GREAT BARRIER REEF
MARINE PARK AUTHORITY

Great Barrier Reef Catchment Water Quality Action Plan

A Report to Ministerial Council on targets for pollutant loads

November 2001

Maria Creek, Kurrimine - 2 February, 1994.

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Executive Summary

Decades of scientific research and evaluation have clearly and unequivocally established that land use activities in the catchments adjacent to the Great Barrier Reef are directly contributing to a decline in water quality. A range of pollutants are measurable in river outflows and these are degrading the inshore ecosystems of the Reef. Similar patterns of pollutant-related decline have lead to the collapse of coral reef systems in other parts of the world.

Increases in pollutants discharged to the Reef since c1850 are as follows -

- Sediment loads - up between 300 and 900%
- Phosphorus - up between 300 and 1,500%
- Nitrogen - up between 200 and 400%
- Pesticide residues - now detectable in coastal sediments

Even more worrying is the fact that almost all pollutant loads are increasing annually and showing no sign of abatement. Of particular concern is the rapid increase in fertilizer delivered inorganic nitrogen (nitrate and ammonia) that is the most dangerous to marine ecosystems and herbicide residues that damage seagrass (and potentially coral) communities.

The pollutant contributions of individual Great Barrier Reef catchments (26 in all) vary significantly. This is due to the size of the catchment, the volume of runoff from these catchments, and the nature of the land use producing the pollutant. Virtually all of the developed Great Barrier Reef catchments show serious concentrations of water borne pollutants. These pollutants have been demonstrated to seriously impact on the health and reproductive capacity of the corals, seagrass and fauna of inshore reefal areas.

In response to the directive of the 8 June 2001 Great Barrier Reef Ministerial Council, a scientific working group was established to review the available data on pollutant runoff and existing national water quality guidelines, to prioritise catchments according to the ecological risk present to the Reef, and to recommend the minimum targets for pollutant loads that would halt the decline in water quality entering the Reef.

This is the first phase in a staged approach which aims to stop the decline of water quality and eventually allowing for the recovery of inshore reefal ecosystems.

Data and guidelines included in the scientific review were drawn from -

- National Land and Water Resources Audit
- Australian Institute of Marine Science (river monitoring studies and long term monitoring studies)
- Co-operative Research Centre for the Great Barrier Reef
- Great Barrier Reef Marine Park Authority (chlorophyll monitoring studies and pesticide residue studies)

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- Australia and New Zealand Environment and Conservation Council (pesticide, sediment and water quality guidelines)

The working group has defined 10-year targets (2011) for the entire Great Barrier Reef catchment (individual catchment targets are detailed in the text). These targets are:

- Sediment – a 38 % reduction from 11,700,000 tonnes per year to 7,300,000 tonnes per year
- Nitrogen – a 39% reduction from 39,300 tonnes per year to 24,000 tonnes per year
- Phosphorus – a 47% reduction from 7,400 tonnes per year to 3,900 tonnes per year
- Chlorophyll – a 30 to 60% reduction below present levels in coastal waters.
- Heavy metals and pesticides –reductions in detectable levels.

The targets are presented in a way that allows for the natural variability in runoff to the Great Barrier Reef, and permits meaningful comparison between years.

This Action Plan suggests specific actions that need to be taken to improve the quality of water entering the Great Barrier Reef World Heritage Area.

The Queensland government has day-to-day responsibility for natural resource management in the catchments adjacent to the Great Barrier Reef. Commonwealth involvement is focussed at the strategic level, through initiatives such as the National Action Plan for Salinity and Water Quality (NAP) and the Natural Heritage Trust.

The water quality targets set out in this report should be specifically incorporated into relevant plans under the NAP (in the Burdekin, Fitzroy and Burnett River Catchments). For the catchments not covered by the NAP, the Queensland Government should prepare, and submit to the Great Barrier Reef Ministerial Council, integrated catchment management plans that set out the actions required to meet the water quality targets.

In this way, the water quality targets for the Great Barrier Reef will be delivered within a framework that ensures strategic Commonwealth input but with the responsibility for on-ground implementation devolved to the appropriate level.

It is important to ensure consultation with stakeholders in the implementation of these water quality targets. However, the degree of consultation needs to be balanced against the urgent need for substantive action.

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PART 1: Great Barrier Reef Water Quality Action Plan

1. Introduction

Internationally, many coral reef systems are under threat from human activity. The International Coral Reef Initiative (1999) reported that over 50% of the world's coral reefs are in decline. While the magnitude of threats varies between countries, there are common concerns including over-fishing, uncontrolled coastal development, pollution and global climate change.

In 1975, the Great Barrier Reef Marine Park was proclaimed under the *Great Barrier Reef Marine Park Act 1975*. The Great Barrier Reef Marine Park Authority (the Authority) is a Commonwealth Government statutory authority. The agency is responsible for the management of the Great Barrier Reef Marine Park. The Authority operates in partnership with other Commonwealth and Queensland Government agencies to ensure that the Great Barrier Reef is preserved and protected for future generations. The Great Barrier Reef Ministerial Council was established in 1979 to coordinate policy between the Commonwealth and Queensland Governments. The Great Barrier Reef was recognised for its outstanding universal value and listed as a World Heritage Area in 1981. This placed obligations on Australia to ensure the protection, conservation and presentation of this unique World Heritage Area.

