross Basin was considered to be 60 GL/year less than the current figure based primarily on a higher run-off rate resulting from the relatively high volume of impervious surfaces associated with the urban area.

3.6 Urban Diffuse Pollutant Sources

The Cooperate Research Centre for Catchment Hydrology (Catchment CRC) has produced a number of reports relevant to urban stormwater pollutants and stormwater quality management options. Findings from key publications are summarized below.

3.6.1 A Review of Urban Stormwater Quality Processes

In this review Duncan (1995) describes the physical processes, which contribute to the contamination of urban stormwater runoff. Understanding of these processes and associated pollutant sources can assist with the development of management actions for reduction of stormwater pollutants.

Some of the processes discussed in the review include:

- Wet and dry deposition of contaminants from the atmosphere including interception on vegetation and artificial above-ground structures;
- Build-up of contaminants on impervious surfaces;
- Wash-off from surfaces into formed channels or pipes;
- Transport along channels and pipes;
- Quality changes during storage; and
- Receiving waters influence.

The review was based on literature, which was predominantly from temperate regions so the findings are not directly translatable to the Dry Tropics. Points made are therefore generalisations and not specific to the Townsville area.

Wet deposition (1) is a function of rainfall while dry deposition (2) occurs without rain i.e. wind and air currents are the vector. Wet deposition tends to be more uniform while dry deposition is much more reliant on conditions close to the ground and is generally more variable. Wet deposition is usually substantially greater than dry deposition. Deposition and rainfall quality are influenced by the land and human activities in the surrounding environment.

While atmospheric deposition can contribute as much nitrogen to stormwater contamination as is washed off in urban run off it is principally a component of air quality. If air quality is at acceptable levels then atmospheric deposition will be minimal and will not significantly impact water quality. Smaller quantities of suspended solids, phosphorus, COD, and heavy metals will also be present in atmospheric deposition.

Interception (3) is the interaction of rainfall with live plants and plant debris, and artificial structures before the rainfall reaches the ground. The main pollutant source of rainfall interception is accumulated dry deposition on roofs and plants, and solution of roof (e.g. zinc and copper) and plant materials. Lawn clippings and fallen leaves are a significant source of nitrogen and organic matter and may be a major source of phosphorus in urban run-off.

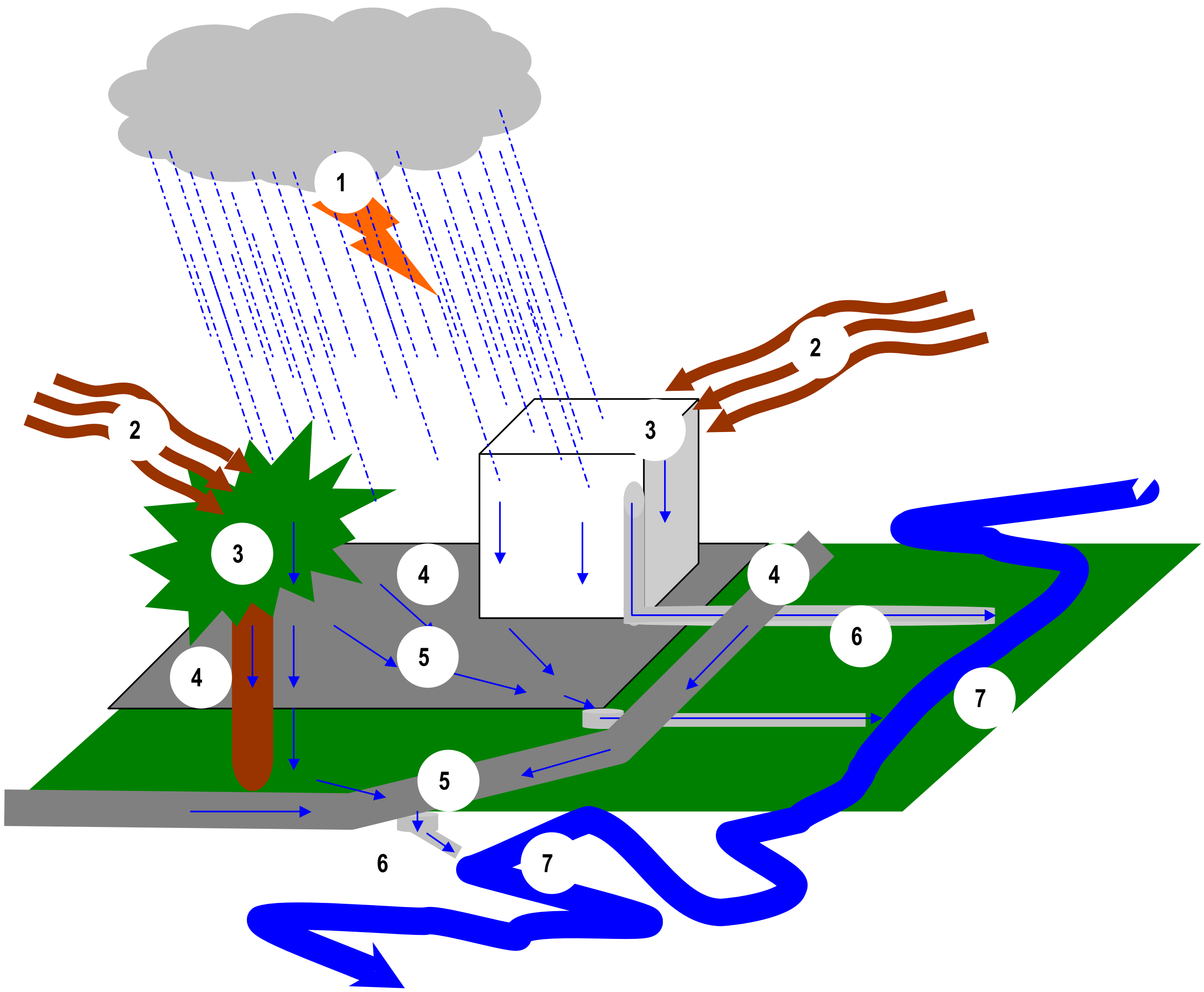
Buildup (4) is the accumulation on impervious surfaces of material from dry deposition. Roads are the main surface for buildup, with car parks and driveways also being significant buildup surfaces.

Wash-off (5) is the process where the accumulated dry deposition material is removed from impervious surfaces by rainfall and run-off and is added to the stormwater flow. The amount of material in wash-off is not directly correlated to the buildup material or to flow from a stormwater catchment. The amount of wash-off material in stormwater is most closely associated with rainfall intensity, which is particularly relevant to the Townsville region. The first flush phenomenon is where a high proportion of material i.e. sediment and dissolved nutrients, is mobilised early in a storm and is transported to receiving waters. First flush material is generated from both pervious and impervious surfaces, and like wash-off is most closely related to rainfall intensity. First flush is a characteristic of small catchments and is particularly noticeable in urban areas where soil is exposed during construction phases.

Transport (6), in the urban stormwater context, is the movement of contaminants through gutters, pipes and channels to receiving waters. Coarse sediment (bed load), suspended matter, litter (natural and artificial) and dissolved matter is transported through the stormwater system often as a drainage function rather than as part of a stormwater management process. The nutrient contribution of natural litter i.e. leaves, grass and other plant material, to receiving waters is often not measured in the short-term and may not be adequately addressed as a result (P content of leaves is about 0.2% of dry weight and N is about 1% with higher nutrient content for grasses).

Receiving waters (7) are the endpoint of the stormwater system, generally a natural system that the 'pipe' empties into. Receiving waters are often seen as the natural system that contaminated urban stormwater has the potential to degrade. To ensure an effective stormwater quality treatment train is designed the receiving waters need to be defined and their environmental values acknowledged. A conceptual model of the processes affecting urban stormwater quality is shown in Figure 3.3 with numerical reference to the processes described above.

Figure 3.3 Urban Stormwater Quality Processes Conceptual Diagram



Note: Numbers relate to the processes described in the text above and are: 1 Wet deposition, 2 Dry deposition, 3 Intercept, 4 Buildup, 5 Wash-off, 6 Transport and 7 Receiving waters

3.6.2 Urban Stormwater Pollution

Chiew et al (1997) discuss the impacts of urban development on the environment in terms of:

- Stormwater pollutants generated;
- Increased run-off; and
- Alteration of natural stream environments.

Principle pollutants of urban areas are; sediments, nutrients (principally nitrogen and phosphorus), oxygen demanding materials (biodegradable organic material), metals, toxic organic wastes (garden and household chemicals), pathogenic micro-organisms (bacteria, viruses etc), hydrocarbons and litter. Nutrient concentrations in urban stormwater are generally less than those from areas of intensive agriculture and significantly greater than from forested catchments (P is two to ten times greater) and undeveloped catchments (N is two to five times greater).

As identified by Duncan (1995) the main process of stormwater contamination is from the accumulation of pollutant material on impervious surfaces during dry weather (buildup) including:

- Settling of fine particles from the atmosphere;
- Accumulation of fine particles and gross pollutants from local sources; and
- Redistribution of surface pollutants by wind and traffic.

Some contaminants can be carried relatively long distances by wind and rain before being deposited (distributed sources) while others have a local origin. Some of the more significant local sources of pollutants are associated with motor vehicles and roadways. Local and distributed sources of urban stormwater pollutants as identified by Chiew et al (1995) are listed in Table 3.19.

Table 3.19 Common Urban Diffuse Stormwater Pollutants

Distributed Sources		Local Sources
Ash and smoke from bush fires		Leaf litter, grass clippings and other vegetation
Sea spray		Dog and other domesticated animal faeces
Swamp gases		Pesticides, herbicides and fertilisers
Windblown pollen, insects and micro-organisms		Sewer overflows
Dust from agricultural activities and roads		Sewer outlets illegally connected to stormwater systems
Dust, ashes and emissions from industry		Septic tank leakage
Agricultural pesticides, herbicides and chemicals		Leakage and spillage of materials from; vehicles, storage tanks and bins
		Seepage from land fill waste disposal sites
		Waste water from cleaning operations
		Corrosion of roofing and other metallic materials
		Industrial emissions
		Vehicle emissions
		Vehicle component wear e.g. tyres and brakes
		Wear of road surfaces
		Erosion from construction activity and vegetation removal
		Litter – plastic, glass and metal containers, plastic, foam etc

Levels and loads of urban stormwater pollution can be calculated relatively easily due to the small size of stormwater catchments and assumptions made which reduce the complexity and uncertainty associated with the calculations. Adequate water quality monitoring assists the process but calculations can also be made using models specifically designed for urban areas where key input information is the amount of impervious surface area in a catchment, local rainfall data and pollutant run-off coefficients for specific land uses.

3.6.3 Urban Pets

Leaving dog poo on streets, parks and beaches is smelly, unsightly and is a concern for local communities and councils. Dog poo is a serious litter issue with wide ranging impacts on amenity, health and the environment. Droppings contain harmful bacteria and nutrients, and some end up washing into natural waterways and Cleveland Bay through the stormwater system. This may contribute to excessive E. coli pollution readings and contributes to the overall nutrient load in waterways following heavy rainfalls.

Townsville has approximately 32,000 registered dogs and if we assume there are another 8,000 unregistered dogs we have approximately 40,000 dogs in the Black Ross WQIP area. From Victorian figures (http://www.litter.vic.gov.au/www/html/272-how-to-use-this-kit-.asp) on average each dog excretes 100g of poo per day. This is equivalent to 4,000 kg per day or 1,460 tonnes per annum. If we assume that cats add to this output and round the figure to 1,700 tonnes then we have an approximate figure for the contribution of pets to the diffuse source pollutant load for the Black Ross WQIP area. The majority of these animals would reside in the main urban catchments, in relative proportion to the human population, with the exception of high density and commercial areas i.e. CBD, high-rise and apartments. We can assume that this pollutant source would be most prominent in catchments dominated by traditional residential land use.

3.6.4 Stormwater Gross Pollutants

Allison et al (1997) examined gross pollutants as a specific contaminant group in the urban context. Gross pollutants are relatively "*large pieces of debris flushed through urban catchments and stormwater systems*". For the purpose of their report Allison et al (1997) describe gross pollutants as "*debris items larger than five millimeters*". Gross pollutants are typically human litter (mostly containers and packaging) as well 'natural' litter comprising vegetation (leaves, grass clippings and twigs). Gross pollutants can also include larger sediment particles that are likely to settle out of the water column given the right conditions.

"*In the CRC studies, organic material – leaves, twigs and grass clippings – constituted the largest proportion of gross pollutant load (by mass) carried by urban stormwater. Vegetation, however, is not a major source of nutrients compared to other sources*" (Allison et al 1997, p.3). However, if vegetation accumulates in waterways and is allowed to break down over time then the nutrient contribution may be more significant.

"*Results from the CRC monitoring program suggest that urban areas contribute about 20-40 kilograms (dry mass) per hectare per year of gross pollutants to stormwater*" (Allison et al 1997, p.2). For Townsville, (based on an urban footprint of 150 square kilometres) this is equivalent to approximately 300-600 tonnes per year (1200-2300 cubic metres) of gross pollutants.

3.6.5 Urban Stormwater Quality A Statistical Overview

A report prepared by Duncan (1999) titled *Urban Stormwater Quality: A Statistical Overview* is the result of a review of literature from around the world. It is used as the main reference document in Australia in the absence of adequate local data on stormwater quality. The report assesses the broad scale behaviour of urban run-off, the quality of stormwater and its interactions with land use and other catchment characteristics.

The water quality variables and catchment characteristics assessed in the review are listed in Table 3.20.

Duncan (1999) found that concentrations in urban stormwater are approximately log-normally distributed for all water quality parameters investigated. The exception was pH, which is approximately normally distributed. "*Concentrations of SS, TN and TP are on average highest for agricultural catchments, intermediate for urban catchments and lowest for forested catchments. Concentrations of lead, BOD, COD and microbiological parameters are higher on average from high urban catchments*"[1] (Duncan 1999, p.v).

[1] High urban catchments have >65% urban landuse

Table 3.20 Water Quality Variables and Catchment Characteristics

Water Quality Variables		Catchment Characteristics	
pH	Metals:	% of:	Catchment area (ha)
Suspended solids (SS)	• Lead	• Residential	Impervious %
Turbidity	• Zinc	• Industrial	Urban %
Total phosphorus (TP)	• Copper	• Commercial	Population density (people/ha)
Total nitrogen (TN)	• Cadmium	• Institutional	Roads %
Chemical oxygen demand (COD)	• Chromium	• Urban open space	Traffic density (vehicles/day)
Biochemical oxygen demand (BOD)	• Nickel	• Other urban	Roofs %
Oil and grease	• Iron	• Agricultural	Mean annual rainfall (mm)
Total organic carbon (TOC)	• Manganese	• Forest	
Microbiological: • Total coliforms • Fecal coliforms • Fecal streptococci	• Mercury	• Other rural	

Note: Microbiological measurement used is number of organisms per 100mL, turbidity measured in NTU and other parameters in milligrams per litre (equivalent to parts per million).

Significant points from the Duncan (1999) study include:

- Elevated chemical oxygen demand (COD) appears to be associated with all kinds of roads and high urban land use. Industrial areas have the highest COD concentrations of the urban land uses (Duncan 1999, p.20).
- It appears that biochemical oxygen demand (BOD) increases with increasing urbanization. In conjunction with this there is an increase in BOD with increasing population density (Duncan 1999, p.23).
- As could be expected levels of oil and grease are highest from roads and in high urban areas (Duncan 1999, p.25).
- Mean turbidity from roofs is significantly lower than from other urban land uses suggesting that the sources of turbidity are concentrated at ground level (Duncan 1999, p.31).
- Traditionally the highest source of lead has been roads with higher vehicle densities giving higher concentrations. This is less relevant now following the removal of lead from petrol (Duncan 1999, p.36).
- The primary source of zinc is associated with roofs followed by roads (Duncan 1999, p.39).
- Copper concentrations are highest from roads and non-residential urban areas (Duncan 1999, p.43).
- It appears that the main source of cadmium is related to non-urban areas i.e. pervious surfaces (Duncan 1999, p.46)[2].
- Assessment of land use associations with chromium, nickel, iron, manganese and mercury are inconclusive due to lack of data (Duncan 1999, pp.48-55).
- Microbiological parameters are twenty times higher for high urban areas than for low urban areas[3] (Duncan 1999, pp.56-61). Within the urban environment residential areas tend to produce lower concentrations of metals and organic carbon, and higher concentrations of phosphorus and microbiological parameters (Duncan 1999, p.v);
- Urban sites with higher mean annual rainfall produce lower stormwater concentrations, on average, for most metal and non-metal parameters, but not for microbiological measures (Duncan 1999, p.v);
- Sites with higher population density produce higher stormwater concentrations on average for TN, BOD fecal coliforms, but not for metals (Duncan 1999, p.v).

Significant points with regard to suspended solids (see Table 3.21) include:

- Increasing the mean annual rainfall by 500mm approximately halves the most likely concentration of SS in runoff (Duncan 1999, p.v);

[2] Possibly a function of fertiliser use
[3] Low urban areas have <35% urban land use

- The greatest mass of SS in urban runoff typically occurs in the 1 – 50 micro metre particle size range (Duncan 1999, p.5);
- Concentrations from roads are significantly related to mean annual rainfall (Duncan 1999, p.6);
- Dry weather redistribution by wind tends to concentrate dense particulate matter at lower elevations (Duncan 1999, p.8);
- In urban areas roofs produce the lowest concentrations of suspended solids followed by high urban sites with high urban roads having the highest average concentrations.

Table 3.21 Suspended Solids by Land Use

	Log transformed data		Untransformed data (mg/L)		
Subgroup	**Mean**	**Std. Dev.**	**Arith. Mean**	**Geo. Mean**	**Median**
High urban roads	2.41	0.46	779	257	232
Low urban roads	1.84	0.66	229	69	64
Roofs	1.55	0.38	47	35	41
High urban	2.19	0.48	294	155	152
Agricultural	2.27	0.47	311	186	133
Forest	1.90	0.30	99	79	71
From Figure 3					
All medium urban	2.248			180	
High Urban					
Residential	2.15			140	
Industrial	2.176			146	
Commercial	2.126			130	

Note: Primary information extracted from Table 1 (Duncan 1999, p.10) with additional median approximated from Figure 3 (Duncan 1999, p.6) No significant difference was found to exist between high urban categories. Arith. Mean is arithmetic mean and Geo. Mean is geometric mean.

Summary statistics for phosphorus are provided in Table 3.22. In urban areas the residential land use produces the highest average concentrations of phosphorus. Production of phosphorus from forest areas is significantly lower than from urban areas with agricultural areas having the highest concentrations of all the land uses.

Table 3.22 Phosphorus Summary Statistics

	Log transformed data		Untransformed data (mg/L)		
Subgroup	**Mean**	**Std. Dev.**	**Arith. Mean**	**Geo. Mean**	**Median**
Roads	-0.59	0.44	0.42	0.26	0.24
Roofs	-0.89	0.29	0.15	0.13	0.14
Residential	-0.40	0.34	0.56	0.40	0.39
High urban/non-res.	-0.50	0.40	0.46	0.32	0.36
Agricultural	-0.27	0.45	0.90	0.54	0.51
Forest	-1.14	0.34	0.095	0.072	0.07

Note: Information extracted from Table 2 (Duncan 1999, p.13)

Summary statistics for nitrogen are provided in Table 3.23. As with phosphorus the highest concentration of nitrogen is produced by agricultural land followed by urban areas with forest areas being significantly lower.

Table 3.23 Nitrogen Summary Statistics

	Log transformed data		Untransformed data (mg/L)		
Subgroup	**Mean**	**Std. Dev.**	**Arith. Mean**	**Geo. Mean**	**Median**
Roads	0.33	0.30	2.7	2.1	2.2
High urban	0.42	0. 82	3.4	2.6	2.5
Agricultural	0.59	0.39	5.3	3.9	4.4
Forest	-0.08	0.36	1.1	0.83	0.95

Note: Information extracted from Table 3 (Duncan 1999, p.18)

3.6.6 Heavy Metals

Moss and Costanzo (1998) present the results of a study between 1975 and 1992 of sediment concentrations of six heavy metals in Queensland freshwater streams, estuaries and coastal waters i.e. zinc (Zn), copper (Cu), cadmium (Cd), lead (Pb), nickel (Ni), and chromium (Cr). Concentrations of cobalt (Co) and mercury (Hg) were also measured but were excluded from the report results as "*cobalt has a low toxicity rating and was present at only very low values at all sites; while mercury results at most sites were below the limits of detection*" (Moss and Costanzo 1998, p.2).

Moss and Costanzo (1998) reported that urban runoff is normally a much more significant metals source than sewage discharges. A special survey carried out in Cleveland Bay, Townsville (Moss 1981), showed little elevation of metal concentrations around the Cleveland Bay STP outfall (Sandfly Creek) compared to local background values.

"*Zn values were in the 40–70mg/kg range. In contrast, Zn values in Townsville city foreshore areas that are affected by urban stormwater drains were in the 90–140mg/kg range. A similar pattern was observed for Pb and Cu. Again, urban runoff was clearly having a larger impact on sediment metals levels than the sewage discharge*" (Moss and Costanzo 1998, p.6). However, such contamination is usually relatively minor when compared to reference levels.

"*Queensland does not have a large industrial base and has few major secondary industry sources of heavy metals. None of Queensland's major east coast rivers or estuaries are significantly contaminated by heavy metals from industry*" (Moss and Costanzo 1998, p.2).

3.6.7 Metals in Sediment

In a study commissioned for the Black Ross WQIP, Butler (2008) investigated metal concentrations in benthic sediments of the lower Ross River basin. "*Samples were taken at 34 sites within the river or its tributaries, and at one estuarine control site situated on Cocoa Ck to the south of Ross River. Site locations included headwater streams, the Ross River weirs and Dam, Stuart Creek, Goondi Creek, Gordon Creek, the estuary, and several urban drains. Samples were analysed for the twelve most toxic metals that could potentially be associated with land uses and activities in the catchment area. These comprise antimony, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, selenium, silver, zinc and thallium*" (Butler 2008, p.i).

"*The survey found no evidence of any significant existing or emerging metal contamination problems at any site in the Ross River catchment. Some very minor isolated anomalies were detected at a few sites but none of these were large enough to be considered ecologically significant or to warrant management attention*" (Butler 2008, p.ii).

While the study showed that metal concentrations are not an issue in the Ross River and Stuart Creek catchments there was a recommendation that a similar study be undertaken for the Bohle River catchment. It was also noted that there is pre-existing evidence showing metal contamination issues associated with Ross Creek and the Townsville Harbour area.

3.7 National Pollutant Inventory

"*Diffuse emissions to air include sources such as: smaller facilities that are not required to report [through the NPI], transport (e.g. motor vehicles) and non-industrial (e.g. barbeques). Diffuse emissions to water include nutrients (total nitrogen and total phosphorus) emissions from water catchments due to different land use types*."

"*Commonwealth, state and territory environment agencies have approved the techniques used to estimate emissions for the NPI. It is important to note that the accuracy of these techniques varies. For the diffuse data in particular, comparative analysis of the data may be misleading, because jurisdictions may have used different approved estimation techniques*."
(Source: http://www.npi.gov.au/database/data-explanation.html)

NPI diffuse data comprises emissions within airshed and water catchment study areas. There are 33 airshed and 32 water catchment regions, and they include urban and rural locations. The location and size of the regions are determined in line with stakeholder priorities. The regions do not cover the whole of Australia. Diffuse data provides a more comprehensive picture of pollution across Australia and provides context for facility emissions.
(Source: NPI 2005 Diffuse emissions data Fact Sheet)

Townsville is not included in the NPI airsheds or water catchment regions.

According to NPI figures the most significant diffuse source of emissions across Australia is motor vehicles (see Table 3.24).

Table 3.24 Top Ten Diffuse Source Emissions

Substance	Tonnes	Major diffuse source	% of total diffuse
Carbon monoxide	4,500,000	Motor vehicles	48%
Total volatile organic compounds	3,000,000	Biogenics (from living organisms)	80%
Oxides of nitrogen	660,000	Motor vehicles	56%
Particulate matter 10.0 um	610,000	Burning/wildfires	36%
Sulphur dioxide	71,000	Fuel combustion – sub reporting	58%
Ammonia (total)	35,000	Agriculture (livestock)	86%
Toluene	30,000	Motor vehicles	60%
Xylenes	22,000	Motor vehicles	64%
Benzene	15,000	Motor vehicles	67%
n-Hexane	7,500	Motor vehicles	43%

Note: Source data from NPI 2008, p.7. Diffuse data is not collected annually and may be from different years. Tonnes figures are totals from all airsheds. % is for the major source relative to total emissions for that substance.

The NPI provides a range of information on diffuse emissions including a range of Manuals. The Diffuse Emissions Manuals assist governments in estimating emissions from:

- Non-industrial activities such as transportation;
- Domestic activities such as lawn mowing;
- Commercial activities such as baking of bread in small bakeries;
- Industrial activities, which are not reported because the relevant thresholds are not exceeded or because the industries are exempt from reporting.