The Great Barrier Reef Marine Park (Figure 1) is managed as a multi-use reserve, with a direct annual economic value associated with marine tourism, commercial fishing and recreational use of over $1 billion. In 1999, more than 1.1 million people visited the inshore regions of the Great Barrier Reef with commercial operators (Environmental Management Charge data). Private recreational usage is significantly higher. The flow-on effect of these industries, which rely intrinsically on the continued health of the Reef system for long-term economic sustainability, underpins a significant and growing proportion of Queensland's regional economy. Declining water quality directly threatens the health of inshore regions of the Reef.

With the increased use of coastal and catchment areas adjacent to the Reef and the growing awareness of the impact of land-based pollution on the Reef, there is a real need for coordinated land and sea management. On 8 June 2001, the Great Barrier Reef Ministerial Council for the noted that activities in the catchments adjacent to the Great Barrier Reef were affecting the quality of water flowing to the Great Barrier Reef World Heritage Area. The Commonwealth Minister for Environment and Heritage directed the Great Barrier Reef Marine Park Authority to develop a Great Barrier Reef Water Quality Action Plan. The objectives of the Plan include:

1. identify the major catchment-based threats to water quality in the Great Barrier Reef World Heritage Area;
2. identify priority catchments and sub catchments in terms of potential risks to the world heritage values of the Great Barrier Reef;
3. recommend specific targets (including pollution loads and concentrations) for outflow water quality in individual rivers and for reef water quality consistent with the National Standards for Coastal Water Quality Protection;
4. suggest specific actions which need to be taken to improve the quality of water entering the Great Barrier Reef World Heritage Area and, in particular, actions which need to be taken to meet the targets referred to in objective 3;

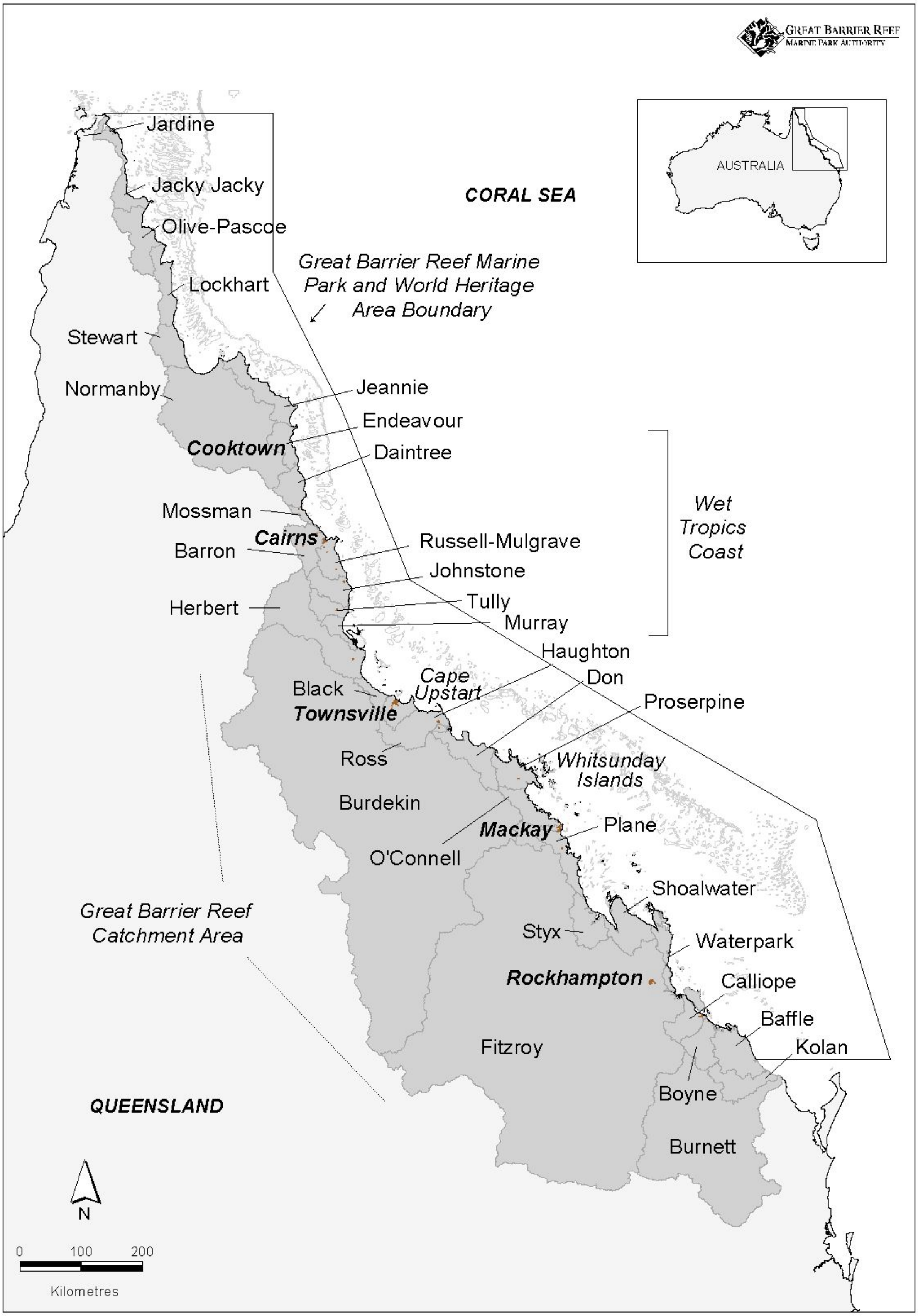

Figure 1. Catchments draining into the Great Barrier Reef World Heritage Area

5. suggest for the actions identified in objective 4, a timetable for implementation; and
6. detail arrangements for:
   - monitoring, including independent monitoring, of water quality;
   - reporting the results of that monitoring, including results which address the specific water quality targets referred to in objective 3; and
   - reporting of all information to the community.

The catchments considered in the Action Plan are shown in Figure 1.

2. Catchment-Based Threats to the Great Barrier Reef

The Great Barrier Reef World Heritage Area (the Reef) contains the largest system of coral reefs in the world. This diverse ecosystem contains more than just coral reefs, it also includes extensive seagrass beds, mangrove forests, sponge and soft coral gardens, soft bottom habitats and island communities. Of the 2,900 individual reefs in the Reef ecosystem, 989 are fringing and/or inshore reefs. It is these inshore reefs[1] that are at greatest risk from catchment run-off. While coral reef systems can grow in a variety of conditions in shallow water tropical habitats, well-developed reef systems (such as the outer Great Barrier Reef) only occur where the waters are typically characterised by low suspended particulate and dissolved nutrient concentrations.

The ecosystem of the Great Barrier Reef has a complex inter-dependent relationship with adjacent river catchments. Many marine species rely on coastal freshwater wetlands and estuaries as breeding and nursery areas. Recreationally important fish species such as barramundi and mangrove jack are obvious examples.

The catchments adjacent to the Great Barrier Reef World Heritage Area are relatively sparsely populated, containing less than 1,000,000 of the State's 2.9 million residents.

Despite the low population, there has been extensive land modification with a focus on developing land and infrastructure for agricultural production, tourism and mining. More than 80% of the Great Barrier Reef catchment supports some form of agricultural activity.

Agricultural activities that have resulted in increased erosion, the destruction of wetlands and stream bank vegetation, and run-off of sediment, fertiliser and chemical residues are the primary human impact on water quality in the Reef. The majority of the discharge of sediment and nutrient occurs during floods. Elevated sediment and nutrient concentrations have long been regarded as the most significant water quality threats to the inshore Reef. Based on the best scientific evidence, there has been a 4 to 9-fold increase in quantities of sediment entering the inshore lagoon of the Reef from the Great Barrier Reef catchment over the last 150 years. There has also been a 3 to 15-fold increase in phosphorus and 2 to 4 - fold increase in total nitrogen inputs. Inorganic nitrogen inputs to the catchments in fertiliser have increased significantly. This form of nitrogen has the most direct effect on marine ecosystems, as it is completely bioavailable[2]. Most of the increase in fertiliser nitrogen application has occurred in the last 40 years as a consequence of expansion of intensive

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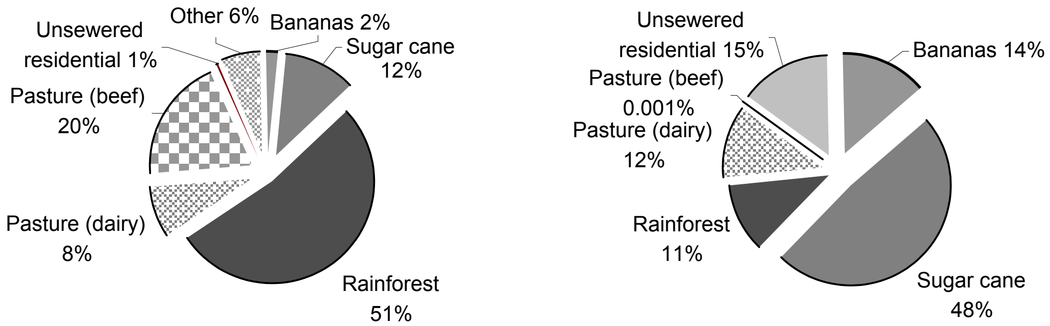
[1] Inshore reef habitats include fringing and near shore coral reefs, seagrass beds and other benthic communities inshore of the 20 metre depth contour.

[2] Bioavailable applies to the availability of the nutrient as a food source for organisms

agriculture. Secondary industry, urban run-off, aquaculture and sewage have also contributed to the pollution loadings of the Reef, but to a much lesser extent (Figure 2).

Figure 2. Example of a comparison of land uses and inorganic nitrogen sources, Johnstone River catchment. Source: Hunter and Walton (1997).



a. Landuse in the Johnstone River catchment (excluding sewered residential).

b. Nitrate nitrogen contributions to total catchment load (excluding sewered residential).