The manuals facilitate consistent reporting by jurisdictions. Diffuse emissions are also known as aggregated emissions data (AED). The twenty-one manuals listed in Table 3.25 are available for use by states and territories for estimating diffuse emissions. Relevance of the manuals to the Black Ross WQIP area is noted in the table.

Table 3.25 NPI Diffuse Emission Manuals

No.	Subject	Relevance to Black Ross WQIP
1	Aircraft	Townsville Airport and RAAF base are located in the Townsville urban area and may have local significance
2	Aquaculture - Temperate	Not applicable
3	Aquaculture - Tropical	Small aquaculture facilities are located in the study area and are included in point source emissions to water as licensed ERAs
4	Architectural Coating	Relevant but not considered significant and mainly VOCs in relatively small quantities
5	Barbeques	Relevant but not considered significant
6	Bushfires and Prescribed Burning	Seasonally relevant especially for particulate matter
7	Commercial Ships/Boats and	Townsville Port and significant recreational boating. Localised

	Recreational Boats	impacts in the vicinity of port and marina facilities
8	Cutback Bitumen	Relevant but not considered significant. Mainly VOCs at the time of application and relatively small amounts thereafter
9	Domestic/Commercial Solvents and Aerosol Use	Relevant but not considered significant as mainly VOCs in relatively small amounts dispersed throughout the area. May be more relevant to wastewater treatment plants and landfill facilities as waste
10	Dry Cleaning	Relevant but not considered significant as it mainly involves solvents and VOCs which are recovered and recycled
11	Fuel Combustion (Sub-Threshold)	Relevant but not considered to be significant for water quality in Townsville with the possible exception of industrial areas, however, emissions are generally above reportable levels and are allocated in point source emissions
12	Gaseous Fuel Burning - Domestic	Relevant but not considered significant for water quality. Gas usage levels are unknown but not as significant as for southern areas for heating and other applications where gas is available through a 'reticulated' supply
13	Industrial Solvents Use	Relevant but not considered significant for water quality
14	Lawn Mowing - Domestic	Relevant but not considered significant for water quality
15	Motor Vehicles	Relevant and potentially significant as atmospheric deposition
16	Motor Vehicle Refinishing	Relevant but not considered significant for water quality
17	Paved and Unpaved Roads	Relevant and potentially significant
18	Printing and Graphical Arts	Relevant but not considered significant for water quality
19	Railways	Relevant and potentially significant for local areas
20	Service Stations	Relevant but not considered significant for water quality
21	Solid Fuel Burning - Domestic	Not significant in the Townsville area

Note: Diffuse Emissions Source descriptions are provided at http://www.npi.gov.au/database/aed-sources.html.
(Source: http://www.npi.gov.au/handbooks/aedmanuals/index.html)

Information from the diffuse emissions manuals considered to be most relevant to the Black Ross WQIP area is provided below. Where appropriate, estimates have been made for emissions in the Townsville region i.e. Townsville City Council local government area.

3.7.1 Aircraft

Table 3.26 lists the NPI substances that are typically emitted from aircraft i.e. gas turbines (jet engines) and reciprocating engines (piston engines).

Table 3.26 Aircraft Emissions

Typical Pollutants Emitted		
Acetaldehyde	Chromium (III) compounds	Particulate matter ≤ 10 μm (PM10)
Acetone	Chromium (VI) compounds	Phenol
Arsenic and compounds	Ethylbenzene	Styrene
Benzene	Formaldehyde	Sulphur dioxide
1,3-Butadiene	Lead and compounds	Toluene
Cadmium and compounds	Nickel and compounds	Total volatile organic compounds (VOCs)
Carbon monoxide	Oxides of nitrogen	Xylenes

Calculation of emissions from aircraft for an airshed is based on a landing/takeoff (LTO) cycle i.e. all of the normal flight and ground operation modes associated with landing and take-off. Operations in the LTO cycle have been grouped into the four standard modes for which emission rate data are readily available. These modes are:

- The approach mode, for which emissions are estimated from 1,000 m above ground level (AGL) to ground level;

- The taxi/idle mode, which applies to both incoming and outgoing aircraft during taxiing and idling operations.
- The takeoff mode, which is defined as the period between commencement of acceleration on the tarmac and the aircraft reaching 200 m AGL, during which time the engine is operated at full throttle and fuel usage is at a maximum for any given engine; and
- The climb out mode, for which emissions are calculated for the period between 200 and 1,000 m AGL.

Data required for estimating aircraft emissions in an airshed is:

- The location of airports, runways, landing and approach flight paths, and associated ground movements, in the airshed;
- The number of landing/takeoff (LTO) cycles for each of the aircraft types operating at these airports;
- The prevalence of the different types of engines (and numbers of engines) and auxiliary power units (APUs) used by each aircraft type i.e. usually diesel powered generators;
- The time spent in each operating mode (approach, taxi/idle, takeoff and climbout) for the airport for estimating aircraft engine emissions; and
- The time spent operating the APU at the airport.

(Source: Environment Australia 2003, *Emissions Estimation Technique Manual for Aggregated Emissions from Aircraft*)

Potential water quality impacts

It is unlikely that any aircraft emissions in flight mode would have any noticeable effect on water quality as a result of emissions settling at ground level and being carried in stormwater run-off to nearby waterways. Emissions from the landing/takeoff (LTO) cycles, and especially the taxi/idle and takeoff modes, may have some impact on water quality in the vicinity of the airport. Monitoring of stormwater outlets collecting run-off from the airport would provide an indication of any water quality issues associated with aircraft and other emissions at the airport. Estimates for Townsville Airport and a commentary are included in Appendix D.

3.7.2 Barbeques

Table 3.27 shows the NPI substances that are typically emitted from domestic barbeques.

Table 3.27 Barbecue Emissions

Typical Pollutants Emitted		
Acetaldehyde	Cyanide compounds	Oxides of nitrogen
Acetone	Dichloromethane	Particulate matter ≤ 10 µm (PM10)
Antimony and compounds	Di-(2-Ethylexyl) phthalate (DEHP)	Phenol
Arsenic and compounds	Ethylbenzene	Polycyclic aromatic hydrocarbons
Benzene	Fluoride compounds	Selenium and compounds
Beryllium and compounds	Formaldehyde	Styrene
1,3-Butadiene	n-Hexane	Sulphur dioxide
Cadmium and compounds	Lead and compounds	Tetrachloroethylene
Carbon disulphide	Manganese and compounds	Toluene
Carbon monoxide	Mercury and compounds	Total volatile organic compounds (VOCs)
Chromium (VI) compounds	Methyl ethyl ketone	Xylenes
Cobalt and compounds	Nickel and compounds	Zinc and compounds

Barbeque use releases emissions from several sources, including the direct burning of fuel to provide heat for cooking, from the product being cooked and from the burning of dripping fats and oils. Depending on the fuel being used emission types and quantities will vary. Emissions from processes other than direct fuel burning are difficult to quantify and are not included in the modeling of the source document.

Estimates of the emissions released from barbeque fuel and briquettes are obtained by using emission factors for the burning of brown coal in 5 hand-fed stoves. Emissions calculations for wood fueled barbeques are based on the quantity of wood fuel consumed and use emission factors for open fireplaces.

Emissions released from barbeques currently have no controls in place to regulate them.

Emissions released from domestic barbeque use vary with season, day of the week and time of the day. In spite of this, bodies such as the NPI more frequently produce annual aggregated emissions reports. Such annual calculations have further inherent variations dependant on the household and population distribution of the target area as well as any sub-regional variations in solid fuel usage.

Data required to calculate aggregated emissions from domestic barbeques is:

- The amount of each type of fuel consumed in barbeques in the relevant jurisdiction or airshed; and
- The distribution of households or population by ABS Collection District.

The amount of each fuel type consumed in domestic barbeques in an airshed can be calculated using the equations found on pages 6-7 of the source document.
(Source: Environment Australia 1999, *Emissions Estimation Technique Manual for Aggregated Emissions from Barbeques*)

Potential water quality impacts
Clusters of barbeque facilities, such as in picnic areas or camping grounds, cause nuisance value to air quality but emissions are too small to have any impact on water quality through emissions settling on or near neighbouring water bodies. In terms of emissions released from wood burning, those emitted from barbeque use comprise a very small fraction of the total and are unlikely to have any significant impacts on water quality.

3.7.3 Aquaculture

Aquatic species are generally very susceptible to chemical pollution; hence, by its very nature the aquaculture industry is largely self-regulating as far as pollutants are concerned. In general, chemical use in aquaculture is kept to a minimum and effluent is usually comprised principally of nutrients and suspended solids.

Total nitrogen (N) and total phosphorus (P) are the main nutrients produced by any aquaculture farm. Initially, estimates are made of the effluent from the ponds, tanks or cages and not necessarily from the farm. These estimates may be viewed as a measure of the potential of the farm to discharge effluent into the environment. In a cage system all of the effluent from the cage will be carried into the surrounding water by currents.

Faeces and uneaten food are flushed out regularly and discharged with wastewater. In a pond system the nutrients will leave by a number of pathways. Suspended solids are considered a significant effluent component by the aquaculture industry and are reportable under Queensland Environmental Protection Agency (EPA) licencing rules. At the present time suspended solids are not included in NPI reporting.

Chemical use in aquaculture
There is a range of minor-use chemicals that are added for special purposes. These include:

- Antibiotics, which may be used to control outbreaks of disease. Use of these are regulated by veterinarians;
- 'Tea seed cake' containing the natural product saponin used to kill fish in prawn ponds;
- Colouring which may be added for final conditioning in prawns.

These are generally complex materials and may contain minor NPI substances, however, even under the most liberal use they will not reach reportable levels.

Chlorine (Cl), which is used for cleaning and sterilizing, may reach aggregate emission levels equal to reportable thresholds in larger facilities. This is especially true for some crocodile farms where there is regular use of chlorine for cleaning pens and abattoir facilities. There are reports of the use of Copper Sulphate ($CuSO_4$) for cleaning and the control of fungal diseases on crocodile farms, however this use is now very minor and appears to be largely discontinued on most farms. Similarly the use of Acetic Acid (ethanoic acid) in prepacking treatment of crocodile meat seems to be being phased out in favour of chlorine.

There may be sources of emissions associated with running a large aquaculture farm, but not directly resulting from aquaculture e.g. use of fuel for generators, outboard motors and other equipment.
(Source: Environment Australia 2000, *Aggregate Emission Data Estimation Technique Manual for the Aquaculture of Barramundi, Prawns, Crocodiles, Pearl Oysters, Red Claw, Tropical Abalone in Tropical Australia*)

Potential water quality impacts
As the main pollutants from aquaculture are nutrients and sediment which are often discharged directly to water the potential impact from this industry is tangible. The industry is licenced through the EPA and is therefore considered to be well regulated. Aquaculture is considered to be a point source pollutant emitter in this report and is included in the section on ERAs (see section 2.2.1).

3.7.4 Bushfires and Prescribed Burning

Prescribed burning and wildfires have a variety of emissions, which are listed in Table 3-4.

Table 3-4 Bushfire Emissions

Typical Pollutants Emitted		
Antimony and compounds	Cobalt and compounds	Oxides of nitrogen
Arsenic and compounds	Copper and compounds	Particulate matter ≤ 10 µm (PM10)
1,3-Butadiene	Lead and compounds	Selenium and compounds
Cadmium and compounds	Manganese and compounds	Total volatile organic compounds (VOCs)
Carbon monoxide	Mercury and compounds	Zinc and compounds
Chromium (VI) compounds	Nickel and compounds	

Note: Speciation profiles are not available to convert estimates of total VOC emissions from these types of sources to emissions of particular organic substances that are listed in the National Environment Protection Measure (NEPM).

Emissions estimation techniques
The data required to calculate aggregated emissions from prescribed burning and wildfires (excluding agricultural burning) are:

- The size of the area burned for each fire event;
- The fuel loading of that burn area; and
- The location of each fire event (for spatial allocation purposes).

Assumptions are made about the actual amount of fuel consumed (72% for wildfires, 42% for prescribed forest burns and 72% for temperate and savanna grasslands) or default fuel loadings for various vegetation types in different locations throughout Australia are used in the calculation. Default fuel loadings for Queensland are:

- 19.3 tonnes per hectare for forest wildfires;
- 3.91 tonnes per hectare for forest prescribed burning; and
- 2.16 tonnes per hectare for savanna burning.

Emission factors for each of the pollutants are required to enable calculations of the emission of each pollutant from a particular type of fire (see page 8 of source document for formula). With the exception of carbon monoxide, oxides of nitrogen, particulate matter and VOCs, which have emission factors measured in grams per kilogram, the other pollutants are measured in micrograms per kilogram (see page 11 of the source document).

Some emissions have been calculated for a 100 hectare fire for each fire type (see Table 3.28) to provide an indication of the quantity associated with selected pollutants. Emissions can also be calculated for agricultural burning i.e. crop residues.

Table 3.28 Calculated Emissions Vegetation Burning (100 hectares)

	Emissions in kilograms for fire types		
Pollutant	**Savanna**	**Forest wildfire**	**Forest prescribed**
Carbon monoxide	18,058	135,100	43,792
Oxides of Nitrogen	1,374	3,860	782
Particulate matter	2,160	14,436	4,692
VOCs	1,058	20,458	2,502
Cadmium and compounds	1.3	1	0.4
Lead and compounds	0.1	0.8	0.4
Mercury and compounds	0.03	0.2	0.09
Nickel and compounds	0.04	0.3	0.1
Zinc and compounds	0.2	1.4	0.06

(Source: Environment Australia 1999, *Emissions Estimation Technique Manual for Aggregated Emissions from Prescribed Burning and Wildfires*)

Potential water quality impacts

To determine the potential impact on water quality the actual fate of the emissions would have to be calculated using a dispersion model. It is assumed that only very large fires would have any significant impact on water quality as a result of the pollutants settling at ground level and subsequently being carried in rainfall run-off to waterways, or settling directly onto water bodies. The emissions that could have an impact on water quality in this situation are particulate matter and, to a lesser extent, oxides of nitrogen.

3.7.5 Commercial Ships/Boats and Recreational Boats

Table 3.29 shows the NPI substances that are typically emitted from commercial ships, commercial boats and recreational boats.

Table 3.29 Emissions from Shipping and Boats

Typical Pollutants Emitted		
Acetaldehyde	Cobalt and compounds	Particulate matter ≤ 10 µm (PM10)
Antimony and compounds	Copper and compounds	Polycyclic aromatic hydrocarbons
Arsenic and compounds	Cyclohexane	Selenium and compounds
Benzene	Ethylbenzene	Styrene
Beryllium and compounds	Formaldehyde	Sulphur dioxide
1,3-Butadiene	Lead and compounds	Toluene
Cadmium and compounds	Mercury and compounds	Total volatile organic compounds (VOCs)
Carbon monoxide	n-Hexane	Xylenes
Chromium (III) compounds	Nickel and compounds	Zinc and compounds
Chromium (VI) compounds	Oxides of nitrogen	

Sources of emissions

Commercial ships may emit air pollutants under two major modes of operation: while underway, and at berth under auxiliary power.

Emissions underway come from a ship's engine exhaust and are influenced by a great variety of factors including engine size, the fuel used (residual oil or diesel oil), operating speed and load.

A ship continues its emissions at berth. Power must be made available for the ship's lighting, heating, pumps, refrigeration, ventilation and so on. Ships normally use diesel-powered generators to furnish auxiliary power. Emissions from these generators may also be a source of underway emissions if they are used away from port.

In addition to engine exhaust emissions, there are fugitive emissions from the loading and ballasting of petroleum tankers in port. During fuel loading and the taking on of ballast, vapour within tankers is vented to atmosphere.

Ballasting operations are a major source of evaporative emissions associated with the unloading of petroleum liquids at marine terminals. Ballasting emissions occur as vapour-laden air in the empty cargo tank is displaced to the atmosphere by ballast water being pumped into the tank. Emissions from ballast operations may occur at dock or at some distance out to sea. The reason for taking on ballast at sea is because of quarantine concerns over the transport of marine life rather than air pollution issues. Little ballast is taken on at dockside, as it is only necessary for trimming the ship when partial cargoes are unloaded. The loading and unloading of certain cargoes (e.g. grain) may release particulate matter into the immediate area if conveyor belts are not enclosed.

The operation of shipboard incinerators is another emission source for some large ships, with the nature of the substances emitted varying with the matter burnt. These two sources of emissions are relatively small in relation to fuel related emissions.

Emissions from commercial and recreational boats arise from boat engines while the boats are travelling. Engines are usually shut down while at berth. While both inboard and outboard engines are used in commercial boats, most recreational boats use outboard engines. All outboard engines use petrol and most inboard engines use diesel as the fuel. Some outboards have underwater exhausts, however only emissions to air are considered in the source document.

Emissions estimation techniques
The data required for estimating emissions from commercial boats are:

- Annual registration of commercial boats by engine type (i.e. inboard and outboard) in an airshed;
- The annual fuel consumption in domestic water transport for a jurisdiction;
- The proportion of commercial boats used in the airshed;
- The proportion of leaded and unleaded petrol used in the airshed (or jurisdiction); and
- The areas where commercial boats carry out their activities.

The data required for estimating commercial ship exhaust emissions are:

- The location of ports in the relevant airshed;
- The number of ships visiting a port in a particular year in the following tonnage ranges:
    - Less than 1 000,
    - 1 000 to 5 000,
    - 5 000 to 10 000,
    - 10 000 to 50 000, and
    - Over 50 000 tonnes;
- The average number of hours at berth;
- The average speed of ships in shipping channels; and
- The locations and lengths of shipping channels in the airshed.

The following data are required for estimating loading and ballasting emissions:

- The volume of petrol or petroleum liquid loaded at port;
- The number of tankers - loading, unloading, and both;
- The average deadweight tonnage (DWT) of tankers; and
- The proportion of ballast emissions at berth.

(Source: Environment Australia 1999, *Emissions Estimation Technique Manual for Aggregated Emissions from Commercial Ships/Boats and Recreational Boats*)

Potential water quality impacts
Emissions from commercial ships and recreational boating may impact on water quality by settling directly onto water bodies from atmospheric emissions or leaching from vessels through corrosion or engine fuel leakages. These substances can be flushed through the area by river and ocean currents, thereby having potentially wider impacts depending on the volume of the emission. While emissions to air from fuel burning may have some

localised impact on water quality in the vicinity of the port the wider impacts are unlikely to pose a significant threat to water quality.

The most serious potential impact on water quality would result from the leakage of hydrocarbons (fuel and oils) directly to water and the discharge of waste and ballast waters. However, such emissions are well regulated by the relevant authorities, including the port, and the transport industry and are more likely to be occasional mishaps than constant pollutant sources.

3.7.6 Lawn mowing

Table 3.30 shows the main NPI substances, which are emitted by lawn mowers.

Table 3.30 Emissions from Lawn Mowers

Typical Pollutants Emitted		
Benzene	Ethylbenzene	Polycyclic aromatic hydrocarbons
1,3-Butadiene	Formaldehyde	Styrene
Carbon monoxide	Lead and compounds	Sulphur dioxide
Chromium (III) compounds	n-Hexane	Toluene
Chromium (VI) compounds	Manganese and compounds	Total volatile organic compounds (VOCs)
Cobalt and compounds	Nickel and compounds	Xylenes
Copper and compounds	Oxides of nitrogen	Zinc and compounds
Cyclohexane	Particulate matter ≤ 10 μm	

Emission sources and related processes

There are four types of lawn mowers used in Australia: two-stroke engine mowers, four-stroke engine mowers, electric mowers and push mowers. Only the first two types emit pollutants to the atmosphere at the point of use (power utilities will report emissions from electricity generation for electric mowers). Four-stroke mowers have lower emissions of VOCs, CO and PM_{10} than two stroke mowers, but higher NOx emissions. Fuel type (leaded or unleaded petrol) can also affect emissions, especially for lead and SO_2. As lead petrol is no longer used in Australia this is no longer a factor.

Lawn mower usage can vary across a region. Important factors affecting local equipment usage include climate, land use, lot size, population demographics, and the availability of water in more arid regions (Heiken *et al*, 1997). Lawn mower usage also varies both seasonally and with day of the week. Emissions from spills during fuel transfer can be significant. Emissions can also be affected by combustion chamber temperature and air/fuel ratio (Priest, 1996).

Emissions estimation techniques

The estimation of aggregated emissions from domestic lawn mowing requires information on the following:

- Annual hours of lawn mower usage per household; and
- Mower type (two- or four-stroke).

Annual usage hours for different fuel types are only required for calculating emissions of lead and SO_2.
(Source: Environment Australia 1999, *Emissions Estimation Technique Manual for Aggregated Emissions from Domestic Lawn Mowing*)

Potential water quality impacts

Lawn mower emissions have the potential to impact on water quality but this is dependant on the proximity to water bodies and the magnitude of use. Leaded petrol lawnmowers are no longer a factor due to the removal of leaded petrol from the market. Emissions have the potential to affect water quality through direct settling or by being flushed in rainfall run-off. However, based on an estimation of lawnmower use and emissions in the Townsville region (see Text Box below and Appendix D), the magnitude of these potential impacts is such that lawn mower use should not be considered a threat to water quality.

Annual lawnmower emission calculations for Townsville
Emissions from lawn mowers have been calculated based on assumptions of 30,000 two stroke mowers and 30,000 four stroke mowers in the Townsville region and usage of 1 hour per mower per fortnight i.e. 780,000 two stroke lawn mower hours per year and 780,000 four stroke lawn mower hours per year.

If we assume that the mowing footprint is 150 square kilometres (same as for gross pollutants) and all of the oxides of nitrogen and particulate matter settles within the mowing footprint then we have a contribution from lawn mowers of 0.43 kg/ha per year of particulate matter and 0.33 kg/ha year of oxides of nitrogen. These quantities are not considered to be significant in terms of water quality impacts.

3.7.7 Motor vehicles

Table 3.31 lists the NPI substances that are typically emitted from motor vehicles.

Table 3.31 Motor Vehicle Emissions

Typical Pollutants Emitted		
Acetaldehyde	Copper and compounds	Particulate matter ≤ 10 μm
Acetone	Cyclohexane	Polycyclic aromatic hydrocarbons
Benzene	Ethylbenzene	Styrene
1,3-Butadiene	Formaldehyde	Sulphur dioxide
Cadmium and compounds	Lead and compounds	Toluene
Carbon monoxide	n-Hexane	Total volatile organic compounds (VOCs)
Chromium (III) compounds	Manganese and compounds	Xylenes
Chromium (VI) compounds	Nickel and compounds	Zinc and compounds
Cobalt and compounds	Oxides of nitrogen	

Emission sources and related processes
The energy to propel the vehicle comes from burning fuel in an engine. Pollution from vehicles arises from the by-products of the combustion process (emitted via the exhaust system) and from evaporation of the fuel itself. Particulate matter is also emitted from brakes and tyre wear.

Various types of pollutants are produced in the combustion process. A range of volatile organic compounds (VOCs) are produced because the fuel is not completely burnt (oxidised) during combustion. Oxides of nitrogen (NOx) result from the oxidation of nitrogen at high temperature and pressure in the combustion chamber. Carbon monoxide (CO) occurs when carbon in the fuel is partially oxidised rather than fully oxidised to carbon dioxide. Sulphur dioxide (SO_2) and lead are derived from the sulphur and lead in fuels.

Particulate matter is produced from the incomplete combustion of fuels, additives in fuels and lubricants, and worn material that accumulates in the engine lubricant. These additives and worn materials also contain trace amounts of various metals and their compounds, which may be released as exhaust emissions.

Evaporative emissions come mainly from petrol (diesel fuel has a much lower vapour pressure) and consist of VOCs and small amounts of lead. These emissions may occur in several ways:

- Diurnal Losses: As the ambient air temperature rises during the day, the temperature of fuel in the vehicle's fuel system increases and increased vapour is produced.
- Running Losses: Heat from the engine and exhaust system can vaporize gasoline when the car is running.
- Hot Soak Losses: Because the engine and exhaust system remain hot for a period of time after the engine is turned off, gasoline evaporation continues when a car is parked.
- Resting Losses: Vapour may be lost from the fuel system or the evaporative emission control system as a result of permeation through rubber components and other leaks.

Another source of emission is the crankcase of early model (pre-1970) vehicles without positive crankcase ventilation systems. In such vehicles, losses occur directly from venting of the crankcase during engine operation.

Evaporative emissions also occur from vehicle refuelling at service stations or from fuel tanker loading and unloading. Emissions can occur when liquid fuel leaks or is spilt, but these emissions are also not considered in the manual. Another type of emission that arises from use of motor vehicles is dust emissions from roads.

Factors affecting vehicle emissions

The main factors affecting vehicle emissions are:

- The vehicle type;
- The type and composition of the fuel used by a vehicle;
- The age of a vehicle; and
- The types of roads on which a vehicle travels.

The emission control technologies employed by an in-service vehicle, the condition of its emission control equipment, and its state of maintenance and repair, have significant impacts on emissions. These factors are reflected in the emissions estimation techniques by considering the age of particular types of vehicles. In particular, the original emission quality and subsequent emission deterioration with time may be simulated by the use of deterioration factors based on the average distance travelled by vehicles of different ages.

Emissions also vary significantly with vehicle and engine operation, which in turn are strongly related to road types (selected on the basis of traffic flow conditions), and hence vehicle speeds and driving patterns. Reid Vapour Pressure (RVP), temperature and number of trips per day have important effects on evaporative emissions. Other factors affecting motor vehicle emissions, include road conditions and grade, weather conditions, the proportions of hot and cold starts, and the use of air conditioners.

Emissions estimation techniques

The following activity data and related information are required for estimating annual emissions from motor vehicles in an airshed:

- Traffic count data or spatially distributed vehicle kilometres travelled (VKT) data by road type in an airshed;
- Relative VKT by vehicle type on each road type in the airshed;
- VKT in a jurisdiction by vehicle/fuel type and year of manufacture;
- The number of vehicles in a jurisdiction by vehicle/fuel type and year of manufacture;
- The average fuel consumption rate of each vehicle/fuel type;
- The sulphur and lead contents of fuels and RVP of petrol used in an airshed; and
- The average temperature and average daily maximum and minimum temperatures (preferably for each month, otherwise for a year) in the airshed.

(Source: Environment Australia 2000, *Emissions Estimation Technique Manual for Aggregated Emissions from Motor Vehicles*)

Potential water quality impacts

Motor vehicles can have significant impacts on water quality through airborne emissions and particularly through particulate matter and chemicals in run-off from road surfaces. Exhaust fumes released into the atmosphere may settle on water surfaces or be washed out in rainfall and subsequently impact water quality. These events would require either extremely high concentrations of motor vehicles close to water bodies or high concentrations of pollutants in the airshed. Fugitive emissions from petrol stations and fuel storage facilities are less significant than the ‘burnt’ emissions from vehicle exhausts.

The main issues associated with motor vehicle emissions in the atmosphere are health related. Nitrogen dioxide is classified as harmful by inhalation at concentrations greater than 0.1% and very toxic by inhalation at concentrations greater than 10%. It is also irritating to the skin, eyes and respiratory system at concentrations greater than 0.5%.

More relevant in terms of water quality is the transport of particulate matter, oils and fuel from road surfaces into water bodies through stormwater systems as a component of rainfall run-off (see 3.7.8 below).

Calculations for motor vehicles for the Townsville region are included in Appendix D with a summary of annual emissions relevant to water quality listed in Table 3.32. On the basis of these calculations it is not considered that emissions to air are a significant water quality issue, although it is likely that there will be a contribution to nitrogen levels resulting from the wetfall deposition of oxides of nitrogen, and in particular nitrogen dioxide.

Table 3.32 Vehicle Emission Estimates Relevant to Water Quality

	Car	LCV	Bus	Truck	Motorcycle	Totals (tonnes)	Max Potential Deposition
NO_x	883	468	89	440	13	**1,893**	76 kg/ha
PM_{10}	67	41	3	17	2	**130**	5.2 kg/ha
SO_2	58	34	3	14	3	**112**	4.5 kg/ha

Note: LCV is light commercial vehicle. Figures exclude trailers, farming machinery and mobile campervans. Values are expressed as tonnes per year. Maximum potential deposition was calculated by assuming 100% deposition of material from the airshed over a 250 square kilometre area. This is a significant overestimation of actual deposition.

While there are implications for air quality and global warming associated with the vehicle emissions calculated for the Townsville region the immediate and localised impacts on water quality are less tangible.

3.7.8 Paved and Unpaved Roads

Table 3.33 lists the NPI substances that are typically emitted from paved and unpaved roads.

Table 3.33 Emissions from Paved and Unpaved Roads

Typical Pollutants Emitted		
Antimony and compounds	Copper and compounds	Nickel and compounds
Arsenic and compounds	Lead and compounds	Particulate Matter ≤10mm
Cadmium and compounds	Manganese and compounds	Selenium and compounds
Cobalt and compounds	Mercury and compounds	Zinc and compounds

Field studies have found that paved and unpaved roads are a major source of atmospheric particulate matter within an airshed (USEPA 1997). Road dusts emitted into the atmosphere may be categorised according to dust particle size as follows:

- Particulate matter less than or equal to 2.5 µm ($PM_{2.5}$);
- Particulate matter less than or equal to 10 µm (PM_{10}), which is a substance listed in Table 2 of Schedule A to the NEPM;
- Particulate matter less than or equal to 15 µm (PM_{15}); and
- Particulate matter less than or equal to 30 µm (PM_{30}), which is assumed to be equivalent to total suspended particulate matter (USEPA 1998).

A number of other NPI substances are found on roadways in trace amounts, and may form part of the particulate matter, which is emitted from paved and unpaved roads.

Paved roads

When a vehicle travels over a paved road, particulate emissions are generated by the suspension or resuspension of loose material on the road surface. The surface loading of this material is the main source of particulate emissions from roads, and is continually moved and removed. Deposition processes lead to a constant supply of loose material accumulating on the road surface. Particulate matter also arises from exhaust and other emissions directly associated with motor vehicles.

Unpaved roads
When a vehicle travels on an unpaved road the force of the wheels on the road surface pulverises the surface material into fine particles. Tests have shown that fine particles are continually removed by traffic through re-entrainment to the atmosphere, leaving a higher percentage of coarse particles on the road surface (USEPA 1998). These fine particles are lifted by and dropped from the rolling wheels of vehicles, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake that is left behind the vehicle continues to act on the road surface after the vehicle has passed, resulting in further particulate emissions.
(Source: Environment Australia 1999, *Emissions Estimation Technique Manual for Aggregated Emissions from Paved and Unpaved Roads*)

Potential water quality impacts
Paved and unpaved roads can have significant impacts on water quality through the collection and subsequent transfer of chemical or particulate matter to water bodies. Traffic use and environmental stressors degrade road condition, releasing particulate and chemical particles. These particles can be transferred to water bodies through aerial vectors or by rainfall run-off.

Fine particulate matter can affect the light penetration and turbidity of water bodies while chemical runoff can have significant impacts on local ecological processes. The magnitude of these effects depends on the proximity of roads to a water body, stormwater drainage pathways to receiving waters as well as the density of traffic.

3.7.9 Railways

Table 3.34 lists the NPI substances that are typically emitted from railway locomotives.

Table 3.34 Emissions from Rail Locomotives

Typical Pollutants Emitted		
Acetaldehyde	Copper and compounds	Particulate Matter ≤10mm
Antimony and compounds	Ethylbenzene	Polycyclic aromatic hydrocarbons
Arsenic and compounds	Formaldehyde	Selenium and compounds
Benzene	Lead and compounds	Sulphur dioxide
Cadmium and compounds	Manganese and compounds	Toluene
Carbon monoxide	Mercury and compounds	Total volatile organic compounds (VOCs)
Chromium (III) compounds	n-Hexane	Xylenes
Chromium (VI) compounds	Nickel and compounds	Zinc and compounds
Cobalt and compounds	Oxides of nitrogen	

Railway locomotives used in Australia are primarily of two types i.e. electric and diesel-electric. Electric locomotives are powered by electricity generated at stationary power plants and emissions are produced only at the electrical generation plant, which is considered a point source and therefore not considered in this section.

Diesel-electric locomotives, on the other hand, use a diesel engine and an alternator or generator to produce the electricity required to power its traction motors.

A third type, the steam locomotive, is used in very localised operations, primarily as tourist attractions. Emissions from these locomotives are insignificant and no emission factors have been developed for them. In addition, the particulates emitted from operating steam locomotives are so large that nearly all particles fall to the surface within 50 metres of the engine.

Other sources of emissions from railroad operations include small gasoline and diesel engines used on refrigerated and heated rail cars. These engines are thermostatically controlled, working independently of train motive power, and are not covered in the manual. Brake dust from trains can also be a source of PM_{10}, however, no emission factor is available for this parameter.
(Source: Environment Australia 1999, *Emissions Estimation Technique Manual for Aggregated Emissions from Railways*)

Potential water quality impacts
Locomotive infrastructure release emissions through the burning of diesel fuel and as chemical or particulate matter released from railways by traffic. Atmospheric emissions may settle on water bodies while aerial processes and rainfall run-off can transfer settled particulate matter to waterbodies. As rail traffic is limited to narrow corridors the influence of the main emissions is confined to a small area in the vicinity of the rail corridor. The overall impact on the Townsville region is not considered significant however there may be localised issues e.g. Stuart Creek catchment. Monitoring of storm water runoff near rail corridors could be used to determine the extent of influence such substances have on local water quality.

3.7.10 Landfills

Landfills are significant sources of methane (CH_4) and carbon dioxide (CO_2). In addition to CH_4 and CO_2, amounts of non-methane organic compounds (NMOC) are also produced. NMOCs include a number of NPI-listed reactive volatile organic compounds (VOCs) and speciated organic compounds.

Emissions to air
CH_4 and CO_2 are the primary constituents of landfill gas, and are produced during anaerobic decomposition of cellulose and proteins in the landfilled wastes. Although neither of these substances are NPI-listed, estimating emissions of these gases is important as they are indicators for emissions of other listed pollutants.

Decomposition is a complex process and requires certain environmental conditions. Environmental factors that affect the decomposition include moisture content of the waste, nutrient concentration, the presence and distribution of microorganisms, the particle size of the waste, water flux, pH, and temperature. Because of the complex set of conditions that must occur before landfill gas is generated, waste may be in place for a year or more before anaerobic decomposition begins and landfill gas is generated. Refuse in a landfill may produce landfill gas for 20 to 30 years, with an average of 25 years. On the other hand, aerobic decomposition results in CO_2 and water. Uncontrolled dumps, where waste is exposed to air, may be subject to aerobic decomposition.

Some emissions may also occur during the operation of the landfill site. Excavation and heavy machinery may be significant sources of emissions through both the combustion of fuel and the compaction of waste.

Emissions to land and water
Leachate is generally considered to be water that has entered a landfill site and become contaminated after diffusion through the waste or liquids within the waste. Leachate is likely to contain a number of NPI-listed substances. Its composition will vary from site-to-site, depending on many factors including; the nature of the waste in the landfill, the filling method, the level of compaction, the engineering design of the landfill, the rainfall of the region, and the stage of decomposition of the waste.

Emissions to land and waters from a landfill generally come from diffusion of leachate to the groundwater (emission to land), leaks to surface waters (emission to water), or run-off from the flow of water across the landfill site. The volume of leachate produced within a landfill will depend mainly on the rainfall of the area, how well the landfill is sealed and capped, and the original water content of the waste deposited.

Emissions of substances to land on-site include solid wastes, slurries, sediments, spills and leaks, and the use of chemicals to control various elements of the environment (such as pesticides and dust suppressants) where these emissions contain listed substances. These emission sources can be broadly categorised as;

- Surface impoundments of liquids and slurries;
- Application farming;
- Unintentional leaks and spills; and
- Emissions of leachate to land/groundwater.

Waste disposed into a landfill is not considered as an emission to land, only emissions from the landfill.

For the purposes of determining whether a landfill exceeds a threshold, the following factors need to be considered:

- Does the landfill accept or coincidentally produce any of the listed substances in excess of 10 tonnes during the reporting period;
- Does the landfill burn more than 400 tonnes of landfill gas, any other fuel or waste on-site during the reporting period; and
- Does the landfill emit more than 15 tonnes of nitrogen or 3 tonnes of phosphorus to a waterway during the reporting period.

Table 3.35 Landfill NPI Substance Typical Concentrations

NPI listed substance	Household waste a (mg/kg)	Waste paper b		Plastic c	
		mg/kg	%	mg/kg	% d
Cadmium & compounds	2.9	0.5	3.4	43.1	84.4
Chromium (VI) compounds	53	15	4.0	19.7	1.5
Chromium (VI) compounds	23	7	1.7	8.5	0.6
Copper & compounds	31	65	41.8	78	14.4
Fluoride compounds	71	104	29.2	14	1.1
Nickel & compounds	13	10.7	16.2	18.8	8.3
Lead & compounds	294	65.7	4.4	171.1	3.3
Zinc & compounds	310	108	6.9	402.3	7.4

Source: Bilitewski, et al, 1994 (translated 1997).
a 30% moisture content. **b** 8% moisture content. **c** 6% moisture content. **d** Percentage contribution of NPI-listed substance to the entire municipal solid waste (MSW) stream e.g. cadmium present in plastic makes up 84.4% of the total amount of cadmium in the MSW.

(Source: NPI 2005, *Emission Estimation Technique Manual for Municipal Solid Waste (MSW) Landfills Version 1.2*, Commonwealth of Australia)

The main landfills in Townsville (Vantassel Street and Harveys Range Road)) are not listed as NPI emitters and are therefore not considered to be a significant source of pollutants to surface water. Monitoring bores are located around the landfills to monitor any seepage to groundwater.

3.8 Diffuse Emissions Summary

A summary of the calculated emissions to air from the main diffuse sources in Townsville is provided in Table 3.36. This includes emissions to air from industry included in the NPI point source register.

Table 3.36 Summary of Main Diffuse Emissions to Air (tonnes per annum)

Type	NOx	PM_{10}	SO_2	Ammonia	CO_2/CO
Aircraft/Airport	48	6.5	7		/ 220
Lawnmowers	5	6.5	0.4		/ 952
Vehicles	1,893	130	112		470,000 / 11,000
Industry (NPI)	4,300	1,500	13,000	1,200	/ 970
Bushfires (100ha)	2	5			/ 50
Total (tonnes/year)	6,250	1,650	13,120	1,200	470,000/ 13,190

Note: Industry figures include data for industrial facilities for the 2006 - 2007 NPI reporting year. Bushfire figures are based on an average of 100 hectares burnt per year. Totals are rounded. See Appendix D for diffuse source calculations and Appendix A for NPI point source emissions.

4. Atmospheric Deposition

4.1 What is Atmospheric Deposition

Atmospheric deposition results from material that is gaseous or suspended in the atmosphere that settles on water, land, vegetation or structures as dry deposition or as wash down by rain (wet deposition). Plants respond to rainfall as the wash down of nitrogen and traces of other elements provides a form of 'natural fertiliser'. Nitrogen is the main nutrient in natural atmospheric deposition.

4.2 Background Levels

Nutrient budget studies for tropical coastal ecosystems are rare hence data to determine background levels of atmospheric nutrient deposition for tropical Australia are very scarce in the literature. A proliferation of agricultural and industrial activity in northern Queensland mean that natural background levels of nutrient and sediment in the atmosphere have been obscured by human produced inputs to the atmosphere. Additionally most studies have been focused on the impacts of industrial activities and have concentrated on measuring the atmospheric levels associated with human activities e.g. industry and agriculture.

The most common pollutants associated with atmospheric deposition from natural sources are shown in Table 4.1.

Table 4.1 Natural Atmospheric Deposition Pollutants

Pollutant	Source/Pathway
Nitrogen	• Lightning (oxides) • Dissolved in rainfall (ammonia) • Soil release/denitrification/volatilisation • Fires
Phosphorus	• Wind erosion (attached to soil particles)
Particulate matter	• Wind erosion • Fires • Volcanic eruptions
Heavy metals	• Wind erosion (attached to soil particles) • Fires • Volcanic eruptions
Salt	• Windborne (on moist coastal breezes)
Volatile organic compounds	• Plant release • Carbon based fuels (especially liquid)
Sulphur dioxide	• Fires • Volcanic eruptions

In the Townsville airshed, the Environment Protection Agency (EPA) has established atmospheric monitoring stations at Pimlico, South Townsville, Garbutt, Stuart and the Townsville Port (see Figure 4.2). These stations were established after 1994 and therefore provide no data without human influences.

4.2.1 Data Limitations

While the direct measurement of atmospheric deposition of nutrients is technically and logistically challenging, wet deposition in rainfall is often easier to measure than dry deposition. As measuring dry deposition is more difficult it often means that it is measured less frequently and at fewer locations than wet deposition.

Using previous studies to model ambient atmospheric nutrient concentrations may introduce error due to differing population demographics, industrial configuration and geographic properties. Other features such as prevailing winds and the proximity of monitoring stations to industry can introduce error into deposition modelling.

4.2.2 Nitrogen Compounds

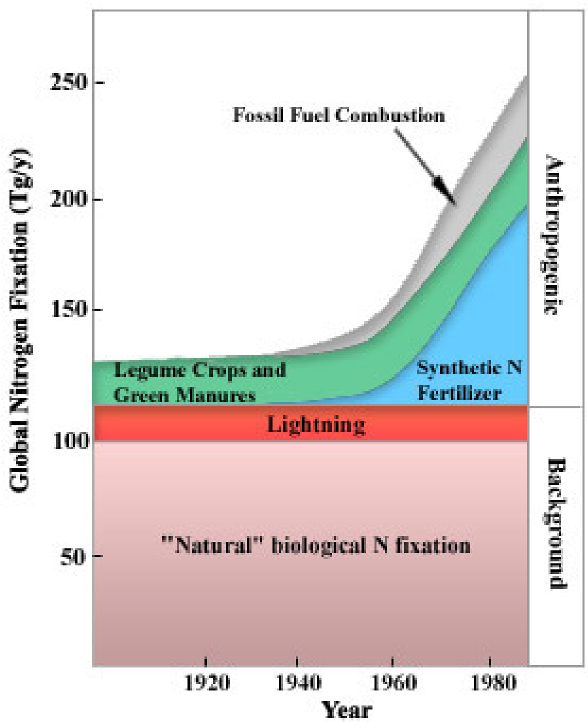
Atmospheric studies outside Australia have been conducted for longer periods of time and have more data to determine potential background atmospheric levels than Australian-based estimates. International research indicates that human activities such as the burning of fossil fuels and the production and application of fertiliser have resulted in an increase in the rate of atmospheric deposition of reactive nitrogen of between two and ten times pre-industrial levels (Clark and Tilman 2008; Bergstrom and Jansson 2006). Further, over 80% of global nitric oxide emissions and 70% of ammonia emissions are thought to be generated by anthropogenic sources (Vitousek et al).

Studies have found that the total dissolved nitrogen in rivers in the North Sea region have increased between six and twenty times pre-industrial levels while in temperate rivers around the North Atlantic Ocean Basin, levels have increased by two to twenty times (Vitousek et al). These increases are thought to be principally from two sources i.e. atmospheric deposition and the use of agricultural fertiliser. The ratio of atmospheric deposition to fertiliser use is not known.

Nitrogen fixation i.e. conversion from N_2 gas to bioavailable forms, occurs naturally in two main ways:

- N_2 is converted to ammonium by nitrogen fixing bacteria often associated with host plants. In the aquatic environments, blue-green algae (cyanobacteria) is an important nitrogen fixer, and
- High-energy events such as lightning; forest fires, volcanism and hot lava flows can cause the fixation of smaller, but significant amounts of nitrogen. The high energy of these natural phenomena can break the triple bonds of N_2 molecules, thereby making individual N atoms available for chemical transformation, often to NO or NO_2.

Figure 4.1 Relative Nitrogen Fixation Activities



(Source: http://www.visionlearning.com/library/module_viewer2.php?mid=98&l=&let1=Ear modified from Modified from Vitousek, P. M. and P. A. Matson 1993)

With an increase in nitrogen fixing activities (see Figure 4.1) there is a greater amount of available nitrogen in the atmosphere and biosphere and therefore greater potential for atmospheric deposition above background levels.

Several studies have monitored global emissions of nitrogen compounds, developing estimates for both pre-industrial and contemporary times (see Table 4.2 and Table 4.3).

Table 4.2 Global Emissions NOx Estimates

Source	Pre-Industrial (TgN/year)	Contemporary (TgN/year)
Fossil Fuel Combustion	0	20-24
Aircraft Emissions	0	0.23-0.6
Biomass Burning	0.25-7	3-13
Lightning	3-25	3-25
Soil NOx Emissions	3.59-18.2	4-21
• Natural	4-15.5	4-15.5
• Agricultural	Unknown	1.8-5.4
NH_4 Oxidation	0.2-0.6	0.5-3
Stratospheric Injection	0.1-0.6	0.1-0.6
Total	7.8-41	23-81

(From Holland et al 2001) Note: Tg is tera grams i.e. 10^{12} grams or 1 mega (million) tonne

Table 4.3 Global Emission NH_4 Estimates

Source	Pre-Industrial (TgN/year)	Contemporary (TgN/year)
Fossil Fuel Combustion	0	0.1 – 2.2
Industrial Process	0	0.2
Domestic Animal Excreta	-	20 – 43
Biomass Burning	-	2.0 – 8.0
Domestic Animals + Biomass Burning	8.95	-
Crops	-	3.6
Wild Animal Excreta	2.5	0.1 – 6.0
Synthetic Fertiliser Use	0	1.2 – 9.0
Oceans	-	8.2 – 13
Soils and Natural Vegetation	3.8	2.4 – 10
Humans and Pets	-	2.6 – 4
Total	15 – 21	45 – 83

(From Holland et al 2001)

Studies have found that pre-industrial atmospheric deposition of oxides of nitrogen (NO_x) and ammonia (NH_4) was greatest in tropical zones, due principally to climatic conditions, with emissions related to soil processes, burning of biomass and lightning activity. Today, the greatest atmospheric deposition of nitrogen occurs in temperate regions of the northern hemisphere. All temperate and tropical ecosystems now receive greater levels of nitrogen deposition than before industrialisation (see Table 4.4).

Table 4.4 Nitrogen Deposition (kg N/hectare/year)

Biome	Northern Hemisphere Temperate Latitudes	Tropical	Southern Hemisphere Temperate Latitudes
Pre-industrial			
Grasslands	0.5	1.42	0.63
Forests	1.02	1.85	0.76
Mixed	0.58	1.19	0.8
Life-forms wetlands and riparian zones	0.77	1.83	0.8
Ice	0.37	-	0.42
Contemporary			
Grasslands	2.81	2.26	1.49
Forests	4.94	3.58	1.43

Mixed	5.98	3.94	1.85
Life-forms wetlands and riparian zones	1.3	4.15	1.54
Ice	-	-	0.05

(From Holland et al 2001)

Hall and Matson (2003) estimated the global rate of atmospheric nitrogen deposition before industrialisation at 2 kilograms per hectare per year. A study by Bristow et al (1998) in the 1970s showed nitrogen loading in wet deposition to be approximately 2kg per hectare per year for Townsville. As wet deposition delivers the bulk of total nitrogen from the atmosphere it can be assumed that nitrogen deposition around Townsville in general has not significantly increased since pre-industrial times. As this data for Townsville is isolated it needs further testing to be accepted as accurate.

Green et al (2004) have estimated no change from pre-industrial to contemporary times in nitrogen deposition across the Australian continent. They also estimate that nitrogen deposition across the Pacific Ocean has increased by around 290% and the increase in total nitrogen deposition across the planet is between 260% and 370% (see Table 4.5).

Table 4.5 Global Nitrogen Mobilisation Estimates

Continent/Ocean	Deposition	Fixation	Fertiliser	Livestock	People	Total
Australia (pre ind.)	0.46	6.99	-	-	-	7.45
Australia (now)	0.46	5.70	0.19	1.48	0.09	7.91
Africa (pre ind.)	3.63	31.99				35.61
Africa (now)	6.58	25.02	0.94	6.43	2.25	41.22
Sth America (pre ind.)	2.75	20.16				22.91
Sth America (now.)	3.51	16.12	1.59	6.63	1.21	29.06
Asia (pre ind.)	3.29	25.45				28.73
Asia (now)	11.21	22.63	20.21	22.41	12.70	89.15
Oceania (pre ind.)	0.02	0.34				0.35
Oceania (now)	0.03	0.17	0.07	0.58	0.02	0.87
Nth America (pre ind.)	1.27	9.81				11.08
Nth America (now.)	6.16	8.76	5.48	5.85	1.95	28.21
Europe (pre ind.)	0.62	3.92				4.54
Europe (now)	4.40	3.06	5.48	10.13	3.09	26.16
Pacific Ocean (pre ind.)	1.91	14.89				16.80
Pacific Ocean (now)	5.48	12.01	13.78	10.67	7.18	49.11
Global totals (pre ind.)	12	99				111
Global totals	32 [44]	81 [112]	34 [71]	54	21	223

From Green et al 2004. Note: Figures are expressed as Tg/year. Not all oceans included in the table, which contribute to the global total. Global totals include second figures [in brackets] corrected for losses.

Conversion of the estimated nitrogen deposition rate for Australia (0.46 Tg/year) to kg/hectare/year gives a figure of 0.6 kilograms/hectare/year (0.46m tonnes or 460 million kilograms divided by the land area of Australia 769 million hectares).

Estimates by Furnas (2003) of annual nitrogen deposition in rainfall across the Great Barrier Reef lagoon were between 14,000 to 44,000 tonnes. This was derived from rainfall estimates of between 140 and 440 km^3 per year with a nitrogen concentration of 100µg per litre of nitrogen (equivalent to 100 t per km^3 rainfall).