Considerable expansion of agricultural activity has occurred in the Great Barrier Reef catchments since 1990. Between 1990 and 1999, the area harvested for sugarcane grew by 26% in the Northern mill region, 65% in the Herbert-Burdekin region, 22% in the Mackay region and 6% in the Bundaberg region (Australian Sugar Year Book, 2001). Overall growth in land use for sugar cultivation in Queensland was 30%, from 323,000 ha to 424,000 ha. Rapid growth has also occurred in banana cultivation. Almost all of this expansion has been in the Tully and Johnstone River catchments. From 1990 to 1998, the area cultivated for bananas expanded by 126%, with around 60% of this increase in the Johnstone River catchment and 40% in the Tully - Murray River catchments. Between 1990 and 1999, the combined usage of nitrogenous-fertilisers for both sugarcane and banana production is estimated to have increased by 55% in the Johnstone River catchment and by 118% in the Tully – Murray River catchments.

Effects of elevated nutrient inputs to Reef waters range from reduced growth and reproduction in marine organisms through to shifts in the community structure and functioning of coral reef and seagrass ecosystems. The focus on water-borne pollutants has recently broadened to acknowledge the potential threat posed by pesticides and heavy metals (diuron, dioxins, dieldrin, mercury and cadmium), which have been detected in sediments and marine life along the Great Barrier Reef and southern Queensland coastline. In general, these pollutants originate in catchments dominated by intensive cropping agriculture, and in the wet tropics region of the Queensland coast, the inputs are exacerbated by high erosion and runoff rates.

Disturbance of acid sulfate soils in the course of drainage programs and coastal development also poses a significant potential risk to local estuarine environments from lowered pH, which in turn enhances heavy metal mobilization. Acid leachate can also contribute to low oxygen conditions and fish kills.

If the current trend in pollution loadings continues unabated, then the health of some inshore areas of the Great Barrier Reef World Heritage Area will to continue to decline.

3. Specific Targets

A scientific working group consisting of experienced scientists working on water quality issues in the Great Barrier Reef was established to develop end-of-catchment targets that will, in the first instance, slow the decline in the quality of freshwater runoff entering the inshore sections of the Reef. These targets are to be the first phase in a staged approach to reverse declining water quality and eventually foster the recovery of inshore reef ecosystems.

The terms of reference for the group included:

1. Identifying the threats to water quality from individual catchments and prioritising catchments on a risk profile basis;
2. Determining the minimum reductions in pollution loads required from each catchment to abate the current trend in declining water quality; and
3. Develop a monitoring program that will enable the effective auditing of the targets.

In setting the targets the working group considered:

1. Estimated pre-development (-ca1850) discharge loads of sediment, nitrogen and phosphorus from each catchment;
2. Estimates of current discharge loads of sediment, nitrogen and phosphorus from each catchment;
3. Queensland's draft ecosystem protection guidelines for the Wet Tropics and East Coast Regions;
4. Proximity of rivers to sensitive ecosystems in the inshore receiving zone;
5. Physical properties and runoff dynamics of individual catchments;
6. Volume and frequency of river discharge from individual catchments;
7. Land use, including land clearing in the catchments;
8. Fertiliser and pesticide use in the catchments;
9. Dissolved inorganic nitrogen loads;
10. Proportion of inorganic nitrogen in the total nitrogen load; and
11. Erosion rates.

The principal sources of primary data used to develop the targets were:

1. Catchment discharge and sediment export models prepared for the National Land and Water Resources Audit (NLWRA).
2. The Australian Institute of Marine Science (AIMS)/ Cooperative Research Centre for the Great Barrier Reef World Heritage Area (Reef CRC) catchment discharge data and modelling.

3. The Great Barrier Reef Marine Park Authority's chlorophyll monitoring program data and the AIMS chlorophyll research data.
4. The Australian and New Zealand Environment and Conservation Council's sediment pesticide guidelines and the Authority's sediment pesticide residue data.
5. Queensland Draft Water Quality Guidelines for ecosystem protection for wet tropic and east coast regions.

The water quality targets that have been set include:

1. Targets for suspended sediment, total nitrogen and total phosphorus discharge from 26 individual catchments for which reasonable estimates of exports could be calculated (Table 2). These 26 catchments comprise 93% of the area of the entire Great Barrier Reef catchment, and 80% of the discharge volume. The catchment areas not considered in this analysis are largely located on Cape York Peninsula and are characterised by minimal land degradation.
2. Target concentrations for a range of toxic trace metals and pesticide residues in benthic sediments of the Reef (Table 3).
3. Chlorophyll concentration targets for nine inshore areas of the Great Barrier Reef World Heritage Area (Table 4).

The methodology for setting the targets is detailed in Part 2 of the Action Plan. The targets are an effective mechanism to measure progress towards achieving the water quality objectives, and assisting with accountability and reporting on water quality.

4. Prioritising Catchments

In developing a risk profile for the status of the inshore regions of the Reef, the main river catchments were placed into four risk categories (very high, medium high, medium, low). The mechanism for this ranking process is explained in further detail in Part 2, Section 2 of this report.

The methodology for deriving the estimates of sediment export is included in Appendix 2. Risk rankings for each catchment are based on the relative increase in sediment export from 1850 to the present. The risk rankings for nitrogen and phosphorus are based on two factors; the relative increase in nitrogen or phosphorus export from 1850 to current, and the nitrogen or phosphorus fertiliser application rate in the catchment. These risk factors were scored and the sum of the scores was used to determine an overall ranking for each catchment. Some additional variables were considered in particular catchments, such as known increases in agricultural activity since the data was produced. These variables are detailed in Part 2, Section 2.2 and 2.3.