4.2.3 Phosphorus

The phosphorus cycle does not contain any long-lived gaseous forms and as such contributes little to the atmosphere. The rate of atmospheric deposition of phosphorus from this source is therefore relatively low. It is assumed that any atmospheric deposition of phosphorus will be a result of wind erosion and in particulate form attached to fine soil particles. It is estimated that the global phosphorus flux as a result of wind erosion has increased as a result of human actions although the actual values are unclear i.e. <3 Mt/year to > 3 Mt/year (Smil 2000).

Estimates by Furnas (2003) of annual phosphorus deposition in rainfall across the Great Barrier Reef lagoon were between 1,000 to 3,000 tonnes. This was derived from rainfall estimates of between 140 and 440 km^3 per year with a phosphorus concentration of 7 µg per litre of phosphorus (equivalent to 7 t per km^3 of rainfall).

4.2.4 Heavy Metals

For toxic heavy metals, trends in atmospheric pollution are little known before 1980 when monitoring began in earnest. However, research in Greenland shows that atmospheric deposition of thallium, cadmium and lead increased by a factor of ten between pre-industrial times and the early twentieth century, after which time levels began to decrease (McConnell and Edwards 2008). It is assumed that atmospheric deposition of heavy metals follows a similar pathway to phosphorus and is associated primarily with wind erosion and attachment to soil particles.

4.3 Anthropogenic Sources

The compounds present in atmospheric deposition can originate from a variety of sources, including industrial and agricultural activity as well as vehicular emissions (see Table 3.24). Compounds most commonly found in atmospheric deposition include nitrogen, sulphur and particulate matter, all of which can have impacts on water quality if atmospheric concentrations are high.

"*Townsville is the third largest city in Queensland and the site of several large industrial facilities, including metals processing, cement production and a busy port. The port handles large quantities of mineral ores and concentrates, cement clinker and other cargo, all of which can contribute to elevated particulate matter levels. Townsville's dry climate also contributes to ambient particulate matter levels*" (Neale 2005, p.64).

4.3.1 Nitrogen and Industry

Results from published studies indicate a long-term increase in the rate of atmospheric nitrogen deposition during the 20th century. The increasing industrialisation of nations, particularly in the northern hemisphere, means that the atmospheric deposition of nitrogen in northern Europe and in the north eastern United States stand at 100kg and 30kg per hectare per year respectively. In comparison, the global rate of atmospheric nitrogen deposition before industrialisation is estimated at 2kg per hectare per year (Hall and Matson 2003).

Such increases in nitrogen deposition have the potential to considerably alter the nutrient balance of natural ecosystems and are further compounded by the accelerating production of nitrogen compounds by industry in developing nations.

The high concentration of heavy industry in the northern hemisphere means that atmospheric deposition of nitrogen compounds is significantly higher in the northern hemisphere than in the southern hemisphere, particularly in terms of nitrate concentration in wet deposition (Harris 2001). The mobile nature of nitrogen compounds in the atmosphere means that some of the atmospheric deposition monitored along the Queensland coast may originate from some distance away.

Limited studies have been undertaken in Australia and none specific to Townsville with the exception of an airshed study undertaken for the proposed Woodstock Industrial site. The study was not available for review and inclusion in this document.

From a study in South Australia by Wilkinson et al (2006) the overall nitrogen input into Adelaide coastal waters, wetfall and dryfall contributes approximately 33 tonnes per year, or less than 1% of the total input from all non-marine sources, which includes WWTP output. When this is compared to stormwater run off only, without the WWTP and other output, then the atmospheric deposition is equivalent to 24% of the total nitrogen input.

The wetfall nitrogen deposition was calculated to have a maximum loading of 8.1 kg N/ha/y, which equates to a maximum urban loading of 6.5 kg N/ha/y (assumed background ambient loading of 1.6 kg N/ha/y). Dryfall total Kjedhal nitrogen (TKN) was estimated at a mean deposition rate of 2.9 kg N/ha/y. South Australian EPA estimates used the TAPM air quality model, which gives a range of deposition rates ranging from approximately 0.3 kg N/ha/yr in the off-shore zone to 8 kg N/ha/y adjacent to major sources of NO_x such as an electricity generation plant. Dryfall deposition rate was assumed to be approximately 0.5 kg N/ha/y NO_x away from the immediate areas influenced by industrial activities.

Mean concentrations of total nitrogen in rainfall were calculated to be 0.403 mg/L. Nitrogen concentrations and other results from the automatic rainfall sampler are shown in Table 4.6.

Table 4.6 Concentrations of C, N and P in Rainfall at Adelaide

(Concentrations in mg/L)	TC	IC	TOC	TN	NO_3	NO_2	NH_4	TDP	SRP
Geometric mean	2.55	0.82	1.58	0.275	0.064	0.021	0.135	0.033	0.025
Mean	3.65	1.05	2.67	0.403	0.171	0.030	0.207	0.098	0.063
Maximum	19.39	11.56	11.49	2.518	2.166	0.261	1.326	1.558	0.732
95 percentile	11.05	1.84	9.70	1.092	0.707	0.099	0.574	0.433	0.375
5 percentile	0.69	0.298	0.27	0.073	0.013	0.013	0.013	0.013	0.013
Minimum	0.07	0.11	0.12	0.049	0.013	0.013	0.013	0.013	0.013

(Source: Wilkinson et al 2006, Table 1 - p.5) Note: TC isTotal carbon, IC is inorganic carbon, TOC is total organic carbon, TN is total nitrogen, NO_3 is nitrate, NO_2 is nitrite, NH_4 is ammoniacal nitrogen, TDP is total dissolved phosphorus, and SRP is soluble reactive phosphorus.

"*Summarising the wetfall nitrogen data into monthly mean concentrations and total loads demonstrates that, for the 2004-5 rainfall season, oxides of nitrogen are the dominant components of the total nitrogen concentration from March to the end of May. From June onwards into the wet season, the mean monthly total nitrogen concentration is significantly lower and ammonia nitrogen is the dominant form of nitrogen. An obvious interpretation of these results is that, during late summer and Autumn, air pollution sources of nitrogen are dominant. Then, with the wetting of soils and streams, microbial ammonia sources become dominant*" (Wilkinson et al 2006, p.6).

In a case study of Adelaide's Port waterways (Australian Government 2006) atmospheric deposition accounted for approximately 34% of nitrogen from land based diffuse sources but only contributed 2% of the overall load when point sources were added.

The amount of NO_2 in the exhaust stream as it is released from combustion sources is typically in the order of 5-10% of total NO_x. In the atmosphere, oxides of nitrogen are rapidly oxidised to nitrogen dioxide (half-life about 50 days), which dissolves in water to produce dilute nitric acid and precipitates in rain. An increased rate of formation of oxides of nitrogen therefore contributes to 'acid rain'.

In the Townsville region the use of motor vehicles and industrial activities burning fossil fuels needs to be taken into account when calculating the extent of atmospheric deposition of nitrogen above background levels.

An estimate of the atmospheric emissions from motor vehicles is provided in section 3.7.7.

Using results from the Pimlico air monitoring station and assuming a maximum NO_2 concentration of 0.04ppm gives a concentration of 82 µg / m³. If we assume the concentration is uniform and multiply it by the volume of our airshed (250km² by 100m high = 25,000,000,000 m³) we have 2,050,000 grams (2,050kg) of NO_2 in the airshed.

If we then assume that 10% of the NO_2 is deposited each day and the total amount of NO_2 is deposited during rainfall events this is equivalent to an annual deposition of 203,975 kg of NO_2 across our 250km² airshed footprint (295 days [365 days – 70 rain days] x 10% of 2,050kg [60,475kg] plus 70 rain days x 2,050kg [143,500kg] = 203,975 kg year). This is equivalent to a deposition rate of 8 kg NO_2/ha/yr. Of this deposition a background deposition rate of 2 kg NO_2/ha/yr is assumed with the remaining 6 kg NO_2/ha/yr assumed to be from human sources. The figure is an overestimation of the actual deposition rate and this can be seen when compared to the cumulative estimation of oxides of nitrogen emissions to air for the Townsville region in Table 3.36.

Dispersion modelling has been carried out by QNI (BHP Billiton) for the Yabulu nickel refinery and a summary of a recent report (Pacific Air and Environment 2007) is included in Appendix C. The results of the report show that emissions from the stack studied are well below the EPA's air quality guidelines for nitrate as well as for particulate matter, sulphur dioxide and a range of volatile organic carbons.

4.3.2 Nitrogen and Agriculture

The anthropogenic application of nitrogen-containing products is beginning to exceed the rate of nitrogen fixation in natural systems. This means that human use is the primary driver of increased levels of wet and dry nitrogen deposition.

Nitrogen compounds are most commonly found in fertiliser use, the cultivation of crops, manure and other organic material, and the burning of fossil fuels. Gases can be released to the atmosphere through processes such as denitrification and volatilization.

Denitrification often occurs when nitrate, carbohydrate and micro-organisms are present in anaerobic soil conditions, with nitrate compounds being converted to gaseous nitrogen products. Denitrification is encouraged when soils are warm and wet; conditions closely replicated when fertilisers are applied in spring prior to heavy rain events or in warm, waterlogged tropical soils. Modification of nitrogen compounds in this way can form acidic compounds and contribute to acid rain events. Losses of nitrogen through denitrification are mainly linked to the application of subsurface fertilisers.

Losses (volatilisation) of ammonia can occur from growing and senescent leaves, plant residues, soil surface litter, urine, dung, surface-applied N fertiliser and through burning of dried herbage. There is general agreement that ammonia losses can be large, particularly where animals are involved, as 60 to 90% (usually >80%) of the N ingested is excreted as urea and nitrosamines, which are rapidly hydrolysed to ammonia (Eckerd 1998).

Ammonia entering the atmosphere is often deposited in large volumes in rainfall or by dry deposition into natural ecosystems. The rate of volatilisation is thought to be encouraged by high soil pH, a characteristic lacking in many humid tropical soil environments. However, the accelerated application of nitrogen products to agricultural and farming land may negate the role of pH and allow for high rates of volatilisation. In intensive agriculture losses of nitrogen through volatilisation are mainly linked to the above ground application of fertilisers.

Losses of gaseous nitrogen vary from region to region and are affected by such factors as rates of plant growth and precipitation, type of mineralisation, and the timing and depth of nitrogen fertiliser application.

In terms of the overall nitrogen cycle the land based impacts of increased nitrogen input (see Table 4.5) through fertiliser and animal manure, and subsequent transport to waterways in stormwater, outweighs the impact of any small increase in atmospheric deposition (unmeasured).

In rainforest systems, wet deposition inputs of nitrogen range from approximately 2 to 21 kg per hectare per year. For northern Australia, the only published data are from Townsville, which records inputs of approximately 2 kg of nitrogen per hectare per year. Modelled projections of atmospheric deposition of nitrogen into the wet tropics agricultural areas are approximately 5-10 kg per hectare per year.

Given the relatively low amount of intensive agriculture in the Black Ross WQIP area the atmospheric inputs of nitrogen from agriculture are not expected to be significant. This is confirmed by the limited amount of water quality data from agricultural catchments (Mitchell et al 2007).

4.3.3 Phosphorus

Many of the anthropogenic inputs into the atmosphere are of a nitrogen, sulphur or carbon-based nature. Anthropogenic sources have, however, significantly altered the global phosphorus cycle outside the atmospheric reservoir. There may be some contribution at the time of fertiliser application as a result of wind drift.

Pollard et al (2001) investigated phosphorus deposition in Moreton Bay and showed an increase from an average of 25 and 18 tonnes per year in 1981 and 1982 respectively, to averages of 95 and 101 tonnes per year (5.5% of total phosphorus loading) from two studies in 1996. While these figures would suggest that atmospheric deposition of phosphorus increased during the period 1981-1996 the ranges were variable and the accuracy of the data to calculate the means is questionable.

Studies in Florida found that dry deposition of phosphorus was significantly higher than wet deposition, accounting for approximately 80% of the total atmospheric input of phosphorus into the study area. Atmospheric deposition of phosphorus was also found to be more highly concentrated in summer storms than winter storms.

Average atmospheric deposition of phosphorus over several sites in Florida was found to be 5 mg per square metre per year (50,000mg per hectare i.e. 0.05kg/ha/year) Similar studies on Lake Michigan measured rates of atmospheric deposition of phosphorus to be 22 to 36 mg per square metre per year (i.e. 0.22 to 0.36 kg/ha/year).

Estimates of atmospheric deposition of phosphorus to the Torrens Lake in South Australia are approximately 20 mg per square metre per year (i.e. 0.2 kg/ha/year). This magnitude of phosphorus input from atmospheric deposition is not significant in terms of water quality impacts. In a case study of Adelaide's Port waterways (Australian Government 2006) atmospheric deposition accounted for approximately 12% of phosphorus from land based diffuse sources but contributed less than 1% of the overall load when marine and point sources were added.

4.3.4 Particulate Matter

A study in Adelaide showed total suspended particulates and PM_{10} (particulate matter that passes through a 10 µm filter) collected by a high volume air sampler over eight years gave a low reading of 3.6 µg/m³, a high reading of 263 µg/m³, with an average of 57 µg/m³ (standard deviation of 49 µg/m³). The dust concentration data when analysed with the rainfall data illustrate the well-known process of washout of dust and aerosols by rainfall.

The annual load of atmospheric particulate matter deposited into the 10 km coastal strip was estimated at between 1,800 and 3,860 tonnes. The mean deposition rate over the entire 10 km coastal strip was 36 kg/ha/y (Wilkinson et al 2006, pp.9-10). The amount of material from natural sources and anthropogenic sources was not quantified but regardless of the source this volume of material is not significant as a water quality issue.

Deposition of particulate matter in the Townsville region is the main air quality issue although it is not chronic and is not considered to be a health issue (see section 4.4.2). While contributing to the amount of suspended solids in waterways, especially in urban areas, it is not in itself a major water quality issue in the Black Ross WQIP area.

An estimate of the amount of particulate matter can be made if we apply a daily average particulate matter concentration of 40 µg/m³ (overestimate of Townsville Port air monitoring station readings - see section 4.4.2) over the 250 square kilometre urban footprint to a height of 100 metres. Our adopted airshed therefore is 25,000,000,000 m³ multiplied by 40 µg / m³ to give 1,000,000 grams per day (1,000kg) of particulate matter in the airshed. If we assume that all of this material settles out onto the catchment each day then this amounts to approximately 365,000 kg/year. This is equivalent to a deposition of approximately 15 kilograms/hectare/year.

4.3.5 Heavy Metals

Industrial and agricultural development has introduced many heavy metals in natural ecosystems, including arsenic, cadmium, copper, zinc and nickel. These compounds are strongly attracted to particulate vectors, which often provide atmospheric transport into the environment and waterways.

Given the estimated atmospheric deposition of particulate matter it is unlikely that there are any significant water quality issues associated with the amount of attached heavy metals. The possible exceptions would be in the vicinity of materials handling facilities where metal ores are treated, loaded and unloaded e.g. Townsville Port, refineries and in the vicinity of roads, railways and airports.

4.3.6 Pesticides

Similarly, organochloride pesticides are often transported into the atmosphere by particulate matter, through direct spraying onto crop foliage and through volatilization of compounds. Given the low level of intensive agriculture in the Black Ross WQIP area it is unlikely that airborne pesticides are a water quality issue apart from a very minor contribution to plant and land based application levels.

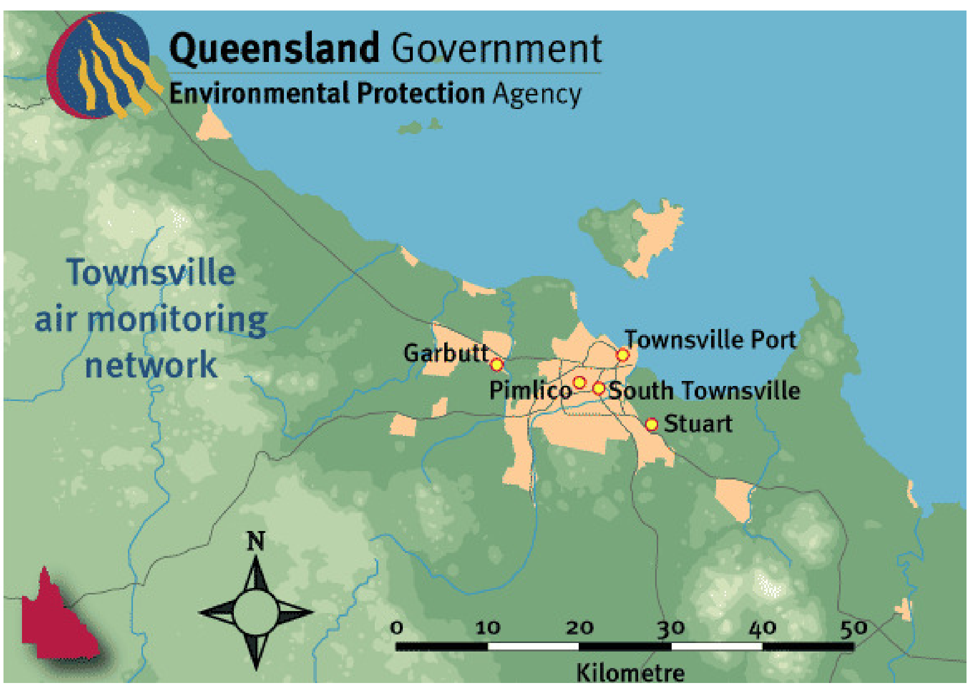
4.3.7 Sulphur Dioxide

Deposition models of sulphur released from industry in Mt Isa show dry deposition of sulphur dioxide and aerosol sulphate to be significantly higher than wet deposition of sulphate. The results of the modelling suggest that rainfall is a relatively inefficient pathway for the removal of sulphur compounds. However, dry deposition was also found to be relatively inefficient, with sulphur particles experiencing long atmospheric residence times and subsequent long-distance advection. Large sulphur particles are less likely to be subject to long distance atmospheric dispersion and can settle on nearby water bodies and soils. The addition of sulphur often results in increasing acidity and consequential environmental impacts. Relatively large emissions of sulphur are required before any adverse impacts are noticeable and such emission levels are not present in the Townsville region.

4.4 Townsville Air Quality Measurement

In the Townsville airshed, the Environment Protection Agency (EPA) has established atmospheric monitoring stations at Pimlico, South Townsville, Garbutt, Stuart and the Townsville Port (see Figure 4.2).

Figure 4.2 Townsville Air Monitoring Network Sites



(Source http://www.derm.qld.gov.au/environmental_management/air/air_quality_monitoring/air_monitoring_network/townsville _region.html) Note: EPA is now part of the Department of Environment and Resource Management (DERM)

A summary of relevant information associated with the Townsville atmospheric monitoring network is provided in Table 4.7.

Table 4.7 Atmospheric Monitoring Stations Summary

Parameter	Garbutt	Pimlico	Tvl Port	Sth Tvl	Stuart	Coastguard
Established	1994	2004	1994	1994	2001	2007
Closed	2004			2004		
Operator	EPA	EPA	TPA	EPA	Sunmetals	
Wind direction		Yes	Yes		Yes	
Wind speed		Yes	Yes		Yes	
Temperature		Yes			Yes	Yes
Humidity					Yes	
Rainfall					Yes	
Ozone		Yes				
Nitrogen oxides		Yes				
Sulphur dioxide		Yes			Yes	
PM10	Yes	Yes	Yes	Yes		
Visibilty		Yes				
TSP						Yes

(Source:http://www.epa.qld.gov.au/environmental_management/air/air_quality_monitoring/northern_queensland_monitoring_stations/) Note: TSP is total suspended particles, PM_{10} is particulate matter < 10 μm i.e. passes through a 10 μm filter.

Monitoring information from some of these stations is available on the DERM / EPA website (http://www.derm.qld.gov.au/environmental_management/air/air_quality_monitoring/search.php /).

DERM / EPA has developed a series of air pollutant standards that are used to assess the acceptability of atmospheric pollutant levels (see Table 4.8).

Table 4.8 EPA Air Pollutant Standards

Pollutant	EPA Standards	Averaging Time	NEPM Standard	Averaging Time
Nitrogen Dioxide	0.12 ppm	1 hour	0.12 ppm	1 hour
			0.03 ppm	1 year
Sulphur Dioxide	0.20 ppm	1 hour	0.20 ppm	1 hour
			0.08 ppm	1year
PM_{10}	50 μg/m3	24 hours	50 μg/m3	24 hours
$PM_{2.5}$	25 μg/m3	24 hours	25 μg/m3	24 hours
Ozone			0.10 ppm	1 hour
			0.08 ppm	4 hours
Carbon monoxide			9.0 ppm	8 hours
Lead			50 μg/m3	1 year

(Source: http://www.epa.qld.gov.au/)

Notes: ppm = parts per million μg/m3 = micrograms per cubic metre

The standards are based on the National Environment Protection Measure for Ambient Air Quality (also referred to as the Air NEPM) released in June 1998 by the National Environment Protection Council (NEPC). The desired environmental outcome of the Air NEPM for ambient air quality is the protection of human health and well-being. It sets air quality standards for six pollutants, together with the maximum exceedence levels of each standard (see Table 4.8).

(Source: http://www.epa.qld.gov.au/environmental_management/air/air_quality_monitoring/national_measures/). Note: This is an old web link and may not be the same following the inclusion of EPA with DERM.

4.4.1 Regional trends

The introduction of continuous PM_{10} monitoring equipment at Gladstone and Townsville in 2000 has contributed to the rise seen in these two regions in the last five years through the availability of more complete measurement data for this period.

The general trend in PM_{10} levels at sites in Gladstone, Rockhampton and Townsville has remained static or been downward since monitoring began in 1994 or later. Dry conditions and smoke particles from bushfires led to a rise in levels in the Gladstone region in 2001-2002. Similarly dry conditions were responsible for increases at Rockhampton and Townsville sites in 2001-2002. The extensive dust storm also contributed to higher PM_{10} levels in all three regions in 2002.

4.4.2 Townsville Air Quality

The Garbutt site in Townsville is located in an industrial area and levels at this site are predominantly influenced by dust-generating activities occurring at adjacent industrial premises rather than being indicative of ambient PM_{10} concentrations for the region (Neale 2005, p.100).

PM_{10} levels measured at the South Townsville site are influenced by loading and unloading activities at the Townsville Port and are more representative of exposure levels experienced by Townsville residents in the inner city area and surrounds. The Pimlico site measures a wider range of pollutants and provides a general indication of the air quality in the Townsville airshed.

As part of the monitoring program Sun Metals Corporation have been monitoring ambient sulphur dioxide levels at a site in Stuart approximately 4km from their metals processing plant and close to residential areas. Data shows that maximum sulphur dioxide levels at this site are very low (see Figure 4.5), rarely exceeding 10 percent of the EPP (Air) goals. Sulphur dioxide levels have been virtually unchanged over the period 2001-2004 (Neale 2005, p.87).

A summary of daily air quality in Townsville from 2004 is provided in Table 4.9.

Table 4.9 Townsville Air Quality Rating

Year	Air Quality Days		
	Poor	Fair	Good
2004 (from May)	0	6	214
2005	5	8	352
2006	2	4	359
2007	0	4	361
2008 (to July)	1	4	208

Notes: Poor - Number of days when at least one NEPM monitoring station did not meet one or more NEPM air quality standards, reflecting high pollution levels.
Fair - Number of days when all NEPM monitoring stations were within the NEPM standards but at least one station reached at least half the standard for one or more pollutants.
Good - Number of days when all NEPM monitoring stations were below half the NEPM air quality standards, reflecting good air quality.
Standards: (see Table 4.8) ozone (1-hour average), nitrogen dioxide (1-hour average), sulphur dioxide (1-hour average), carbon monoxide (8-hour average) and PM_{10} (24-hour average)
(Source: http://www.epa.qld.gov.au/environmental_management/air/air_quality_monitoring/regional_trends/). Note: This is an old web link and may not be the same following the inclusion of EPA with DERM.

Air quality in Townsville is generally good with Poor and Fair days usually resulting from higher levels of particulate matter being present in the air, usually emanating from industrial activities in the vicinity of the air monitoring stations. On occasion the particulate levels are raised as a result of extended dry conditions and the mobilisation of dust by strong winds (see section 4.4.1). Particles from bushfires can also raise levels.

Poor air quality days as a result of high levels of NO_3, SO_2, ozone, carbon monoxide or lead have not been measured to date through the Townsville air-monitoring network. Given that the air quality is relatively good in the Townsville airshed it is unlikely that there will be any adverse impacts on water quality as a result of atmospheric deposition in either wetfall or dryfall, although there is a potentially measurable contribution of particulate matter, albeit unquantified, to receiving waters as a result of atmospheric deposition. While not measured directly through the air-monitoring network it is assumed that some amount of nitrogen and phosphorus will be associated with the particulate matter as well as traces of organic material, other compounds and metals.

Examples of the data outputs from the Townsville air-monitoring network are included as Figure 4.3, Figure 4.4 and Figure 4.5.

Figure 4.3 Air Quality at Pimlico Monitoring Station (Nitrogen dioxide in 2007)

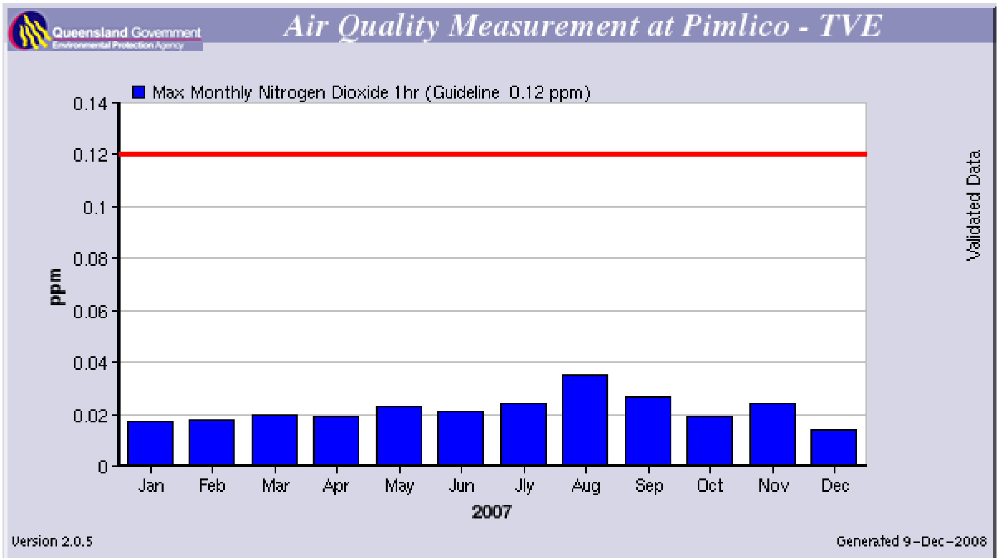


Figure 4.4 Townsville Port Air Quality by Month (PM_{10} in July 2007)

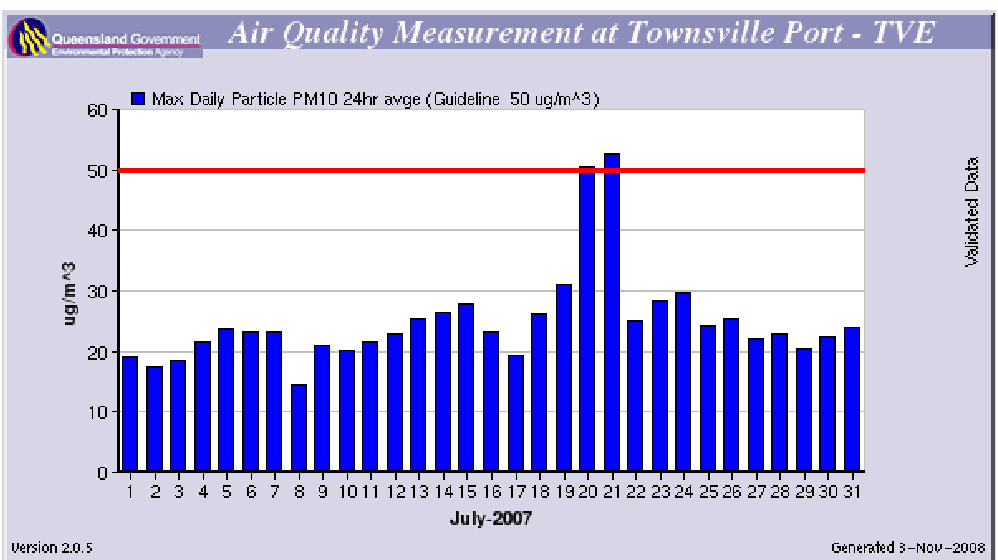
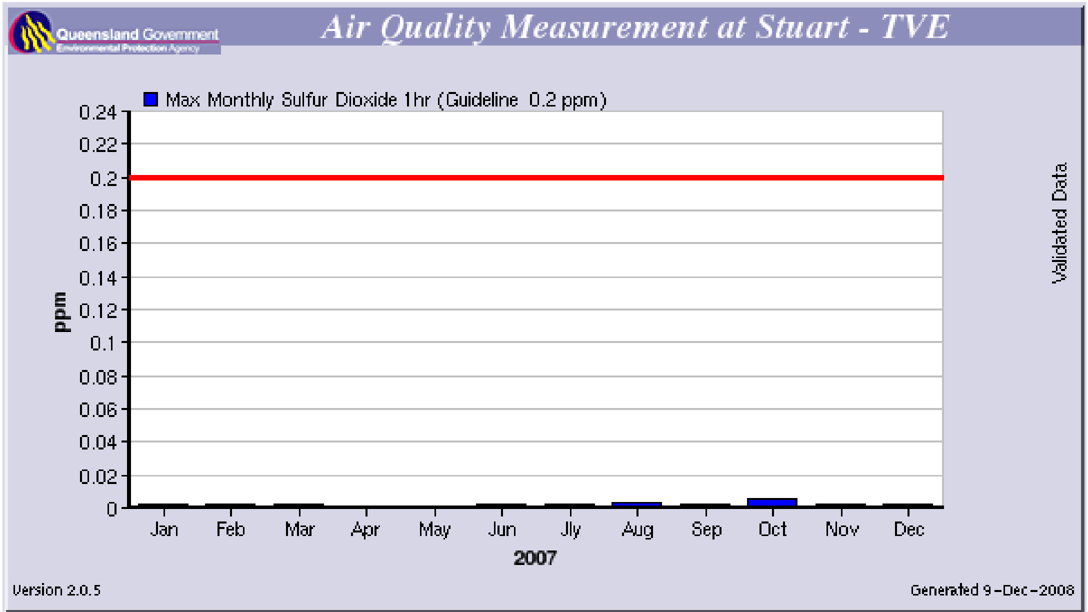


Figure 4.5 Stuart Air Quality Monitoring (Sulphur dioxide in 2007)



4.4.3 Future Air Studies

The Department of State Development and Innovation recognises the need to maintain air quality at the same time as promoting industrial development at the Townsville State Development Area (TSDA) at Stuart. The department has entered into an agreement with the EPA to develop an air quality model for the Townsville airshed. When fully developed the model will be used to assess the potential impact on air quality of current and future proposed industrial development in the TSDA and other sites around Townsville.

The application of the Townsville model will provide a consistent approach to air quality modeling including the assessment of cumulative impacts of new and expanding industries and the establishment of appropriate emission targets for ongoing air quality in the region.

Figure 4.6 Townsville Regional Air Quality is Generally Good

5. Pollutant Profiles

5.1 Pollutants and Impacts

At the 2006 census, there were approximately 836,000 people living in the Great Barrier Reef Catchment with an average annual growth rate of 1.23 percent. This is approximately 21 percent of Queensland's resident population of almost 4 million. The infrastructure for supporting the growing regional population with associated manufacturing, agricultural and urban services represents a substantial modification of the Great Barrier Reef's coastal and catchment landscape. The effect of 68,000 personal watercraft, active commercial fisheries, 1.9 million tourist visits annually, defence activities and development of infrastructure to support visitors and residents accessing and enjoying the Great Barrier Reef combines to make an extensive ecological footprint. This will affect the Great Barrier Reef in far more complex forms than tropical marine ecosystems that are more isolated.
(Source: Johnson and Marshall (eds) 2007, pp.6-8)

It is in the context of expanding population and infrastructure, land use change and outdated land management practices that water quality pollutants become an issue i.e. increased beyond 'natural' levels. It is also recognised that extreme natural events contribute significant pollutant loads to receiving waters, however, it is the amount of ongoing additional material resulting from anthropogenic activities that we seek to reduce.

Potential impacts of pollutants on water quality are discussed below under the broad pollutant groupings:

- Particulate matter and sediment;
- Nitrogen and compounds (ammonia, oxides);
- Phosphorus;
- Hydrocarbon derivatives;
- Metals and compounds; and
- Sulphur compounds.

Principles sources of information for this section are Duncan 1999 and Chiew et al 1997.

5.1.1 Particulate matter and sediment

Particulate matter is the term used to describe particles that are suspended in the air. Particles may be solid or liquid and are one of the most obvious forms of pollution as they are visible in the hazes that cover a city or region.

Size is the main determinant of the behaviour of an atmospheric particle influencing the aerodynamic properties and falling speed. Larger particles (greater than 50µm) usually only remain in the air for a few minutes and settle near the source. Smaller particles (less than 10µm, known as PM_{10}) can remain in the air for several days and can be spread by winds over wide areas or long distances from the original source. Fine particles (between 0.1-2.5µm) may remain in the atmosphere indefinitely [Note: The average human hair has a diameter of 60µm].

Windblown dusts, pollens from plants and sea salts are natural sources of particles in the atmosphere. Bushfires, agricultural and forest hazard-reduction burning release smoke particles into the air. Combustion processes using coal and other fossil fuels, such as power generation, industrial operations and motor vehicle fuels, emit most of the particulate matter in urban areas. (Source: http://www.epa.qld.gov.au/environmental_management/air/air_ quality _monitoring/air_pollutants/airborne_particulates/)

The main issues associated with air borne particulate matter are health related with some environmental issues if other pollutants are attached e.g. oxides of nitrogen or sulphur dioxide.

Particulate matter can have multifaceted and often significant impacts on water quality if present in large enough quantities. Particulate matter in water is usually referred to as suspended solids or suspended sediment. The main source is usually from terrestrial run-off either through soil erosion or transport of built up material from impervious surfaces in urban areas. Impacts range from causing blockages in waterways, increasing turbidity and changing local hydrology. Secondary impacts include decreased light penetration in the water column due to increased sediment loads.

Further, particulate matter often acts as a vector for organic chemicals, inorganic nutrients, hydrocarbons and heavy metals. Changes in these features often result in corresponding changes to water quality.

Major sources of particulate matter relevant to this study include:

- Degradation of roads (paved and unpaved);
- Motor vehicular traffic;
- Wind and water erosion of pervious surfaces (principally soil);
- Construction and demolition operations; and
- Atmospheric deposition.

5.1.2 Nitrogen and compounds

Nitrogen is found in many forms, including organic nitrogen (N), ammonia (NH_3), ammonium (NH_4), nitrite (NO_{2-}), nitrate (NO_{3-}), and nitrogen gas (N_2). These different forms can be dissolved, however organic nitrogen is usually particulate and transported on sediment particles.

Organic nitrogen, ammonia and ammonium are often consolidated into a group known as total kjeldahl nitrogen while nitrite and nitrate are grouped as oxidized nitrogen (NO_x).

Major sources of nitrogen relevant to this study include:

- Combustion of fossil fuels;
- Fertilisers;
- Rainfall; and
- Aerial dust movement.

Nitrogen is an essential, and often a limiting, nutrient. As such, increasing levels of nitrogen in water bodies can often stimulate accelerated rates of growth in plants and algae and result in eutrophication.

The most common gaseous forms of nitrogen, apart from N_2, are:

NO_2 (nitrogen dioxide):
- Is a dark brown, fuming liquid or gas with a pungent, acrid odour detectable at 0.12 ppm.
- Is highly soluble in water, to form nitric acid (a strong acid).
- Is produced (by oxidation of nitrogen) for the manufacture of nitric acid (by its dissolution in water). Most nitric acid is used in the manufacture of fertilisers; some is used in the production of explosives.

NO (nitric oxide):
- Is a colourless gas with a sharp, sweet odour, brown at high concentrations in air.
- Is slightly soluble in water, to form nitrous acid (a weak acid).

N_2O (nitrous oxide):
- Is a colourless gas with a slight, sweetish odour.
- Is non-flammable and has anaesthetic properties.
- Has been used as an anaesthetic (known as 'laughing gas').

Excessive levels of the oxides of nitrogen, particularly nitrogen dioxide, can cause death in plants and roots and damage the leaves of many agricultural crops. Excessive levels increase the acidity of rain (i.e. lower the pH) and thus lower the pH of surface and groundwaters as well as soils. In turn, this lowered pH can have harmful effects, including death, on a variety of biota.
(Source: http://www.environment.gov.au/atmosphere/airquality/publications/sok/oxides.html)

5.1.3 Phosphorus

Phosphorous is an essential nutrient often found in limiting quantities in natural ecosystems. By increasing phosphorous levels in water bodies, growth rates of plants and algae can be stimulated and may result in eutrophication. Phosphorous can be found in either dissolved or particulate form.

Major sources of phosphorous include:

- Fertilisers;
- Industrial waste;
- Atmospheric deposition; and
- Detergents and lubricants.

5.1.4 Hydrocarbon derivatives

Major sources of hydrocarbon derivatives stem from oil and grease used in:

- Detergents;
- Lubrication;
- Combustion; and
- Protective coatings.

Spills of such oils can exceed recommended levels and result in short term toxicity. Further, surfactants found in detergents can impact on aquatic flora and fauna by damaging biological membranes.

5.1.5 Metals and compounds

Heavy metals are often found to be more highly concentrated in urban areas than in rural areas, as a result of higher densities of source emissions such as wear of tyres and brakes, vehicle emissions, road and pavement degradation, water pipe, roof corrosion and industrial activity. Metals and their compounds are therefore a pollutant issue in the Black Ross WQIP area.

Metals relevant to water quality investigations include: Lead, Zinc, Copper, Cadmium, Chromium, Nickel, Iron, Manganese and Mercury. Characteristics of these metals are summarized below.

Lead

Lead in urban storm water is most commonly measured in dissolved and particulate forms that create a stratum of suspended lead solids. These solids often exceed recommended environmental and drinking water levels.

The presence of lead poses serious threats to floral and faunal health due to its ability to bio-accumulate and reach toxic levels. Due to this characteristic, lead is often regarded as a primary contaminant of concern in water quality monitoring. The incidence of lead as a water quality contaminant in urban areas has reduced considerably since the removable of leaded petrol from the market.

Major sources of lead include:

- Petrol additives (no longer significant in Australia);
- Tyres;
- Leaded water pipes, paints and roofs; and
- Industrial emissions.

Zinc

Zinc is an essential element for all living organisms from bacteria to humans. However, too much or too little zinc can harm your health. The seriousness of health effects can be expected to increase with both level and length of exposure. Zinc and compounds emitted to land can remain in the environment for years and can bio-accumulate in fish if the substance reaches waterways. Zinc is most commonly measured in dissolved form and is often transported on other suspended sediments and particles. Excessive levels of zinc in drinking water yield an unpleasant taste and cloudy appearance.

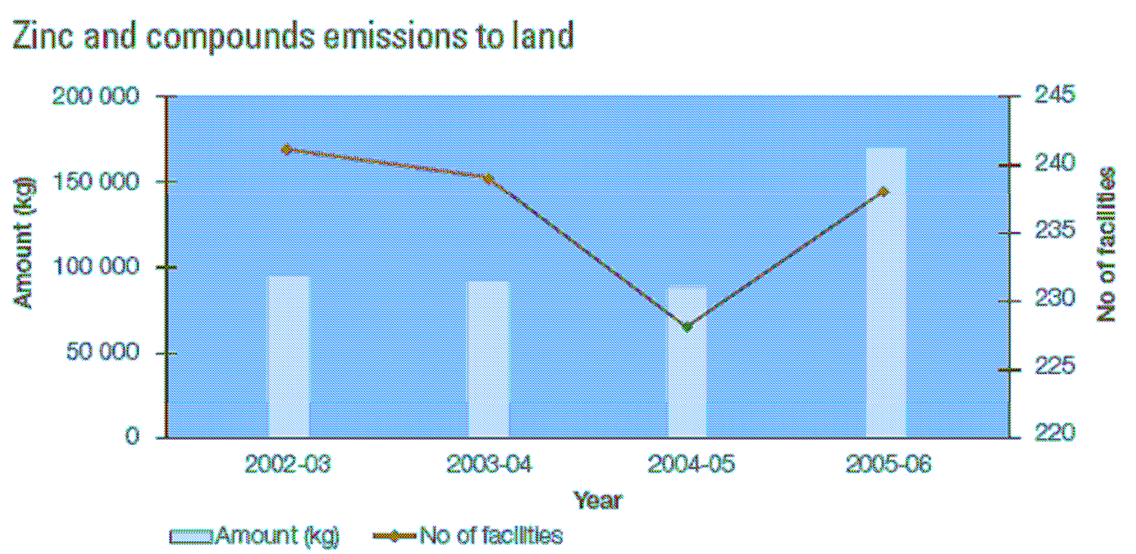
Major sources of zinc include:

- Corrosion of products such as galvanized roofs and metal piping;
- Wear of tyres and brake pads; and
- Combustion of lubricants.

"*The largest industry source of emissions of zinc and compounds to land is zinc smelting and refining. 238 facilities emitted 170,000 kilograms of zinc and compounds to land during the 2005-06 reporting year. Emissions increased by 95% compared to the previous year, chiefly due to an increase in production from a large mining facility*."

Figure 5.1 shows the emissions of zinc and compounds to land for the reporting years 2002-03 to 2005-06 and the number of facilities reporting the substance to the NPI.

Figure 5.1 Zinc Emissions to Land



(Source NPI Report 2005-2006 pp.14-15)

Copper

While copper is essential to human metabolism, in large doses it has the potential to be a powerful irritant. While toxicity to humans is rare, high levels of copper can accumulate in plants and animals and become toxic to aquatic organisms. Environmental guidelines for copper in storm water and drinking water are frequently exceeded. High levels of copper in drinking water yield an unpleasant taste and tinted colour.

Major sources of copper include:

- Wear of tyres and brake pads;
- Combustion of lubricants;
- Industrial emissions;

- Corrosion of products such as galvanized roofs and metal piping;
- Pesticide use; and
- Wear of moving engine components.

Cadmium

Cadmium is most commonly measured in dissolved and particulate form and is often transported on other suspended sediments. Levels can become particularly concentrated in shellfish and can accumulate in organs such as the liver and kidneys of humans and animals. Cadmium has been shown to be highly toxic as well as having carcinogenic properties.

Major sources of cadmium include:

- Wear of tyres and brake pads;
- Combustion of lubricants;
- Industrial emissions;
- Leaching from land fill;
- Corrosion of galvanized products; and
- Pesticide and fertiliser use.

Chromium

Chromium is found in various forms, with differing impacts of each on water quality. Trivalent chromium is found commonly in chlorinated or aerated water, is essential for human metabolism and is not thought to be toxic. Hexavalent chromium is thought to be carcinogenic and can cause liver, kidney and gastrointestinal damage. In aquatic organisms, hexavalent chromium is toxic.

Major sources of chromium include:

- Pesticide and fertiliser use;
- Corrosion of metal plating;
- Wear of moving engine components;
- Dyes, paints, ceramics, paper; and
- Heating and cooling coils.

Nickel

Nickel is often found with suspended solids and organic matter in storm water. Nickel is not thought to be toxic to animals in elevated concentrations, does not bio-accumulate and in appropriate quantities is essential for adequate animal nutrition.

Major sources of nickel relevant to this study include:

- Corrosion of metal plating;
- Wear of engine components;
- Electroplating; and
- Alloying.

Iron

Iron is a naturally occurring element in the environment and is essential to human nutrition. However, high levels of iron in water produce an unpleasant taste and stained colour and may prove toxic to fish and invertebrates.

Major sources of iron include:

- Corrosion of motor vehicles;
- Combustion of coal;

- Emissions from the iron and steel industry;
- Leaching from land fill; and
- Corrosion of water pipes and fittings.

Manganese

Manganese is essential to human and animal nutrition and metabolism and is not considered to be highly toxic. In drinking water, manganese produces an unpleasant taste and can stain fixtures and products it comes into contact with. Manganese is found in both dissolved form and as suspended solids.

Major sources of manganese include:

- Wear of tyres and brake pads;
- Manufacture of paints and dyes;
- Manufacture of steel and steel products; and
- Fertilisers.

Mercury

Mercury is highly toxic to fish, mammals and invertebrates and can accumulate in concentrated doses along the food chain. There are no known benefits of mercury to animal physiology or metabolism. As such, mercury is a highly damaging substance in the aquatic environment.

Major sources of mercury include:

- Combustion of coal;
- Production of paint products;
- Run-off from gold mines; and
- Emissions from the clor-alkali industry.

5.1.6 Sulphur compounds

Sulphur compounds, particularly sulphur dioxide, can have damaging effects to human health including burns, headache, respiratory irritation and damage to the reproductive system.

In natural ecosystems, excessive amounts of sulphur are harmful to plants and can affect productivity of crops. Sulphur in water increases acidity and can have adverse effects on a range of features.

Sources of sulphur relevant to this study include:

- Combustion of fossil fuels (particularly in petroleum and metal refineries and smelting of sulfide containing ores such as lead, silver and zinc); and
- Vehicular emissions.

(Source:www.npi.gov.au/database/substance-info/profiles/77.html)

5.1.7 Gross pollutants

Gross pollutants refers to debris items larger than 5mm, but often includes smaller sediment particles. Gross pollutants include plastics and other packaging, garden waste (lawn clippings, leaves and other plant material) and coarse sediment. While the litter component of gross pollutants is an aesthetic water quality detractor there can also be deleterious impacts on aquatic animals from plastic litter in waterways through ingestion and entanglement. Organic material can lead to oxygen depletion during decomposition.

5.1.8 Impacts on Water Quality

Atmospheric nitrogen has been recognised as an important source of external nitrogen for a wide variety of marine and freshwater ecosystems. Despite the low deposition rates of nitrogen in Australia relative to the rest of the world, atmospheric deposition of nitrogen and nutrients into estuaries can influence primary production and biomass concentration.

Both nitrogen and phosphorus are essential nutrients often found in limiting quantities in natural ecosystems. As such, the introduction of external nutrient loads can rapidly alter natural water bodies. Accelerated rates of plant and algal growth can clog waterways and stimulate eutrophication. If present in large enough quantities, oxidised nitrogen and sulphur compounds can lower water pH levels and thereby increase acidity.

Elevating sediment loads can affect the turbidity and clarity of water, potentially impacting on integral processes such as photosynthesis and compromising natural aesthetics. Excessive sediment can alter environment conditions and habitat and biological functions of organisms.

Introduced heavy metals can bioaccumulate in flora and fauna, impacting growth rates, reproductive processes and mortality. This accumulation can be passed on through the natural food chain and eventually impact the ‘top’ of the chain predators, including humans.

Figure 5.2 The Lakes and Cleveland Bay

6. Load Estimates

6.1 Event Monitoring Results

Event monitoring was conducted by the Australian Centre for Tropical Freshwater Research (ACTFR) for the Black Ross WQIP over the 2006/07 and 2007/08 wet seasons. Load estimates from the subsequent report (Lewis et al 2008) are provided for sediment (see Table 6.1), nitrogen (see Table 6.2) and phosphorus (see Table 6.3).

Table 6.1 Sediment Load Main Catchments 2006-2008

	2006/07			2007/08			Comparison to model	
Catchment	Sediment load (tonnes)	Total flow volume ML	EMC mg/L	Sediment load (tonnes)	Total flow volume ML	EMC mg/L	Load adjusted to mean annual flow *	Sednet model ** (tonnes)
Alligator Creek	600	41,500	15				530	8,500
Black River	33,000	135,000	240	41,000	180,400	230	17,000	20,200
Bluewater Creek	2,700	63,500	40				1,600	12,500
Bohle River	22,000	147,000	150	35,100	154,200	230	39,000	59,000
Ross River	26,500	261,000	100	14,500	290,000	50	2,500	1,400

Notes: *As specified by the SedNet model. **Kinsey-Henderson et al. (2007).

Source: Table 3. Suspended sediment loads of the major catchments in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons. (Lewis et al 2008, p.17)

Table 6.2 Nitrogen Load Main Catchments 2006-2008

	2006/07			2007/08			Comparison to model	
Catchment	TN load (kilograms)	Total flow volume ML	EMC µg/L	TN load (kilograms)	Total flow volume ML	EMC µg/L	Load adjusted to mean annual flow *	Annex model ** (kilograms)
Alligator Creek	9,440	41,500	228				8,320	46,700
Black River	59,700	135,000	435	91,500	180,400	507	35,000	1,208,970
Bluewater Creek	17,630	63,500	275				10,240	89,700
Bohle River	71,200	147,000	481	83,400	154,200	547	105,600	475,700
Ross River	173,000	261,000	667	149,700	290,000	521	17,200	28,800

Note: *As specified by the SedNet model. **Kinsey-Henderson et al. (2007). Loads and EMC calculated by adding all data from N components tables (Lewis et al 2008, Tables 5, 9, 13, 15 and 16). DIN (Table 16) was used for Annex model and ammonia and NOx were used for monitored sites i.e. DIN = ammonia (Table 13) + NOx (Table 15)

Table 6.3 Phosphorus Load Main Catchments 2006-2008

	2006/07			2007/08			Comparison to model	
Catchment	TP load (kilograms)	Total flow volume ML	EMC µg/L	TP load (kilograms)	Total flow volume ML	EMC µg/L	Load adjusted to mean annual flow *	Annex model ** (kilograms)
Alligator Creek	1,540	41,500	38				1,360	12,200
Black River	15,200	135,000	112	17,900	180,400	100	7,800	23,500
Bluewater Creek	1,240	63,500	20				711	18,100
Bohle River	23,000	147,000	156	24,300	154,200	158	32,300	82,900
Ross River	20,800	261,000	79	22,300	290,000	78	2,290	6,700

Note: *As specified by the SedNet model. **Kinsey-Henderson et al. (2007). Loads and EMC calculated by adding all data from P components tables (Lewis et al 2008, Tables 6, 10 and 18)

6.2 Modelling

BMT WBM was commissioned to undertake catchment modelling to provide estimates of the sediment and nutrient discharge loads for the main catchments in the Black Ross WQIP area. Event mean concentrations (EMC) and data from the ACTFR event water quality monitoring was used as input to the model. The set of preliminary modelled results is provided in Appendix F.