Chlorophyll targets were set for two regions; north of Cape Upstart (northern region) and south of Cape Upstart (southern region). The mean of measured concentrations in the northern region (Great Barrier Reef Marine Park Authority data, 0.27 mg m^{-3}, refer to Figure 3) is considered to be representative of the pristine condition for most of the inshore Great Barrier Reef. The targets have been set at values about 30% above probable pristine conditions in the northern and southern regions. Contaminant targets are primarily derived from the Australian and New Zealand guidelines for freshwater and marine water quality (ANZECC, 2000) and data collected by the Authority.

The catchment details in Table 1 highlight the risk to the inshore Reef from the river discharge in the Wet Tropics, and catchments with significant areas of land clearing and cultivation. A more detailed assessment of catchment risk is currently being undertaken (Brodie *et al*. in prep). Minor river systems and small watercourses that flow directly to the coast have not been included in the priority listing. However these smaller river systems often drain sections of the floodplain with significant agricultural disturbance and can have very high nutrient and sediment loadings that directly influence adjacent reef and seagrass communities. Further assessment and monitoring of these smaller river systems is required to allow appropriate runoff reduction targets to be developed. These rivers and creeks are noted in Table 1.

Table 1. Great Barrier Reef catchment risk assessment.

High Risk	Medium/High Risk	Medium Risk	Low Risk	Small High Risk Watercourses[3]
Barron	Russell-Mulgrave	Endeavour	Jacky-Jacky	Mowbray R
Johnstone	Tully	Daintree	Olive	Trinity Inlet
Herbert	Murray	Mossman	Pascoe	Moresby R
Proserpine	Haughton	Black	Stewart	Liverpool Ck
O'Connell	Burdekin	Ross	Annan	Maria Ck
Pioneer	Don	Styx	Normanby	Hull R
Plane	Fitzroy	Boyne	Bloomfield	Kennedy Ck
	Calliope		Shoalwater	Cattle Ck
	Baffle		Waterpark	Barrattas Ck
	Kolan			Molongle Ck
	Burnett			Elliot R
				Euri Ck
				Gregory R
				St Helen's Ck
				Ilbilbie Ck
				Carmila Ck
				Auckland Ck

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[3] These are small water courses that have a high priority in terms of the risk to water quality of the Reef but have not been included in the primary prioritisation of river catchments. These systems represent approximately 7% of the total pollutant loading and are significant on a local level.

Table 2. Suspended sediment, total nitrogen and total phosphorus discharge from 26 individual catchments and proposed targets.

Catchment Name	Sediment				Nitrogen				Phosphorus			
	[1]1850 export (t/y)	[1]Current export (t/y)	2011 Target (t/y)	2011 Target (t/km^3)	[2]1850 export (t/y)	[2]Current export (t/y)	2011 Target (t/y)	2011 Target (t/km^3)	[2]1850 export (t/y)	[2]Current export (t/y)	2011 Target (t/y)	2011 Target (t/km^3)
Normanby River	540,000	1,620,279	1,620,279	327,273	1,206	1,960	1,960	396	60	208	208	42
Endeavour River	97,000	486,871	486,871	267,582	245	721	483	265	12	76	51	28
Daintree River	23,000	94,132	94,132	74,603	169	499	334	265	8	53	36	28
Mossman River	3,000	15,131	15,131	25,424	79	234	117	198	4	25	17	28
Barron River	18,000	145,877	97,738	120,765	109	321	215	265	5	34	23	28
Mulgrave-Russell River	37,000	222,425	149,025	40,863	489	1,441	721	198	24	153	103	28
Johnstone River	10,000	305,142	152,571	32,655	628	1,849	925	198	31	196	98	21
Tully River	15,000	88,084	59,016	17,921	442	1,303	652	198	22	138	92	28
Murray River	3,000	17,098	11,456	10,745	142	420	210	198	7	45	30	28
Herbert River	83,000	664,787	445,407	111,109	539	1,588	794	198	26	168	113	28
Black River	28,000	82,887	82,887	218,421	93	411	275	725	5	90	60	159
Ross River	29,000	58,383	58,383	118,367	119	530	355	725	6	116	78	159
Haughton River	17,000	172,454	115,544	155,729	180	801	401	541	9	175	88	119
Burdekin River	163,000	2,443,232	1,221,616	118,708	2,508	11,134	7,460	725	126	2,438	1,219	119
Don River	46,000	509,528	341,384	455,600	183	812	544	725	9	178	89	119
Proserpine River	7,000	227,314	113,657	105,092	263	1,169	585	541	13	256	128	119
O'Connell River	8,000	366,309	183,155	118,831	375	1,666	833	541	19	365	183	119
Pioneer River	10,000	288,343	144,172	121,008	160	471	236	198	8	50	25	21
Plane Creek	2,000	114,860	57,430	38,591	363	1,612	806	541	18	353	177	119
Styx River	4,000	136,011	68,006	**	145	642	430	**	7	140	**	**
Fitzroy River	126,000	2,635,482	1,317,741	216,694	1,482	6,579	4,408	725	74	1,440	720	119
Calliope River	2,000	60,772	30,386	101,667	73	325	218	725	4	71	47	159
Boyne River	2,000	16,974	11,373	39,276	71	314	210	725	4	69	46	159
Baffle Creek	3,000	103,376	51,688	66,026	190	844	565	725	10	185	123	159
Kolan River	2,000	61,589	30,795	75,610	100	444	297	725	5	97	49	119
Burnett River	8,000	728,607	364,304	316,957	280	1,244	833	725	14	272	136	119
Total	1,286,000	11,665,944	7,324,147		10,633	39,334	24,437		530	7,391	3,939	

Note: ** insufficient data to calculate estimates

Source: [1] National Land and Water Resources Audit; [2] Australian Institute of Marine Science.

Table 3. Inshore marine water and sediment toxicant target concentrations.

Compound	Organic carbon (%)	Log K_{ow}	Log K_{oc}	Water toxicity trigger Concentrations (µg L^{-1})	Sediment toxicity trigger concentrations (µg L^{-1} dry wt)	Sediment toxicity trigger concentrations (µg kg^{-1} dry wt)	Reference
Organics							
Atrazine	1	2.5	2.4	10	25	50	Ralph (2000)
Diuron	1	2.8	2.6	0.1	0.4	0.8	Haynes *et al.* (2000b)
Chlorpyrifos	1	4.96	4.57	0.0005	0.2	0.4	ANZECC (2000)
Glyphosate	1		3	1000	10000	20000	Ralph (2000)
Endosulfan	1		3.5	0.005	0.2	0.3	ANZECC (2000)
2,4-D	1	2.81	1.3	100	20	40	Glynn *et al.* (1984)
ΣDDT	1		5.4	0.0012	2	3	ANZECC (2000)
Dieldrin	1		4.5	0.000063	0.02	0.04	ANZECC (2000)
Lindane	1		3.11	0.025	0.3	0.5	ANZECC (2000)
Metal				**Water toxicity trigger Concentrations (µg L^{-1})**		**Sediment toxicity trigger concentrations (mg kg^{-1} dry wt)**	
Arsenic						20	ANZECC (2000)
Mercury						0.2	ANZECC (2000)
Cadmium				0.7		2	ANZECC (2000)
Chromium						80	ANZECC (2000)
Copper				0.3		65	ANZECC (2000)
Lead				2		50	ANZECC (2000)
Nickel				7		21	ANZECC (2000)
Zinc				7		200	ANZECC (2000)

Table 4. Chlorophyll a targets.

Area	Targets for inshore waters (<20km) mg m^{-3}
Shelburne Bay	0.4
Princess Charlotte Bay	0.4
Cooktown	0.4
Cairns	0.4
Innisfail	0.4
Townsville	0.4
Whitsunday Islands	0.6
Broadsound	0.6
Capricorn Coast	0.6

4. Management Responses

The Great Barrier Reef Ministerial Council agreed that this Action Plan will suggest specific actions which need to be taken to improve the quality of water entering the Reef and, in particular, which need to be taken to meet the targets identified in this document.

This Action Plan recognises that the Queensland Government has 'day to-day' responsibility for natural resource management in the catchments adjacent to the Reef.

The Commonwealth is also involved in helping to meet the natural resource management challenges now faced by landholders and other stakeholders. However, the Commonwealth's involvement is focussed at a strategic level with initiatives such as the National Action Plan for Salinity and Water Quality (NAP) and the Natural Heritage Trust. In this way, the Commonwealth provides national leadership within a framework that respects the primary role of the Queensland Government in the delivery of sustainable natural resource management.

The National Action Plan for Salinity and Water Quality (NAP) provides an appropriate mechanism within which the Commonwealth and Queensland Governments should deliver on the water quality targets for the relevant Great Barrier Reef catchments i.e. the Burdekin River, Fitzroy River and the Burnett River. The NAP has established a devolved model for government investment, whereby funds are provided for the implementation of accredited integrated regional plans. To achieve accreditation, these plans need to incorporate targets for salinity, water quality, and in-stream and terrestrial biodiversity, consistent with the National Framework for NRM Standards and Targets due to be finalised in December 2001. In addition to the water quality targets, regional water quality needs, including wetlands, human and industry uses; the costs and feasibility of the required management actions; and the requirements of downstream water users and environments will need to be considered.

It is recommended that the targets set out in this report should be specifically incorporated into the relevant plans under the NAP.

For the Great Barrier Reef catchments not covered by NAP, it is recommended that the Queensland Government prepare integrated catchment management plans that specifically recognise the targets in this report and set out actions required to meet these targets.

The catchment plans should be submitted to the Great Barrier Reef Ministerial Council for consideration.

The water quality targets for these catchments will in this way be achieved in a similar manner to the NAP catchments; that is with Commonwealth input at a strategic level but with on-ground responsibility for the implementation devolved to the appropriate level. In this respect, it is noted that the Natural Heritage Trust (NHT) should be able to provide some funding through regional plans accredited by the Commonwealth.

It is important to ensure consultation with stakeholders in the development of the regional plans. However, the degree of consultation needs to be balanced against the urgent need for the implementation of plans and the requirement for substantive action to be taken as soon as possible to reverse the decline in water quality.

In order to meet the defined water quality targets, the relevant plans (both NAP and catchment plans) will need to include or be accompanied by an appropriate mix of regulatory and non-regulatory measures. Some reform of Queensland legislation or the manner in which it is administered may be necessary.