After reviewing the preliminary modelled results some adjustments were made to EMC values for 'wet' and 'dry' catchments and the new figures used for additional runs of the model. Scenarios were also modelled based on predicted population growth coupled with known dwelling occupancy rates, known and anticipated urban expansion areas, planning scheme zonings, the Townsville-Thuringowa Strategy Plan and land use mapping. The resulting population and development growth maps were used for the following scenario horizons:

- 2005 (Base case),
- 2012 (Wastewater upgrades),
- 2021 (Achievable management practice adoption timeframe), and
- 2045 (Measurable water quality outcomes timeframe).

The following tables show the results of the modelled scenarios with no additional management action intervention for diffuse source pollutants. The base case (2005) and 2045 land use scenarios were modelled and the 2021 results were interpolated from those results.

Table 6.4 Base Case (2005) Modelled Load Summary by WQIP Sub Basin

Sub Basin		Area	Flow	TSS	TN	TP
	No.	Hectares	ML/year	kg/year	kg/year	kg/year
Crystal Creek	1	22,629	239,443	5,513,449	90,122	9,383
Rollingstone Creek	2	21,822	144,387	1,603,046	40,448	4,021
Bluewater Creek	3	28,872	145,698	2,806,946	92,700	4,641
Black River (no STP)	4	29,539	114,396	7,195,425	69,178	10,022
Black Basin total		102,861	643,925	17,118,866	292,448	28,067
Bohle River (no STP)	5	33,194	131,708	9,295,613	78,328	14,146
Lower Ross River	6	13,244	53,714	4,205,854	33,120	6,981
Upper Ross River	7	74,929	196,870	8,108,550	100,444	12,784
Stuart Creek (no STP)	8	11,024	47,483	1,650,930	18,956	2,959
Alligator Creek	9	27,490	104,834	2,104,936	42,716	4,811
Ross Basin total		159,882	534,608	25,365,882	273,565	41,680
Magnetic Island	10	4,815	27,390	342,217	6,286	944
Black Ross Total		267,559	1,205,923	42,826,965	572,299	70,690

Note: Updated using 9/6/09, 10/6/09 and 12/6/09 data. Does not include WWTP discharge contributions

Table 6.5 Interpolated Load Summary 2021

Sub Basin		Area	Flow	TSS	TN	TP
	No.	Hectares	ML/year	kg/year	kg/year	kg/year
Crystal Creek	1	22,629	239,283	6,515,695	97,966	10,352
Rollingstone Creek	2	21,822	144,635	2,168,745	45,643	4,572
Bluewater Creek	3	28,872	145,245	2,807,092	95,213	4,515
Black River (no STP)	4	29,539	114,411	7,408,731	70,669	10,246
Black Basin		102,861	643,574	18,900,263	309,491	29,686
Bohle River (no STPs)	5	33,194	132,384	9,494,820	78,326	14,225
Lower Ross River	6	13,244	54,146	5,081,431	36,718	7,766
Upper Ross River	7	74,929	196,578	10,153,950	110,232	14,741

Stuart Creek (no STP)	8	11,024	47,483	2,429,643	23,559	3,777
Alligator Creek	9	27,490	104,410	3,792,099	53,248	6,586
Ross Basin		159,882	535,001	30,951,942	302,083	47,094
Magnetic Island	10	4,815	27,430	399,459	6,383	1,000
Black Ross Total		267,559	1,206,004	50,251,665	617,957	77,780

Note: Updated using 9/6/09, 10/6/09 and 12/6/09 data. Does not include WWTP discharge contributions

Table 6.6 Modelled Loads Summary 2045

Sub Basin		Area	Flow	TSS	TN	TP
	No.	Hectares	ML/year	kg/year	kg/year	kg/year
Crystal Creek	1	22,629	239,042	8,019,064	109,732	11,806
Rollingstone Creek	2	21,822	14,5008	3,017,294	53,436	5,400
Bluewater Creek	3	28,872	144,566	2,807,312	98,983	4,327
Black River (no STP)	4	29,539	114,433	7,728,690	72,904	10,581
Black Basin		102,861	643,048	21,572,359	335,055	32,115
Bohle River (no STPs)	5	33,194	133,397	9,793,631	78,322	14,343
Lower Ross River	6	13,244	54,795	6,394,797	42,114	8,943
Upper Ross River	7	74,929	196,139	13,222,050	124,916	17,678
Stuart Creek (no STP)	8	11,024	47,483	3,597,713	30,462	5,004
Alligator Creek	9	27,490	103,775	6,322,843	69,047	9,248
Ross Basin		159,882	535,589	39,331,033	344,860	55,216
Magnetic Island	10	4,815	27,489	485,322	6,527	1,084
Black Ross Total		267,559	1,206,126	61,388,714	686,442	88,416

Note: Updated using 9/6/09, 10/6/09 and 12/6/09 data. Does not include WWTP discharge contributions

Estimated changes in load values over time with no management interventions are shown in Table 6.7 for total suspended solids, Table 6.8 for nitrogen and Table 6.9 for phosphorus.

Table 6.7 TSS Load Change 2005 to 2045

Catchment	2005	2021			2045		
	Load (kg/year)		Change from 2005		Load (kg/year)	Change from 2005	
			kg/year	%		kg/year	%
Crystal Creek SB	5,513,449	6,515,695	1,002,246	18	8,019,064	2,505,615	45
Rollingstone Creek SB	1,603,046	2,168,745	565,699	35	3,017,294	1,414,248	88
Bluewater Creek SB	2,806,946	2,807,092	146	0	2,807,312	365	0
Black River SB	7,195,425	7,408,731	213,306	3	7,728,690	533,265	7
Black Basin	17,118,866	18,900,263	1,781,397	10	21,572,359	4,453,493	26
Bohle River SB	9,295,613	9,494,820	199,207	2	9,793,631	498,018	5
Lower Ross River SB	4,205,854	5,081,431	875,577	21	6,394,797	2,188,943	52
Upper Ross River SB	8,108,550	10,153,950	2,045,400	25	13,222,050	5,113,500	63
Stuart Creek SB	1,650,930	2,429,643	778,713	47	3,597,713	1,946,783	118
Alligator Creek SB	2,104,936	3,792,099	1,687,163	80	6,322,843	4,217,907	200
Ross Basin	25,365,882	30,951,942	5,586,060	22	39,331,033	13,965,151	55
Magnetic Island SB	342,217	399,459	57,242	17	485,322	143,105	42
Black Ross WQIP area	42,826,965	50,251,665	7,424,700	17	61,388,714	18,561,749	43

Note: Diffuse sources only. Percentage is the change from the base case (2005) as a percentage of the 2005 load.

Table 6.8 TN Load Change 2005 to 2045

Catchment	2005	2021			2045		
	Load (kg/year)		Change from 2005		Load (kg/year)	Change from 2005	
			kg/year	%		kg/year	%
Crystal Creek SB	90,122	97,966	7,844	8.7	109,732	19,610	21.8
Rollingstone Creek SB	40,448	45,643	5,195	12.8	53,436	12,988	32.1
Bluewater Creek SB	92,700	95,213	2,513	2.7	98,983	6,282	6.8
Black River SB	69,178	70,669	1,490	2.2	72,904	3,726	5.4
Black Basin	292,448	309,491	17,043	5.8	335,055	42,606	14.6
Bohle River SB	78,328	78,326	-2	0.0	78,322	-6	0.0
Lower Ross River SB	33,120	36,718	3,598	10.9	42,114	8,994	27.2
Upper Ross River SB	100,444	110,232	9,789	9.7	124,916	24,472	24.4
Stuart Creek SB	18,956	23,559	4,602	24.3	30,462	11,505	60.7
Alligator Creek SB	42,716	53,248	10,532	24.7	69,047	26,331	61.6
Ross Basin	273,565	302,083	28,518	10.4	344,860	71,296	26.1
Magnetic Island SB	6,286	6,383	96	1.5	6,527	241	3.8
Black Ross WQIP area	572,299	617,957	45,657	8.0	686,442	114,143	19.9

Note: Diffuse sources only. Percentage is the change from the base case (2005) load as a percentage of the 2005 load.

Table 6.9 TP Load Change 2005 to 2045

Catchment	2005	2021			2045		
	Load (kg/year)		Change from 2005		Load (kg/year)	Change from 2005	
			kg/year	%		kg/year	%
Crystal Creek SB	9,383	10,352	969	10.3	11,806	2,423	25.8
Rollingstone Creek SB	4,021	4,572	552	13.7	5,400	1,380	34.3
Bluewater Creek SB	4,641	4,515	-125	-2.7	4,327	-313	-6.7
Black River SB	10,022	10,246	224	2.2	10,581	559	5.6
Black Basin	28,067	29,686	1,620	5.8	32,115	4,049	14.4
Bohle River SB	14,146	14,225	79	0.6	14,343	197	1.4
Lower Ross River SB	6,981	7,766	785	11.2	8,943	1,962	28.1
Upper Ross River SB	12,784	14,741	1,958	15.3	17,678	4,894	38.3
Stuart Creek SB	2,959	3,777	818	27.7	5,004	2,045	69.1
Alligator Creek SB	4,811	6,586	1,775	36.9	9,248	4,437	92.2
Ross Basin	41,680	47,094	5,415	13.0	55,216	13,536	32.5
Magnetic Island SB	944	1,000	56	6.0	1,084	141	14.9
Black Ross WQIP area	70,690	77,780	7,090	10.0	88,416	17,726	25.1

Note: Diffuse sources only. Percentage is the change from the base case (2005) load as a percentage of the 2005 load.

Table 6.10 Diffuse Source Loads Summary 1850 to 2045

Sub Basin	Area Hectare	1850 Flow ML/year	1850 TSS kg/year	1850 TN kg/year	1850 TP kg/year	2005 Flow ML/year	2005 TSS kg/year	2005 TN kg/year	2005 TP kg/year	2021 TSS kg/year	2021 TN kg/year	2021 TP kg/year	2045 Flow ML/year	2045 TSS kg/year	2045 TN kg/year	2045 TP kg/year
Crystal Creek	22,629	241,419	967,949	45,919	4,693	239,443	5,513,449	90,122	9,383	6,515,695	97,966	10,352	239,042	8,019,064	109,732	11,806
Rollingstone Creek	21,822	145,337	581,003	27,628	2,943	144,387	1,603,046	40,448	4,021	2,168,745	45,643	4,572	14,5008	3,017,294	53,436	5,400
Bluewater Creek	28,872	145,516	582,464	27,704	3,102	145,698	2,806,946	92,700	4,641	2,807,092	95,213	4,515	144,566	2,807,312	98,983	4,327
Black River	29,539	112,643	1,521,997	38,790	4,120	114,396	7,195,425	69,178	10,022	7,408,731	70,669	10,246	114,433	7,728,690	72,904	10,581
Black Basin	102,861	644,915	3,653,413	140,041	14,859	643,925	17,118,866	292,448	28,067	18,900,263	309,491	29,686	643,048	21,572,359	335,055	32,115
Bohle River	33,194	119,673	1,955,625	46,633	4,895	131,708	9,295,613	78,328	14,146	9,494,820	78,326	14,225	133,397	9,793,631	78,322	14,343
Lower Ross River	13,244	46,692	760,268	18,181	1,909	53,714	4,205,854	33,120	6,981	5,081,431	36,718	7,766	54,795	6,394,797	42,114	8,943
Upper Ross River	74,929	198,331	3,119,235	77,433	7,962	196,870	8,108,550	100,444	12,784	10,153,950	110,232	14,741	196,139	13,222,050	124,916	17,678
Stuart Creek	11,024	37,986	609,968	14,793	1,538	47,483	1,650,930	18,956	2,959	2,429,643	23,559	3,777	47,483	3,597,713	30,462	5,004
Alligator Creek	27,490	110,086	1,902,587	42,778	4,621	104,834	2,104,936	42,716	4,811	3,792,099	53,248	6,586	103,775	6,322,843	69,047	9,248
Ross Basin	159,882	512,769	8,347,683	199,817	20,925	534,608	25,365,882	273,565	41,680	30,951,942	302,083	47,094	535,589	39,331,033	344,860	55,216
Magnetic Island	4,815	26,755	107,077	5,088	518	27,390	342,217	6,286	944	399,459	6,383	1,000	27,489	485,322	6,527	1,084
Black Ross Total	267,559	1,184,438	12,108,173	344,945	36,302	1,205,923	42,826,965	572,299	70,690	50,251,665	617,957	77,780	1,206,126	61,388,714	686,442	88,416
Change from 2005		-21485	-30,718,792	-227,354	-34,388	0	0	0	0	7,424,700	45,657	7,090	202	18,561,749	114,143	17,726
% change from 2005		-1.8	-72	-39.7	-48.6					17	8	10	0.0	43	19.9	25.1
Change from 1850		0	0	0	0	21,485	30,718,792	227,354	34,388	38,143,492	273,011	41,478	21,688	49,280,542	341,497	52,114
% change from 1850						1.8	254	66	95	315	79	114	1.8	407	99	144

Note: Diffuse sources only. Updated using 9/6/09, 10/6/09 and 12/6/09 data

Management intervention scenarios were subsequently modelled for:

- Water sensitive urban design (WSUD) applied to new (Greenfield) developments;
- WSUD retrofit of all urban areas; and
- Rural best management practice.

Results of the modelled scenarios and implications for the Black Ross WQIP can be found in the *Black Ross Water Quality Improvement Plan Options, Costs and Benefits Report* (Gunn and Manning 2009).

7. Relative Contributions

7.1 Determining Relative Contributions

Determining the relative contributions of pollutants to receiving waters is an imprecise process due to a high dependence on the availability of reliable monitoring information. In general the information required is not available for the Black and Ross Basins. Determining relative contributions of pollutants to receiving waters for Townsville is therefore based on a number of assumptions and indirect measurements using tools such as catchment and water quality models.

As a starting point the receiving waters are important to define as different processes operate in different receiving waters. For example nutrient sources and cycling are different in the marine environment compared to estuaries and freshwater. Along with nutrient inputs from terrestrial sources the Great Barrier Reef marine environment also receives nutrients from; upwelling from the Coral Sea, rainfall; and nitrogen fixation by cyanobacteria. As we are principally concerned with the contribution to the marine environment from the terrestrial environment the cycling of pollutants in the marine environment will not be considered in this report.

For Townsville the main consideration is the relative contribution of various land uses to sediment and nutrient loads at the end of the catchment i.e. the material that is exported to the marine environment (receiving waters). Various other sources are also taken into consideration e.g. point sources (see section 2) and atmospheric deposition (see section 4). In the context of the urban environment the export of heavy metals, hydrocarbons, pesticides and gross pollutants is also an important consideration for water quality.

7.2 Land Use

Land use is the key parameter for determining the relative contribution of pollutants from the terrestrial environment to receiving waters. In reality it is not just the land use that determines the contribution of pollutants, as the management activities associated with the land use are also a significant factor. Land use is chosen as the initial indicator as it is relatively easy to measure and place in a geographic context relative to the receiving waters. Determining variations associated with management practices is a more difficult task and requires monitoring at the 'paddock' scale to detect the differences between paddock scale management practices.

Assumptions and generalisations are made about the generic management practices associated with a land use that results in characteristic pollutant run-off profiles for the land use. Obviously there will be differences at the paddock scale between 'good', 'average' and 'bad' land management practices that will affect the amount of pollutants in run-off. For the purposes of modelling, average profiles are used for various land uses to reflect the 'normal' management practices associated with the land use across a catchment.

Relative diffuse source contributions of pollutants from different land uses were discussed in section 3. Summaries of the findings from various studies are included in Table 7.1 in terms of broad land use categories and in Table 7.2 with respect to urban land uses.

Table 7.1 Broad Land Use Group Pollutant Contributions

Black Ross Combined	Forest	Grazing	Sugar	Crops	Other	Total	Export
Area (ha)	57,330	142,550	810	1,680	17,870	220,240	
SS (t/yr)	63,000	163,000	1,000	2,000	14,000	243,000	243,000
SS kg/ha/yr	1,099	1,143	1,235	1,190	783	1,103	
Total N (t/yr)	310	1,039	4	9	79	1,441	877
TN kg/ha/yr	5.4	7.3	4.9	5.4	4.4	6.5	
Total P (t/yr)	59	154	1	2	10	226	143
TP kg/ha/yr	1.0	1.1	1.2	1.2	0.6	1.0	
Black Ross Export	**Pristine**	**Grazing**		**Cropping**	**Urban**	**Total**	**Export**
Area (ha)	53,000	225,000		1,000	10,000	289,000	
Sediment (t/yr)	13,000	223,000		2,000	4,000		242,000

Sediment (kg/ha/yr)	247	990		2,474	400	833	
Total N (t/yr)	63	1,079		17	74		1,233
TN kg/ha/yr	1.2	4.8		17.3	[7.4]	4.3	
Total P (t/yr)	9	154		3	7		173
TP kg/ha/yr	0.17	0.69		2.57	[0.7]	0.6	

Source: Brodie et al 2003 (top of table) and Moss et al 1992 (bottom of table). Figures in [square brackets] are interpreted from a graph.

Note: Annual flow from Moss 1,100,000ML with 0.38 ML/km² run-off.

Table 7.2 Urban Land Use Pollutant Contributions

	SS (mg/L)		Nitrogen (mg/L)		Phosphorus (mg/L)	
Land use subgroup	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**
High urban roads	779	232				
Low urban roads	229	64				
Roads			2.7	2.2	0.42	0.24
Roofs	47	41			0.15	0.14
Residential					0.56	0.39
Industrial						
Commercial						
High urban/non-res.	294	152	3.4	2.5	0.46	0.36
Agricultural	311	133	5.3	4.4	0.90	0.51
Forest	99	71	1.1	0.95	0.095	0.07

Source: Information extracted from Duncan 1999 (p.10, p.13, p.18)

7.2.1 Event Monitoring Results

Along with the information derived from other studies additional work has also been undertaken for the Black Ross WQIP area by the ACTFR through the design and implementation of event based water quality monitoring during the 2006/07 and 2007/08 wet seasons.

Subsequent interpretation of the results, in a 2008 report (Lewis et al), confirmed the strong water quality 'signals' associated with catchments draining different land uses, which were indicated in the 2006/07 wet season monitoring.. The EMC values calculated from the event monitoring have been used as input to the catchment modelling study to provide more locally relevant data. A summary of the results from the event monitoring report (Lewis et al 2008) is provided below

The main points (see Table 7.3) associated with total suspended solids (TSS) and land use are:

- Waterways draining the developing urban sites contained elevated TSS concentrations,
- A developing urban hillslope site had a peak TSS concentration of 20,000 mg/L,
- Comparison undeveloped hillslope samples were all consistently below 100 mg/L,
- The developing urban sites on the coastal plain (Kern Drain and Gordon Creek) had considerably higher TSS concentrations compared to the established urban site,
- TSS event mean concentration (EMC) calculated for the established urban sites (20 mg/L) is similar to the conservation land use (19 mg/L),
- Minimal use, rural residential, urban industrial (Stuart C. d/s site) and the light industrial sites had slightly elevated TSS EMCs,
- Developing urban sites all had considerably higher TSS EMCs,
- The large difference between the TSS EMC for the two urban industrial sites reflects the difference in catchment area and land use i.e. Stuart Creek (ds) larger grazing catchment and Louisa Creek smaller urban catchment.

(Source: Lewis et al 2008, pp.13-15)

Table 7.3 Event Monitoring Suspended Solids Data 2006-2008

Dominant land use	Site	Year	Mean (all data)	Median (all data)	Rise (mean)	Peak (mean)	Fall (mean)	Mean rise, peak and fall	Mean EMC mg/L
Established urban	Woolcock St drain	06/07	22	24	20	29	22	24	20
		07/08	15	10	51	17	8.8	26	
	Captain Ck	06/07	15	15	25	12	7.4	15	
Developing urban (Coastal plain)	Kern drain	06/07	339	278	612	284	185	360	795
		07/08	502	445	637	770	389	599	
	Gordon Ck	06/07	409	351	783	444	184	470	
		07/08	662	130	4,600	500	123	1741	
Dev. urban (hillslope) *	Riverview Ck		11,142	4,975					11,140
Light industrial	Hill St drain	07/08	49	43	100	46	26	57	57
Urban industrial	Stuart Ck (ds)	06/07	237	200	257	305	169	244	130
	Louisa Ck	06/07	14	12	21	15	7.8	15	
Rural residential	Sachs Ck	06/07	29	7.1	139	21	5.6	55	35
	Bluewater Ck (ds)	06/07	27	8.3	40	45	4.4	30	
	Alligator Ck (ds)	06/07	20	19	20	14	24	19	
Minimal use	Stuart Ck (us)	06/07	96	63	41	224	49	105	56
	Hencamp Ck	06/07	27	9.3	46	47	14	36	
	Campus Ck	06/07	14	3.5	10	49	1.9	20	
	Bluewater Ck (us)	06/07	55	18	130	48	9	62	
Conservation	Alligator Ck (us)	06/07	12	7	34	19	4.6	19	19

Source: Table 2. Summary of TSS concentrations (mg/L) for the different land uses in the Black Ross WQIP Region over the 2006/07 and 2007/08 wet seasons (Lewis et al 2008, p.16)
Note: * This land use was not fully sampled over the hydrograph and most samples were collected over the rise and peak stages. Therefore this mean is probably an overestimation.

In terms of nutrients, water samples were analysed for total nitrogen (TN) and phosphorus (TP), particulate nitrogen (PN), particulate phosphorus (PP), total filterable nitrogen (TFN) and total filterable phosphorus (TFP), ammonia, NO_x (nitrate and nitrite) and filterable reactive phosphorus (FRP). TN and TP results were not included in the Lewis et al (2008) report so TN and TP were calculated by Creek to Coral by aggregating the four nitrogen components and three phosphorus components. Medians were calculated from TN and TP raw data.

Lewis et al (2008) base their commentary on the nitrogen and phosphorus components rather than TN (see Table 7.4) and TP (see Table 7.5) and this is reflected in the summary comments on nutrients below.

The main points associated with nitrogen and land use in the sampled waterways are:

- Summary EMC for PN show there is little variability in PN across the different land uses,
- Established urban sites had higher PN EMC compared to the developing urban sites indicating runoff from more fertile (or fertilised) soils in the established urban lands,
- Waterways draining the urban and light industrial lands contained elevated concentrations of DON,
- All sites displayed a higher DON EMC than the conservation land use,
- On average, ammonia concentrations were relatively higher at Woolcock St Drain,
- Ammonia EMC were higher for all land uses compared to the conservation land use,
- Highest ammonia EMCs were in the established and developing urban sites,
- NO_x EMC was higher in all land uses compared to the conservation land use,
- NO_x EMC was particularly elevated for the established urban, developing urban and rural residential sites.

(Source: Lewis et al 2008, pp.18-26)

Table 7.4 Event Monitoring Total Nitrogen Data 2006-2008

Dominant land use	Site	Year	Mean (all data)	Median (all data)	Rise (mean)	Peak (mean)	Fall (mean)	Mean rise, peak and fall	Mean EMC mg/L
Established urban	Woolcock St drain	06/07	716	643	653	724	798	725	**744**
		07/08	793	826	770	684	825	760	
	Captain Ck	06/07	740	642	632	570	1020	740	
Developing urban (Coastal plain)	Kern drain	06/07	767	806	695	625	869	729	**748**
		07/08	830	666	744	987	832	854	
	Gordon Ck	06/07	746	694	758	555	794	702	
Light industrial	Hill St drain	07/08	858	648	684	821	973	826	**822**
Urban industrial	Stuart Ck (ds)	06/07	674	642	772	698	587	685	**626**
	Louisa Ck	06/07	572	533	542	526	611	560	
Rural residential	Sachs Ck	06/07	568	564	801	487	537	608	**510**
	Bluewater Ck (ds)	06/07	403	368	498	436	311	414	
	Alligator Ck (ds)	06/07	432	363	392	680	368	480	
Minimal use	Stuart Ck (us)	06/07	632	644	498	729	603	611	**482**
	Hencamp Ck	06/07	400	397	402	219	444	354	
	Campus Ck	06/07	447	327	552	305	363	407	
	Bluewater Ck (us)	06/07	529	421	672	429	497	533	
Conservation	Alligator Ck (us)	06/07	331	254	699	270	253	407	**404**

Source: Lewis et al 2008 total nitrogen compiled from N components in Tables 4, 8, 12 and 14.
Note: Means were calculated by adding all data from N components tables while the Median figure was calculated from TN raw data

The main points associated with phosphorus and land use in the sampled waterways are:

- Elevated PP was measured in the developing urban land use,
- PP typically follows the TSS EMC with the highest concentrations in the developing urban land,
- Urban and light industrial lands contained elevated concentrations of DOP,
- EMC for DOP in the different land uses were all higher than the conservation land use,
- DOP EMC at the light industrial site was twice that of any other land use,
- Waterways draining the urban and industrial lands had considerably elevated FRP EMC,
- The highest FRP EMC was found at the light industrial site.