Examples of the actions that could be implemented to achieve the water quality targets include:

- Reforms to ensure that in the catchments adjacent to the Reef, all environmentally significant activities (including significant new agricultural activities or the significant intensification of existing activities) are subject to proper environmental impact assessment and approval processes. Environmental assessments should address potential impacts on water quality. Appropriate conditions should be attached to ensure that agricultural activities are carried out in a manner that protects and, as necessary, improves current water quality.
- Constraint mapping for current and future agricultural development in the Great Barrier Reef catchment should be promoted;
- Catchment habitats and features at risk such as, freshwater wetlands and riparian vegetation should be protected and rehabilitated;
- Standards for sewage, wastewater and stormwater discharge from coastal developments to watercourses should be established and enforced;
- Environmental management plans should be promoted for agricultural activities. These plans should promote farming practices that minimise downstream impacts, such as:
    1. minimising erosion through conservation cropping techniques and pasture management;
    2. minimising nutrient loss by aligning fertiliser amount, type and application methodology to the physiological requirements of the crop; and
    3. implementing integrated pest management techniques.
- Promote full compliance to Industry Codes of Practice; and
- Initiate public and catchment specific education program about the connectivity between land use and the impacts on the Reef.

Education and extension have an important role to play in parallel with specific management tools to address water quality decline. Raising the awareness of stakeholders about the sources and impacts of pollution represents an ongoing challenge. The over riding impediment to the uptake of this information is the fact that the impacts and the causes are frequently remote from each other, creating difficulties for recognition and responsibility. While significant progress has been made by some sectors of the community in recognising and addressing water quality problems, this effort must now be accelerated. The voluntary approaches (e.g. industry code of practice) that presently guide many activities that influence water quality have not been sufficiently adopted by agricultural industries to bring about fundamental change. Individual land and water management plans, industry codes of practice, integrated catchment management plans and numerous studies have identified the individual mechanisms required to reduce pollutant inputs to the water ways. These mechanisms must be implemented on the ground in order to effect improvements in land management practices.

5. Monitoring programs

An effective water quality monitoring program to reliably measure progress towards achieving the water quality targets determined in this Action Plan should have the following six components:

River flux monitoring

River discharge load or 'flux' monitoring should be conducted at a lower-catchment site for the following rivers: Normanby, Barron, Russell-Mulgrave, Johnstone, Tully, Herbert, Proserpine, Pioneer, Burdekin, Fitzroy and Burnett. The intent is to determine the total annual discharge of pollutant materials from the catchment. The parameters measured should include; suspended sediment, total nitrogen, total phosphorus, nitrate, nitrite, ammonia, phosphate, particulate nitrogen, particulate phosphorus and water volume. Sampling should be flow weighted, i.e. intensive sampling in times of high flow and low intensity sampling in times of low flow conditions.

Suspended sediment monitoring using turbidity loggers and water volume (gauging) is required for the following rivers: Daintree, Haughton, O'Connell, Plane and Mossman Rivers.

Chlorophyll monitoring

The Authority currently conducts a long-term chlorophyll monitoring program in coastal and reef waters throughout the Great Barrier Reef. The objective is to determine whether chlorophyll concentrations (as a proxy for nutrient availability) are increasing in reef waters. Approximately sixty sites are sampled monthly from a selection of ninety sites located throughout the length of the Reef and across the shelf.

Pesticide residue monitoring

Intertidal and subtidal coastal and inshore reefal sediments should be surveyed for concentrations of priority pesticide residues every three years. This should be done on an annual rotational basis in each of the northern, central and southern sections of the Great Barrier Reef. This would repeat the surveys conducted by Haynes *et al*. (2000) in 1998.

Point source discharge monitoring

All outfalls into the Great Barrier Reef World Heritage Area (direct and indirect) should continue to be monitored for principal pollutant loads in the discharge stream. These outfalls should include sewage, industry and aquaculture farm discharges.

Seagrass monitoring

A comprehensive monitoring program of seagrasses in the Reef should be developed. This program should allow for estimation of seagrass area and health.

Inshore reef monitoring

A monitoring program aimed at providing an estimation of the status of the inshore reef ecosystem with respect to water quality impacts is required.

6. Reporting

Reporting of progress against the Action Plan must consider the actions required to improve water quality and achieve the actual water quality targets. Even with the immediate adoption of methods that will reduce pollution loadings to the river systems, it is anticipated that there will be a lag before water quality parameters begin to improve.

The Authority will report to the Commonwealth Parliament through:

the Great Barrier Reef Marine Park Authority Annual Report;

the Marine Park Authority;

the Great Barrier Reef Ministerial Council; and

the State of the Great Barrier Reef World Heritage Area Report.

The Authority will undertake to develop performance indicators to measure the progress of the Action Plan in association with the progress made by Queensland.

The Authority will also report on Great Barrier Reef catchment based information sourced from existing reporting programs. This information will include:

- Resources allocated for land management practices in the Great Barrier Reef catchment e.g., specific monitoring or rehabilitation programs and Natural Heritage Trust funded projects;
- Riparian vegetation – extent and condition;
- Land clearance – (Statewide Landcover and Trees Study and Queensland Herbarium data - Environmental Protection Agency);
- Wetlands – extent and condition;
- Point source discharges – quality and quantity of effluent discharges;
- Chemical use including fertiliser and pesticides; and
- Land use – including urban development, agricultural cropping and grazing.