(Source: Lewis et al 2008, pp.18-26)

Table 7.5 Event Monitoring Total Phosphorus Data 2006-2008

Dominant land use	Site	Year	Mean (all data)	Median (all data)	Rise (mean)	Peak (mean)	Fall (mean)	Mean rise, peak and fall	Mean EMC mg/L
Established urban	Woolcock St drain	06/07	314	297/285	308	268	353	309	**279**
		07/08	357	329/330	312	365	363	346	
	Captain Ck	06/07	236	202/245	279	230	196.2	235	
Developing urban (Coastal plain)	Kern drain	06/07	353	321/362	394	386	317	366	**279**
		07/08	338	328/340	363	386	321	357	
	Gordon Ck	06/07	213	217/197	230	207	205	213	
Light industrial	Hill St drain	07/08	465	224/209	360	455	526	447	**445**
Urban industrial	Stuart Ck (ds)	06/07	282	219/204	288	315	252	286	**229**
	Louisa Ck	06/07	179	187/175	163	172	193	176	
	Sachs Ck	06/07	65.4	51.9/50	133	68.6	49.6	83	**56**

Rural residential	Sachs Ck	06/07	65.4	51.9/50	133	68.6	49.6	83	
	Alligator Ck (ds)	06/07	66	50.6/50	81	34	60	58	
	Stuart Ck (us)	06/07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	Hencamp Ck	06/07	25.5	23.6/26	20.2	22.6	27.5	23.8	
	Campus Ck	06/07	102	89/90	117	94.3	84	98	
	Bluewater Ck (us)	06/07	79.6	48/50	101.2	77.8	67.4	81.8	
Conservation	Alligator Ck (us)	06/07	31.2	28.5/30	21.4	54	28.8	34.2	**34.2**

Source: Lewis et al 2008 total phosphorus compiled from P components in Tables 6, 10 and 17.

Note: Means were calculated by adding all data from P components tables while the Median figure was calculated from TP data

"*The results from the 2007/08 water quality monitoring program further support the conclusions drawn from the 2006/07 results and strengthen the water quality dataset available for urban and industrial land uses in dry tropical environments*."

"*The latest data from 2007/08 show two of the key water quality concerns identified in the previous 2006/07, namely suspended sediment in the developing urban sites and FRP in the urban and industrial land uses, are consistent over the two monitored wet seasons. The addition of the light industrial site in the 2007/08 monitoring program showed very high levels of FRP and DOP from this land use and helped to highlight the possible main sources of dissolved phosphorus in the Black Ross WQIP Region*."

(Source: Lewis et al 2008, p.39)

Water Sensitive Urban Design (WSUD) literature supports the Townsville monitoring results with regard to sediment exported from developing catchments. Annual sediment discharge rates from developing catchments are one to two orders of magnitude higher than for developed catchments (i.e. 50 m^3/ha and 200 m^3/ha of sediment each year compared to 1.6 m^3/ha).

7.2.2 Preliminary MUSIC Model Land Use Contributions

Initial input data was required to test the Bayesian Belief Network (BBN) model being developed to factor in changes in management practices and impacts on water quality. This information was provided by BMT WBM, who were commissioned to provide the modelled catchment loads for the Black Ross WQIP area. The preliminary areal pollutant export rates and event mean concentrations for the BBN were extracted from a MUSIC model prior to the broader catchment modelling study. The preliminary pollutant export rates are listed in Table 7.21.

7.2.3 Monitoring modified modelling

After a review of the draft outputs from the BMT WBM catchment modelling it was decided that the northern catchments of the Black Basin should be treated differently to the drier southern catchments of the Ross Basin due to the difference in rainfall regime, vegetation and run-off and erosion characteristics. The Paluma Ranges in the northern catchments more closely resemble the conditions found in the wet tropics than the drier Hervey Range of the Ross Basin. This is partly due to the closer proximity of the ranges to coast resulting in greater orographic rainfall.

To account for these differences data from the Black Ross event monitoring was combined with event monitoring data from the Tully catchment to provide a set of 'dry' and 'wet' catchment EMC values for grazing and green space. The 'new' figures (replacing Minimal Use and Conservation in Table 7.3, Table 7.4 and Table 7.5) are provided in Table 7.6 for TSS, Table 7.7 for nitrogen and Table 7.8 for phosphorus.

The modified EMC values, and other data from the event water quality monitoring, were subsequently used as input to the final catchment and water quality modelling used to determine diffuse source end of catchment pollutant loads discharging to the receiving waters of the Great Barrier Reef (see section 6.2).

Table 7.6 Wet and Dry Catchment TSS EMC values

Dominant land use	Site	Year	Mean (all data)	Median (all data)	Rise (mean)	Peak (mean)	Fall (mean)	Mean rise, peak and fall	Mean EMC mg/L
Dry savanna grazing	Stuart Ck (us)	06/07	96	63	41	224	49	105	**130**
	Black River	06/07						240	
	Black River	07/08						230	
	Bluewater Ck (us)	06/07	55	18	130	48	9	62	
Green space (dry)	Alligator Ck (us)	06/07	12	7	34	19	4.6	19	**25**
	Campus Creek	06/07	14	3.5	10	49	1.9	20	
	Hencamp Ck	06/07	27	9.3	46	47	14	36	
Wet Tropics grazing	Davidson Ck	05-07	29	12					**25**
	Warrami Creek	05-07	25	13					
Green space (wet)	Murray Falls	05-07	1	0.35					**4**
	Tully Gorge	05-08	7	4					
	North Hull River	05-07	10	4					

Note: (us) is upstream

Table 7.7 Wet and Dry Catchment Nitrogen EMC values

Dominant land use	Site	Year	Mean (all data)	Median (all data)	Rise (mean)	Peak (mean)	Fall (mean)	Mean rise, peak and fall	Mean EMC µg/L
Dry savanna grazing	Stuart Ck (us)	06/07	632	558	498	729	603	610	**535**
	Black River	06/07						435	
	Black River	07/08						507	
	Bluewater Ck (us)	06/07	529	447	672	429	497	533	
Green space (dry)	Alligator Ck (us)	06/07	331	261	699	270	253	407	**383**
	Campus Creek	06/07	447	347	552	305	363	407	
	Hencamp Ck	06/07	400	329	402	219	444	355	
Wet Tropics grazing	Davidson Ck	05-07	493	452					**768**
	Warrami Creek	05-07	1489	1323					
Green space (wet)	Murray Falls	05-07	131	106					**193**
	Tully Gorge	05-08	233	155					
	North Hull River	05-07	241	168					

Note: Figures calculated by adding DON, PN, NOx and ammonia values provided by ACTFR (see Appendix E).

Table 7.8 Wet and Dry Catchment Phosphorus EMC values

Dominant land use	Site	Year	Mean (all data)	Median (all data)	Rise (mean)	Peak (mean)	Fall (mean)	Mean rise, peak and fall	Mean EMC µg/L
Dry savanna grazing	Stuart Ck (us)	06/07	142	135	117	190	126	144	**110**
	Black River	06/07						112	
	Black River	07/08						100	
	Bluewater Ck (us)	06/07	80	48	101	78	67	82	
Green space (dry)	Alligator Ck (us)	06/07	31.2	28.5	21.4	54.0	28.8	34.7	**51**
	Campus Creek	06/07	102.0	89.0	117.0	94.3	84.0	98.4	
	Hencamp Ck	06/07	25.5	23.6	20.2	22.7	27.5	23.5	
Wet Tropics grazing	Davidson Ck	05-07	24.5	21.0					**27**
	Warrami Creek	05-07	30.0	27.0					
Green space (wet)	Murray Falls	05-07	13.0	12.0					**15**
	Tully Gorge	05-08	16.0	13.0					
	North Hull River	05-07	17.0	14.0					

Note: Figures calculated by adding FRP, PP, and DOP values provided by ACTFR (see Appendix E). (us) is upstream

7.3 Point Sources

Point source facilities that discharge to air have been included in the section on atmospheric deposition as a diffuse source contribution. Point source facilities that discharge to land have not been included in contributions as it is assumed that the licensing conditions associated with the activities and facilities preclude constant discharge to water. Accidental or intentional discharges, which contravene licence conditions, have not been considered as these are intermittent contributions at the most and are dealt with through legislative means.

The main point sources considered as pollutant contributors are the wastewater treatment plants as they discharge directly to water and contribute significant amounts of nutrients. They are also the subject of major upgrade operations and discharge concentrations of nutrients will be reduced in the near future (2012).

Contributions from point sources have been derived from catchment modelling and from calculations associated with the event monitoring undertaken by the ACTFR (Lewis et al 2008). The ACTFR results are summarised below by catchment.

7.3.1 Bohle River Catchment

Three wastewater treatment plants (WWTP) discharge into the Bohle River (Condon, Deeragun and Mt St John WWTPs) either directly or to tributaries. The discharge from Deeragun (Saunders Creek) and Mt St John WWTP (a drain entering the lower reaches) enters the Bohle River below the water quality monitoring site. Discharge data was obtained from Townsville City Council and load estimates calculated and compared to a previous report prepared by GHD (2007) (see Table 7.9).

Table 7.9 Bohle River WWTP Load Estimates

Water year	Condon WWTP (kg)		Deeragun WWTP (kg)		Mt St John WWTP (kg)	
	TN	TP	TN	TP	TN	TP
1998/99	2,110	1,920	1,300	1,490		
1999/2000	1,980	1,740	1,560	1,350		
2000/01	1,320	2,090	1,400	1,460		
2001/02	2,150	2,640	1,550	1,710		
2002/03	2,480	2,620	1,890	1,920		
2003/04	1,190	2,470	2,250	2,050		
2004/05	1,760	2,590	2,590	1,700	107,000	22,800
2005/06	950	2,310	3,250	1,680	136,000	21,900
2006/07	1,550	2,710	1,370	1,560	136,000	18,200
2007/08					139,000	14,200
ACTFR average	**1,721**	**2,343**	**1,907**	**1,658**	**129,500**	**19,275**
GHD 2007	**4,380**	**2,920**	**2,847**	**1,971**	**68,255**	**12,045**

Source: Lewis et al 2008, Table 19 and Table 20, p.34.

Load estimates for the Mt St John WWTP were considered to be more accurate than for the Condon and Deeragun WWTPs due to the higher resolution dataset and the greater consistency in the concentration data over time. ACTFR calculations suggest that the previous GHD load estimates for all three WWTPs may be too high.

Mt St John WWTP data show that high proportions of the TN and TP load consist of the dissolved inorganic fractions including DIN (~85% of TN) and phosphate (~75% of TP). This is also expected for the Condon and Deeragun WWTPs.

Estimated nutrient load contributions from the Condon WWTP at the event water quality monitoring site are indicated in Table 7.10.

Table 7.10 Condon WWTP Nutrient Load Contributions

Period	Monitoring Site		Condon WWTP			
	TN (kg)	TP (kg)	TN (kg)	TP (kg)	TN (%)	TP (%)
2006/07	70,600	23,000	1,700	2,300	2	10
2007/08	83,400	24,300	1,700	2,300	2	9.5

Source: Lewis et al 2008, p.33

The Mt St John WWTP is a much larger facility and when combined with the Deeragun WWTP the two have the potential to contribute another 131,000 kilograms of TN and 21,000 kilograms of TP to the annual end of catchment load of the Bohle River.

The estimated contributions to the end of catchment nutrient load of the Bohle River from the WWTPs are shown in Table 7.11. Collectively the three WWTPs contribute up to ~61% of TN and ~50% of TP to the total end of catchment load of the Bohle River.

Table 7.11 Bohle End of Catchment WWTP Nutrient Contributions

	Condon WWTP		Deeragun WWTP		Mt St John WWTP	
	TN	TP	TN	TP	TN	TP
Discharge (kg)	1,700	2,300	1,900	1,700	129,500	19,300
EoC contribution	1%	5%	1%	4%	59%	41%

Source: Lewis et al 2008, p.33. Bohle River end of catchment loads are approximately 218,300 kg TN and 46,700 kg TP

The WWTPs may contribute up to 90% of the total DIN load and 60% of the total phosphate load from the Bohle River. These are the more bioavailable forms of nutrients and have the potential for greater water quality impacts in terms of biological activity and eutrophication.

7.3.2 Black River Catchment

The Mt Low WWTP discharges into the lower reaches of the Black River below the monitoring site. As such a direct measurement of the contribution of the Mt Low WWTP by water quality monitoring is not possible. The contribution of TN and TP from the Mt Low WWTP to the end-of-catchment discharge is assumed as a ratio of the average annual WWTP discharge (see Table 7.12) to the annual discharge from the Black River (see Table 7.13).

Table 7.12 Mt Low WWTP Discharge Loads

Water year	TN (kg)	TP (kg)	Water year	TN (kg)	TP (kg)
1998/99	1,160	1,000	2003/04	1,620	1,590
1999/2000	2,290	1,460	2004/05	1,430	1,600
2000/01	2,770	1,270	2005/06	2,400	1,090
2001/02	1,800	1,640	2006/07	1,520	1,020
2002/03	1,850	1,410	Average	**1,871**	**1,342**

Source: Lewis et al 2008, Table 19, p.34.

Table 7.13 Mt Low WWTP Nutrient Contribution to Black River Load

Year	Total nitrogen (kilograms)			Total phosphorus (kilograms)		
	Black River	STP	%	Black River	STP	%
2006/07	59,700	1,520	2.5	15,200	1,020	6.7
2007/08	91,500	1,870	2.0	17,900	1,340	7.5

Note: Mt Low discharge figures were used for 2006/07 and average discharge figures were used for 2007/08.

Notes: Estimated (from Lewis et al 2008) discharge for 2006/07 and 2007/08 were 59,700kg and 91,500kg N and 15,200kg and 17,900 kg P.

7.3.3 Sandfly Creek Catchment

The Cleveland Bay WWTP discharges directly into the near coastal waters just beyond the mouth of Sandfly Creek at high tide (see Figure 7.1Table 7.14). At low tide the discharge point is into the intertidal channel of Sandfly Creek (see Figure 7.2). As the discharge point is so close to the mouth of Sandfly Creek the Cleveland Bay WWTP has been included as a point source discharge for the Sandfly Creek catchment, within the Stuart Creek sub basin.

Figure 7.1 Cleveland Bay WWTP Outfall High Tide

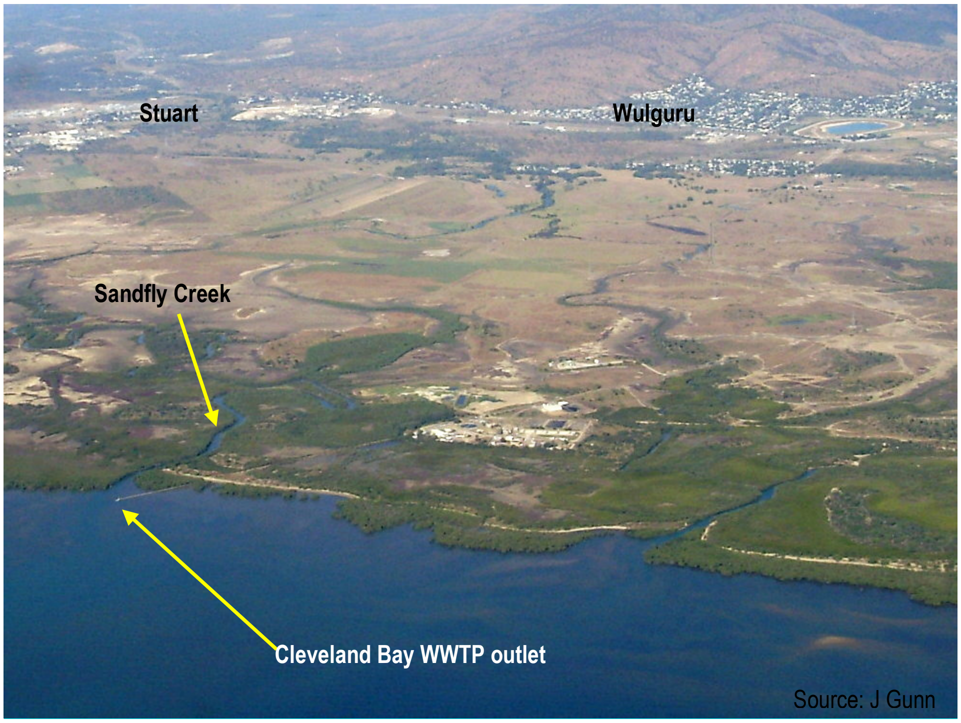
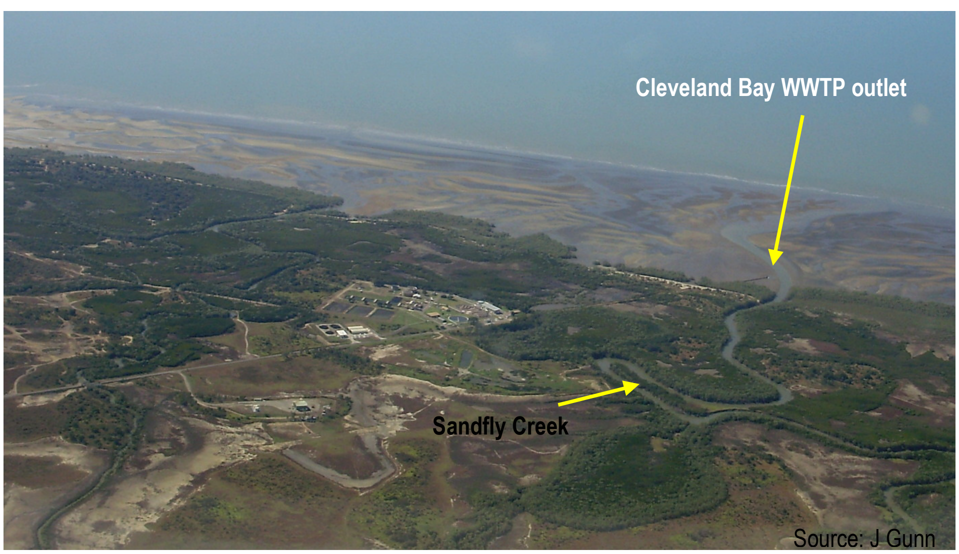


Figure 7.2 Cleveland Bay WWTP Outfall Low Tide



The Cleveland Bay WWTP is the largest facility in the Townsville region and has historically contributed considerable amounts of bioavailable nitrogen and phosphorus to Cleveland Bay. There would have been water quality impacts on the estuarine and near coastal environments in the vicinity of the outfall, including the Sandfly Creek estuary, Stuart Creek estuary and, to a lesser extent, the Ross River estuary.

It should be noted that the water quality issues associated with event flow conditions are different to the constant discharge of the WWTP throughout the year during low flow conditions. Event flows effectively dilute and flush the nutrients away from near shore areas as opposed to low flow conditions where tidal influences and estuarine processes see nutrient rich water remaining relatively close to the coast and cycling in and out of the estuaries.

The Cleveland Bay WWTP has been upgraded (2006) and this showed as a marked reduction in the loads of nitrogen and phosphorus discharged in the 2007/08 event monitoring results (see Table 7.14).

"*Loads from the sewerage treatment plants show that they may contribute a high proportion of bioavailable nitrogen and phosphorus exported from the Black Ross Region. However, plant upgrades have the potential to considerably reduce the loads of N and P*."
(Source: Lewis et al 2008, p.39)

Table 7.14 Cleveland Bay WWTP Discharge Loads

Water Year	Ammonia-N	Nitrate-N	Total N	Phosphate-P	Total P
2004/05	69,600	33,500	125,000	2,900	41,000
2005/06	73,500	26,900	126,000	2,600	39,200
2007/08	620	16,700	27,300	460	5,900
Average 2004-06	**71,550**	**30,200**	**125,500**	**2,750**	**40,100**

Source: Lewis et al 2008, Table 20, p.34. Note: Loads are in kilograms

Estimates of load contributions from catchment modelling results for the Cleveland Bay plant are shown by sub basin, basin and Black Ross WQIP area in Table 7.16.

A summary of proposed upgrade works to Townsville's wastewater treatment network is provided in Appendix B and the Options, Costs and Benefits background report (Gunn and Manning 2009).

Cleveland Bay WWTP discharge was initially treated as a direct input to Cleveland Bay rather than an end of catchment load. The load contribution to Cleveland Bay was calculated by adding the discharge loads for the Ross River, Stuart / Sandfly Creeks (estimate) and Alligator Creek and expressing the point source input as a proportion of the aggregated loads i.e. point source load divided by the combined waterway loads plus the point source load, to give a Cleveland Bay receiving waters load contribution.

Calculations were based on 2004 to 2006 discharge figures. Post upgrade contributions to Cleveland Bay were calculated using the same discharge rate and the nutrient concentrations measured after the upgrade. Results of the pre and post-upgrade calculations are displayed in Table 7.15.

Table 7.15 Alternate Cleveland Bay Load Calculations

Nutrient/Year	Alligator	Stuart	Ross	CBay WWTP	Total	Percentage
TN 2006/07 (Pre)	9,440	6,560	173,000	126,000	315,000	40
TN 2007/08 (Post)	9,440	4,300	149,700	27,300	190,740	14
TP 2006/07 (Pre)	1,540	960	20,800	40,000	63,300	63
TP 2007/08 (Post)	1,540	940	22,300	5,900	30,680	19

Source: Lewis et al 2008 and BMT WBM initial catchment modelling results

7.3.4 Modelled WWTP Contributions

As wastewater treatment plants (WWTP) are a significant point source contributor to end of catchment pollutant loads catchment modelling was also used to calculate the relative contribution from point sources. This is particularly relevant given the upgrades to WWTPs underway. Pre and post upgrade scenarios were modelled with the final upgrade scenario (2012) modelled based on the 2008 report prepared for Townsville City Council (Maunsell 2008). The base case (2007) modelling results for sub basins with contributions from WWTPs are shown in Table 7.16 along with total modelled loads for the Black and Ross Basins and the WQIP area. All other sub basins do not have any WWTP discharge and their load figures are therefore unchanged (see Table 6.4).

Table 7.16 2007 Modelled Load Summary by WQIP Sub Basin With WWTPs

Sub Basin		Area	Flow	TSS	TN	TP
	No.	Hectares	ML/Year	kg/Year	kg/Year	kg/Year
Black River	4	29,539	114,396	7,190,500	70,591	11,063
Black Basin total		102,861	643,925	17,107,149	293,708	29,095
Bohle River	5	33,194	131,708	9,289,250	191,753	29,795
Stuart Creek	8	11,024	47,483	1,649,800	61,320	20,039
Ross Basin total		159,882	534,608	25,348,520	429,232	74,391
Black Ross Total		267,559	1,205,923	42,797,652	729,223	104,429

Note: These figures include the upgrade to Cleveland Bay WWTP and are therefore post 2006/07 wet season. The Black Ross total includes the total for Magnetic Island sub basin. For pre upgrade loads see Appendix F

A comparison of sub basin loads with and without WWTPs is provided in Table 7.18 along with pre and post upgrade values for the Cleveland Bay WWTP.

Based on the proposed upgrades in the *Wastewater Upgrade Program Planning Report* (Maunsell Australia 2008), population growth figures and projected resulting pollutant discharge rates over time, estimates of the discharge loads of nitrogen and phosphorus from all WWTPs in the Black Ross WQIP area were made using catchment modelling (WaterCAST). Point source load change over time associated with WWTPs is shown in Table 7.17.

Table 7.17 Point Source Loads Over Time

Years	Total Flows (ML/day)	Total TSS loads (t/yr)	Total TN loads (t/yr)	Total TP loads (t/yr)
Pre 2006	41.54	91.03	296.32	72.08
2008 [1]	41.54	91.03	157.41	33.83
2010	43.24	94.77	163.29	36.68
2012 [2]	48.43	106.14	70.02	23.92
2021 [3]	55.65	121.97	92.10	28.67
2045	74.43	163.12	124.64	37.06

Note: Loads are in tonnes per year. Flows are daily discharge flows based on expected population growth. [1]Cleveland Bay WWTP upgrades are in place by 2008. [2]All other WWTP upgrades are assumed to be in place by 2012. Upgrades are based on reduction of nutrient concentrations. [3] Nutrient discharge increases after 2012 due to population increase

Increasing population and subsequent increase in point source discharge means that the relative contribution from point sources will increase over time (post 2012) if no other reduction measures are introduced.

Table 7.18 Load Comparisons With and Without WWTPs

Sub Basin	Flow	TSS	TN	TP
	ML/Year	kg/Year	kg/Year	kg/Year
Crystal Creek	239,279	5,509,675	90,060	9,376
Rollingstone Creek	144,288	1,601,949	40,420	4,018
Bluewater Creek	145,599	2,805,025	92,637	4,637
Black River (with WWTP)	114,318	7,190,500	70,591	11,063
Black River (no WWTP)	114,318	7,190,500	69,131	10,016
		Difference	1,460 (2.1%)	1,047 (9.5%)
Black Basin	643,484	17,107,149	293,708	29,095
Black Basin	643,484	17,107,149	292,248	28,047
		Difference	1,460 (0.5%)	1,047 (3.6%)
Bohle River (with WWTP)	131,618	9,289,250	191,753	29,795
Bohle River (no WWTP)	131,618	9,289,250	78,275	14,136
		Difference	113,478 (59.2%)	15,659 (52.6%)
Lower Ross River	53,677	4,202,975	33,097	6,976
Upper Ross River	196,735	8,103,000	100,375	12,775
Stuart Creek (with WWTP)	47,450	1,649,800	61,320	20,039
Stuart Creek (no WWTP)	47,450	1,649,800	18,944	2,957
		Difference	42,376 (69%)	17,082 (85%)
Alligator Creek	104,762	2,103,495	42,687	4,807
(with WWTP) **Ross Basin**	534,242	25,348,520	429,232	74,391
(no WWTP) **Ross Basin**	534,242	25,348,520	273,378	41,651
		Difference	155,854 (36.3%)	32,740 (44%)
Magnetic Island	27,371	341,983	6,282	943
(with WWTP) **Black Ross Total**	1,205,098	42,797,652	729,223	104,429
(no WWTP) **Black Ross Total**	1,205,098	42,797,652	571,908	70,641
		Difference	157,315 (21.6%)	33,788 (32.5%)
Pre Cleveland Bay WWTP Upgrade				
Stuart Creek	47,450	1,649,800	100,375	58,400
		Difference	39,055 (38.9%)	38,461 (65.9%)
		Difference	81,431 (81.1%)	55,443 (94.9%)
Ross Basin	534,242	25,348,520	567,932	112,753
		Difference	39,055 (6.9%)	38,461 (34.1%)
		Difference	81,431 (19%)	55,443 (74.5%)
Black Ross Total	1,205,098	42,797,652	867,922	142,791
			39,055 (4.5%)	38,461 (26.9%)
		Difference	81,431 (11.2%)	55,443 (53.1%)

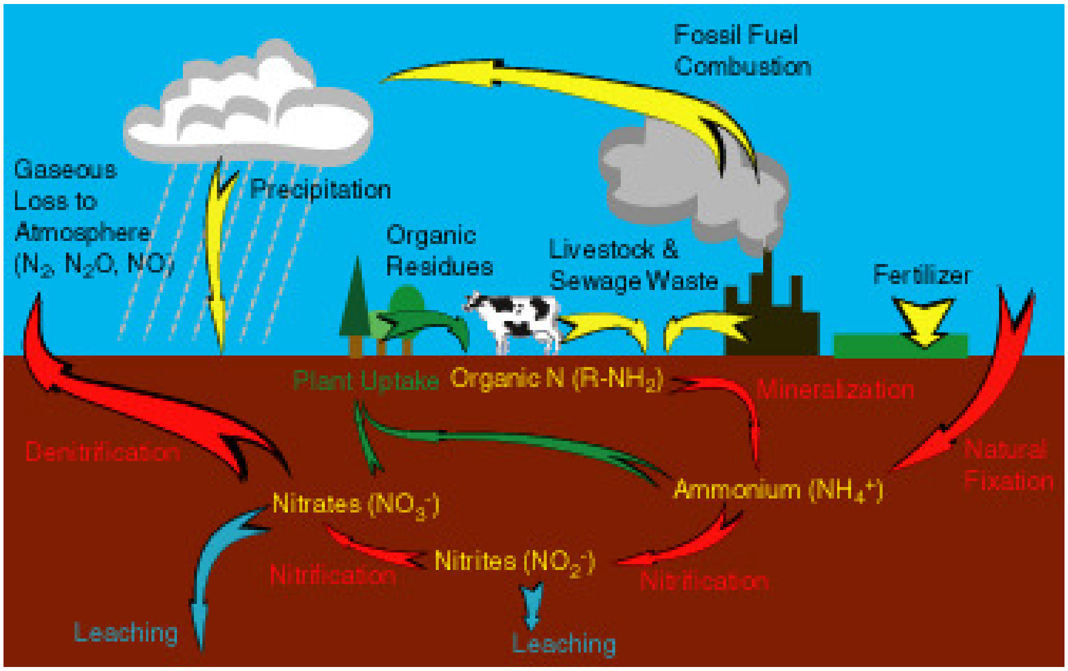
Notes: Uncoloured rows are load estimates for 2007 with WWTPs i.e. with Cleveland Bay upgrade. Tan shading are figures without WWTP loads and the difference relates to the 2007 load estimates. Blue rows are loads prior to Cleveland Bay WWTP upgrade and only relate to the Stuart Creek sub basin. Differences are from pre upgrade to post upgrade (2007 with WWTPs). Yellow difference is between pre Cleveland Bay upgrade and no WWTPs and again is only relevant for the Stuart Creek sub basin.

Further information on modelled point source pollutants can be found in the *Black Ross Water Quality Improvement Plan Options, Costs and Benefits Report* (Gunn and Manning 2009).

7.4 Atmospheric Deposition

The principal pollutants by volume associated with atmospheric deposition are particulate matter and oxides of nitrogen. Background levels of both these pollutants are not known specifically for the Townsville area and current air quality monitoring is principally associated with airborne concentrations as a function of human health. Contributions from atmospheric deposition of both particulate matter and oxides of nitrogen are a combination of natural background levels and any additional contributions from human sources. This is illustrated for the nitrogen cycle in Figure 7.3 (see section 4 for more detail on potential sources of atmospheric deposition).

Figure 7.3 The Human Modified Nitrogen Cycle



(Source: http://www.visionlearning.com/library/module_viewer2.php?mid=98&l=&let1=Ear)
Notes: Yellow arrows indicate human sources of nitrogen to the environment. Red arrows indicate microbial transformations of nitrogen. Blue arrows indicate physical forces acting on nitrogen. And green arrows indicate natural, non-microbial processes affecting the form and fate of nitrogen.

The main sources of particulate matter in Townsville, above background levels, are industrial facilities loading and unloading metal ores and quarry products, industrial facilities burning fossil fuels, motor vehicles, roadways, and construction sites. Dispersion and deposition of particulate matter is generally confined to the area around the generation site with finer particles drifting greater distances.

An estimate of average atmospheric deposition of particulate matter from all sources for the Townsville urban footprint (250 square kilometres) is 15 kg/ha/year (see section 4.3.4). This is equivalent to a depth of 0.0015 millimetres. The average annual contribution of particulate matter from atmospheric deposition to the sediment load of waterways in the Black Ross WQIP area is considered to be minimal across the region although it may be locally significant at Townsville Port and in close proximity to quarrying and earthmoving operations.

The main nitrogen dioxide (NO_2) source is a by-product of the combustion of fossil fuels from industrial facilities and motor vehicles. Background levels of atmospheric nitrogen deposition are in the order of 2-3 kg/ha/year (see section 4.2.2). Maximum potential deposition of NO_2 from human sources is estimated to be approximately 5-6 kg/ha/year to give a total NO_2 deposition of 8 kg/ha/yr (see 4.3.1). This is considered to be a significant overestimate and a more realistic figure of 2 kg/ha/year has been adopted for calculating the human induced contribution of atmospheric deposition of nitrogen in the urban footprint.

Atmospheric deposition of phosphorus, heavy metals, pesticides and sulphur dioxide is not considered to contribute significantly to water quality issues (see sections 4.3.3, 4.3.5, 4.3.6 and 4.3.7).

7.5 Relative Contributions Summary

Relative contributions of sediment and nutrients to the end of catchment and receiving waters loads from the Black Ross WQIP area are summarised below.

7.5.1 Point Sources

According to the results from event monitoring (Lewis et al 2008) and subsequent calculations by the authors of this report, point sources are significant contributors of nutrient loads to Halifax Bay from the Bohle and Black catchments, and to Cleveland Bay from Stuart Creek sub basin, as a result of discharges to water from wastewater treatment plants.

The estimated contributions from point sources to the end of catchment nutrient loads based on ACTFR event monitoring and calculations are:

- Black River - (from Mt Low WWTP) ~3% of TN (1.9 tonnes) and ~8% of TP (1.3 tonnes);
- Bohle River - (from Condon, Deeragun and Mt St John WWTPs) ~60% of TN (131 tonnes) and ~50% of TP (21 tonnes);
- Sandfly Creek (Stuart Creek sub basin) / Cleveland Bay - (Cleveland Bay WWTP) 126 tonnes of total nitrogen and 40 tonnes of total phosphorus (these figures are pre-upgrade and results cannot be considered as an indicative current contribution).

Results from catchment modelling are displayed in Table 7.19. Estimated contributions from point sources to the end of catchment nutrient loads based on the modelled results are:

- Black River - (from Mt Low WWTP) ~2% of TN (1.4 tonnes) and ~9% of TP (1.0 tonnes);
- Bohle River - (from Condon, Deeragun and Mt St John WWTPs) ~59% of TN (113 tonnes) and ~53% of TP (16 tonnes);
- Sandfly Creek / Stuart Creek - (Cleveland Bay WWTP) ~69% TN (42 tonnes) and ~85% of TP (17 tonnes)

Table 7.19 WWTP Contributions from Modelled Results

Sub Basin	Total N (kg/yr)		Difference		Total P (kg/yr)		Difference	
	With	Without	kg/yr	%	With	Without	kg/yr	%
Black River	70,591	69,178	1,413	2.0	11,063	10,022	1,041	9.4
Black Basin total	293,861	292,448	1,413	0.5	29,108	28,067	1,041	3.6
Bohle River	191,753	78,328	113,425	59.2	29,795	14,146	15,649	52.5
Stuart Creek	61,320	18,956	42,364	69.1	20,039	2,959	17,080	85.2
Ross Basin total	429,353	273,565	155,788	36.3	74,409	41,680	32,729	44.0
Black Ross Total	729,500	572,299	157,201	21.5	104,461	70,690	33,771	32.3

Note: Nutrient load contribution totals for basins and the Black Ross WQIP area are from all sources (point source and diffuse) and all sub basins. Only the sub basins with contributions from WWTPs have been included in the table. "With" is the total for sub basins with WWTP discharge figures included and "Without" is diffuse source loads only. Percentage difference is the kilogram difference as a percentage of the total end of catchment load with WWTP discharge.

Relative contributions for the Black River and Bohle River catchments are similar for the ACTFR and modelled results while the results for the Cleveland Bay WWTP cannot be readily compared due to the ACTFR results being pre-upgrade. In reality the Cleveland Bay WWTP discharges directly into Cleveland Bay and is not a true contributor to the Stuart Creek sub basin end of catchment loads.

7.5.2 Atmospheric Deposition

There are two components to atmospheric deposition i.e. direct deposition to water and deposition to land.

Atmospheric deposition to land as a water quality issue is not directly measurable as the processes associated with nutrient uptake and cycling as well as intra catchment erosion and sedimentation make the estimation of a contribution to catchment loads extremely difficult and potentially redundant. Atmospheric deposition to land is therefore treated as an integral component of the terrestrial run-off contribution and is accounted for through the pollutant coefficients of the different land uses.

Deposition to water is a direct contribution and has been calculated by determining the area of water in each catchment and multiplying this by the deposition rate to give a load that can be used to determine the overall contribution in terms of end of catchment loads.

The sub basins have been divided into urban and non-urban and separate deposition rates applied to reflect the assumed level of atmospheric deposition i.e. background levels only for non-urban areas. In Table 7.20 the modelled end of catchment loads have been used to calculate the atmospheric deposition contribution for each sub basin.

Table 7.20 Atmospheric Deposition

Sub basin	Area (ha)	Water (ha)	PM_{10} (kg)	%	TN (kg)	%	TP (kg)	%
Crystal Creek	22,629	268 [1]	2,144	0.04	536	0.59	54	0.58
Rollingstone Ck	21,822	110 [0.5]	880	0.05	220	0.54	22	0.55
Bluewater Ck	28,872	426 [1.5]	3,408	0.12	852	0.92	85	1.83
Black River	29,539	513 [1.7]	4,104	0.06	1,026	1.48	103	1.03
Bohle River	33,194	532 [1.7]	7,980	0.09	2,128	2.72	213	1.51
Ross River (btd)	13,244	754 [5.6]	11,310	0.27	3,016	9.11	302	4.33
Ross River (atd)	74,929	4,372 [5.8]	34,976	0.43	8,744	8.71	874	6.84
Stuart Creek	11,024	1,047 [10]	15,705	0.95	4,188	22.09	419	14.16
Alligator Creek	27,490	1,798 [6.8]	14,384	0.68	3,596	8.42	360	7.48
Magnetic Island	4,815	0	0		0		0	
Totals	267,558	9,820 [3.7]	94,891	0.22	24,306	4.25	2,432	3.44

Notes: Atmospheric deposition rates used: Urban footprint (Bohle River, Lower Ross River, and Stuart Creek sub basins) - PM_{10} 15 kg/ha/year, N 4kg/ha/yr (2kg/ha/yr background and 2kg/ha/yr anthropogenic), and P 0.4 kg/ha/year (equivalent to double the figure from a South Australian study). Non-urban (all other sub basins) footprint - PM_{10} 8 kg/ha/year, N 2kg/ha/yr and P 0.2 kg/ha/year. End of river load figures to calculate % contributions were sourced from BMT WBM modelled results. Figures in [brackets] in the Water column are the percentage of the sub basin defined as water through land use categories. Totals are for the Black Ross WQIP area

As can be seen the percentage contribution of atmospheric deposition for the modelled end of catchment loads is variable across the region and directly related to the area of water defined for the sub basin. It should be noted that the contribution assigned to atmospheric deposition is an estimate only and there is no monitoring information available to confirm the estimate.

It should be noted also that the there was considerable variation between the estimations obtained using ACTFR event monitoring data and the catchment modelling. It appears that the main difference was associated with the end of catchment load estimates, which were in turn dependent on estimations of flow volume. This is not an indication that the modelling is more accurate but rather a reflection on the need to obtain better volumetric data associated with water quality monitoring to enable improved calculation of end of catchment loads that are being discharged to the marine environment.

7.5.3 Land Use Contributions

Pollutant contributions from land use are often expressed as an areal load i.e. kilograms per hectare per year. This is useful for determining relative contributions from different land uses and providing input figures for catchment models however it does not necessarily reflect actual catchment condition and health.

The most influential factors in pollutant export to waterways from terrestrial sources are percentage ground cover, soil/land disturbance, soil type, slope and proximity to waterways. It is important to note that erosion is the main initial mobiliser of water pollutants from terrestrial sources however the transport of sediment and nutrients in run-off is another associated function, which determines the actual amount of pollutants that enter receiving waters.

Figure 7.4 Expanding Urban Areas are Sediment Sources

Source: J Gunn (CCI\Images\20080703 tvl air\enhanced\fairfield waters widesmall)

In the urban context it is the developing areas that contribute the greatest sediment pollutant loads to waterways while the developed urban areas contribute greater relative contributions of nutrients. In the rural context grazing lands contribute greater relative amounts of sediment while intensive agriculture contributes greater relative loads of nutrients.

Land use contributions in the Black Ross WQIP area have been investigated through the event water quality monitoring program undertaken in 2006/07 and 2007/08 by the ACTFR. The results showed the significance of land use classification and the development stage associated with the land use. The relative contributions from the various land uses used for the initial run of Bayesian Belief Network model for the Bohle River catchment are listed in Table 7.21. These figures were adopted for the WaterCAST catchment model as derived from ACTFR event water quality monitoring data.

After a review of the draft outputs from the catchment modelling it was decided that the northern catchments of the Black Basin should be treated differently to the drier southern catchments of the Ross Basin due to the difference in rainfall regime, vegetation and run-off and erosion characteristics. The Paluma Ranges of northern catchments more closely resemble the conditions found in the wet tropics than in the drier Hervey Range of the Ross Basin.

Table 7.21 Relative Pollutant Contribution by Land Use

Landuse	Run-off coefficient	Export rate (kg/ha/yr)			Adopted EMC (mg/L)		
		TSS	TP	TN	TSS	TP	TN
Formal parks	0.32	42.4	0.21	1.29	9	0.05	0.33
Rural residential	0.35	55.9	0.18	1.74	11	0.04	0.43
Traditional residential	0.40	823.0	1.31	3.01	152	0.26	0.64
High density residential	0.44	954.0	1.49	3.29	152	0.26	0.64
Commercial/light industrial	0.51	984.0	1.17	3.75	143	0.19	0.62
Heavy industrial	0.66	1330.0	1.57	4.75	143	0.19	0.62
Bare ground	0.33	4340.0	1.29	7.60	1000	0.32	1.95
Natural areas	0.32	43.3	0.21	1.24	9	0.05	0.33
Forestry	0.32	37.8	0.19	1.30	9	0.05	0.33
Grazing	0.32	1180.0	0.62	3.09	260	0.15	0.80
Intensive agriculture	0.32	1390.0	1.30	7.11	300	0.32	1.95
Mining	0.35	692.0	0.83	2.52	143	0.19	0.62

Source: BMT WBM Internal memo 13 November 2008. Note: Bare ground is the default landuse applied to developing areas.

Data from the Black Ross event monitoring was combined with event monitoring data from the Tully catchment to provide a set of 'dry' and 'wet' catchment EMC values (event mean concentrations) for grazing and green space. The EMCs for the other main land use categories delineated during the event monitoring were also recalculated and nitrogen and phosphorus species were separated. The amended EMC values are shown in Table 7.22.

Table 7.22 Recalculated EMC Values

Landuse	TSS	NH_4	NO_x	PN	DON	TN	FRP	PP	DOP	TP
	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Dry savanna grazing	130	15	105	175	240	535	29	70	11	110
Green space (dry)	25	8	50	125	200	383	25	20	6	51
Wet Tropics grazing	25	18	500	90	160	268	7	14	6	27
Green space (wet)	4	8	50	45	90	193	3	8	4	15
Urban/peri-urban										
Rural residential	35	10	149	114	228	501	26	20	10	56
Established urban	20	29	127	221	364	741	152	69	60	281
Light industrial	57	17	102	313	394	826	195	123	129	447
Urban industrial	129	7	94	210	313	624	104	111	15	230
Developing urban[1]	793	38	122	190	397	747	130	128	19	277
Developing urban[2]	11,142									

Source: Unpublished data (Stephen Lewis (ACTFR) 2009). Notes: [1] is coastal plains and [2] is hillslopes. Highest values are highlighted with the exception of Developing urban[2] which is an anomalous value and not considered to be a 'typical' average figure.

7.5.4 Overall contributions

Relative land use contribution figures were used in catchment and water quality modelling to obtain end of catchment loads. The end of catchment loads were then used as the base figures to calculate contributions from atmospheric deposition and were combined with discharge data from wastewater treatment plants to calculate contributions from point sources. The overall relative contribution of pollutants from all sources to end of catchment loads for the Black Ross WQIP area are displayed in Table 7.23.

Table 7.23 Relative Pollutant Contributions

Sub Basin Pollutant Source	TSS	TN	TP
	kg/year	kg/year	kg/year
Crystal Creek-atmospheric deposition	2,144	536	54
Crystal Creek- atmospheric deposition %	0.04	0.59	0.58
Crystal Creek-terrestrial run off	5,511,305	89,586	9,329
Crystal Creek- terrestrial run off %	99.96	99.41	99.42
Crystal Creek-diffuse total	5,513,449	90,122	9,383
Rollingstone Creek- atmospheric deposition	880	220	22
Rollingstone Creek- atmospheric deposition %	0.05	0.54	0.55
Rollingstone Creek-terrestrial run off	1,602,166	40,228	3,999
Rollingstone Creek- terrestrial run off %	99.95	99.46	99.45
Rollingstone Creek-diffuse total	1,603,046	40,448	4,021
Bluewater Creek- atmospheric deposition	3,408	852	85
Bluewater Creek- atmospheric deposition %	0.12	0.92	1.83
Bluewater Creek-terrestrial run off	2,803,538	91,848	4,556
Bluewater Creek- terrestrial run off %	99.88	99.08	98.17
Bluewater Creek-diffuse total	2,806,946	92,700	4,641
Black River- atmospheric deposition	4,104	1,026	103
Black River- atmospheric deposition %	0.06	1.45	0.93
Black River-terrestrial run off	7,191,321	68,152	9,919
Black River- terrestrial run off %	99.94	96.48	89.61
Black River-diffuse total	7,195,425	69,178	10,022
Black River-wastewater treatment plant		1,460	1,047
Black River- wastewater treatment plant %		2.07	9.46
Black River-diffuse and point sources	7,195,425	70,638	11,069
Black Basin atmospheric deposition **total**	10,536	2,634	264
Black Basin atmospheric deposition **%**	0.06	0.90	0.91
Black Basin terrestrial run off total	17,108,330	289,814	27,803
Black Basin terrestrial run off %	99.94	98.61	95.50
Black Basin diffuse total	17,118,866	292,448	28,067
Black Basin wastewater treatment plant **total**		1,460	1,047
Black Basin wastewater treatment plant **%**		0.50	3.60
Black Basin diffuse and point sources	17,118,866	293,908	29,114
Bohle River- atmospheric deposition	7,980	2,128	213
Bohle River- atmospheric deposition %	0.09	1.11	0.71
Bohle River-terrestrial run off	9,287,633	76,200	13,933
Bohle River- terrestrial run off %	99.91	39.73	46.75
Bohle River-diffuse total	9,295,613	78,328	14,146
Bohle River- wastewater treatment plant		113,478	15,659
Bohle River- wastewater treatment plant %		59.16	52.54
Bohle River-diffuse and point sources		191,806	29,805
Lower Ross River- atmospheric deposition	11,310	3,016	302
Lower Ross River- atmospheric deposition %	0.27	9.11	4.33
Lower Ross River-terrestrial run off	4,194,544	30,104	6,679
Lower Ross River- terrestrial run off %	99.73	90.89	95.67
Lower Ross River-diffuse total	4,205,854	33,120	6,981

Upper Ross River- atmospheric deposition	34,976	8,744	874
Upper Ross River- atmospheric deposition %	0.43	8.71	6.84
Upper Ross River-terrestrial run off	8,073,574	91,700	11,910
Upper Ross River- terrestrial run off %	99.57	91.29	93.16
Upper Ross River-diffuse total	8,108,550	100,444	12,784
Stuart Creek- atmospheric deposition	15,704	4,188	419
Stuart Creek- atmospheric deposition %	0.95	6.83	2.09
Stuart Creek-terrestrial run off	1,635,226	14,768	2,540
Stuart Creek- terrestrial run off %	99.05	24.08	12.67
Stuart Creek- wastewater treatment plant		42,376	17,082
Stuart Creek- wastewater treatment plant %		69.09	85.24
Stuart Creek-diffuse total		18,956	2,959
Stuart Creek-diffuse and point sources	1,650,930	61,332	20,041
Alligator Creek- atmospheric deposition	14,384	3,596	360
Alligator Creek- atmospheric deposition %	0.68	8.42	7.48
Alligator Creek-terrestrial run off	2,090,552	39,120	4,451
Alligator Creek- terrestrial run off %	99.32	91.58	92.52
Alligator Creek-diffuse total	2,104,936	42,716	4,811
Ross Basin atmospheric deposition **total**	84,354	21,672	2,168
Ross Basin atmospheric deposition **%**	0.33	5.05	2.91
Ross Basin terrestrial run off total	25,281,529	251,892	39,513
Ross Basin terrestrial run off %	99.67	58.66	53.09
Ross Basin diffuse total		273,565	41,680
Ross Basin wastewater treatment plant **total**		155,854	32,741
Ross Basin wastewater treatment plant **%**		36.29	43.99
Ross Basin diffuse and point sources total	25,365,882	429,419	74,421
Magnetic Island-diffuse total	342,217	6,286	944
Black Ross atmospheric deposition **total**	94,890	24,306	2,432
Black Ross atmospheric deposition **%**	0.22	3.33	2.33
Black Ross terrestrial run off **total**	42,389,859	541,706	67,316
Black Ross terrestrial run off **%**	98.98	74.25	64.43
Black Ross diffuse **total**		572,299	70,690
Black Ross wastewater treatment plant **total**		157,314	33,788
Black Ross wastewater treatment plant **%**		21.56	32.34
Black Ross Diffuse and Point Sources Total	42,826,965	729,613	104,478

Note: Based on an annual average discharge of 1,205,923 ML. Diffuse total is the sum of terrestrial run off and atmospheric deposition. WWTP is the contribution from wastewater treatment plants and is applicable to the Black River, Bohle River and Stuart Creek sub basins only.

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