Communication of water quality information and the outcomes of the Action Plan to stakeholders and the community will be a critical component of the reporting process.

PART 2: Setting End-of-Catchment Discharge Targets

1. Modelled and Measured Estimates of Sediment and Nutrient Discharges to the Great Barrier Reef

A variety of evidence indicates that agricultural and urban land-use in the Great Barrier Reef catchment has led to increased nutrient and sediment run-off. A number of models for estimating sediment, nitrogen (N) and phosphorus (P) discharge to the Great Barrier Reef (GBR) have been developed over the last 20 years. The sophistication and reliability of the models and data supporting them has increased through time.

Sediment inputs to the GBR have been calculated from the estimated accumulation of sediment in the coastal zone (Belperio, 1983) or weighted discharge-export relationships derived from a small number of rivers (Neil and Yu, 1995; 1996). Working from this type of data, simple models of run-off, land-use, and sediment delivery suggest that riverine sediment (and associated nutrient) fluxes to the Reef have increased several-fold since the commencement of European agricultural practices (Moss *et al*. 1992; Rayment and Neil, 1997; Wasson, 1997). More recent modelling has refined these estimates (NLWRA, 2001), and empirical data from river sampling has confirmed the estimates (Furnas and Mitchell, 2001; Furnas *et al*. 2001).

Whilst the models do give varying estimates of 1850 loads, it can be stated with some certainty that loads have increased substantially since 1850. For sediment, the estimated increase is between 3 and 8 times, for N between 2 and 4 times, and for P between 3 and 15 times. Generally pre-1850 export estimates cannot yet be fully verified on the basis of river monitoring, as there are few 'pristine' rivers which could be used as proxies for 1850 conditions.

2. Target Setting Methods

This section outlines the methodology used to develop the end-of-catchment targets. As noted in Part 1, the data was primarily sourced from the National Land and Water Resources Audit (NLWRA), the Australian Institute of Marine Science (AIMS) and the Great Barrier Reef Marine Park Authority (the Authority).

The targets for each parameter are presented both in tonnes per year (long-term average) and tonnes per cubic kilometre of annual discharge of water from the river. The latter unit allows for meaningful comparison within and between specific catchments over different years. Discharge rates from individual rivers vary considerably between years, which make tonnage per year an unsuitable unit to assess the status of river pollutant loads against water quality targets. However, an aggregate targets for the total GBR catchment cannot be expressed on a volume basis (tonnes per cubic kilometre) due to variations between catchments, hence the long term aggregate target is expressed as tonnes per year. The total mean annual discharge from the 26 catchments is 53 cubic kilometres.

A data confidence index for nutrient and sediment exports is discussed in Box 3, and is shown for each catchment in Part 3 of this report.

2.1 Sediment

Spatial modelling is the most effective way to assess the patterns of sediment and nutrient transport from large complex areas such as catchments. There are natural differences in suspended sediment load across diverse environments. To assess the extent to which the current sediment loads reflect the natural state of the catchments, or accelerated erosion, requires a robust estimation of natural sediment loads. There is uncertainty in this process as apart from some short-term data sets (Appendix 1), there is limited information about sediment losses from catchments under entirely natural conditions. For this reason, the NLWRA modelled estimates for sediment export in 1850 and estimates for current sediment export were used (summarised in Box 1, detailed in Appendix 2).

Box 1: National Land and Water Resources Audit sediment export modelling methodology

Propagators and receivers of sediment include hillslope erosion, gully erosion, and river links. Algorithms used to model these were developed concurrently with the National Land and Water Resources Audit. Algorithms were adjusted to account for the Australian tropical environment based on climatic, topographic, and geological factors. As data for the catchments is limited and there is a requirement for long-term assessment of the patterns of sediment and nutrient transport across catchments, remotely sensed imagery together with rule-based predictive modelling and/or empirical decision tree model were used. This provides a cheaper and less time consuming alternative to expensive ground collection. Sources of data include twenty years (1980-1999) of daily rainfall data mapped across Australia and 13 years (1981-1994) of satellite vegetation data, the 9" digital elevation model (DEM), and aerial photograph interpretation. Predictor environmental variables were also sampled; these included climatic parameters such as mean annual rainfall, various soil attributes, geology, land use, terrain attributes derived from the 9" DEM, and remote sensing data of MSS bands. Other data included values for mean annual flow, which were derived from available gauging records and a simple empirical rule based upon rainfall and catchment area (used to predict values in ungauged river links).

Calculation of suspended sediment and bedload through river networks was achieved by using the SedNet model. Supply of sediment from riverbanks was modified in the project to account for the condition of riparian vegetation. It was assumed that the bank erosion rate was negligible on rivers with intact native riparian vegetation. The presence and absence of native riparian vegetation was determined from the Australian Land Cover Change.

Due to the variation in catchment size and discharge volume, sediment delivery to the coast varies considerably. There are strong spatial patterns in sediment delivery to the coast because some tributaries are confined in narrow valleys with little opportunity for deposition, while others may have extensive open floodplains.

Stream orders were used to calculate deposition in the network, working from the top of the basin to the sea. Calculation of the mean annual suspended sediment export to the sea was achieved with an algorithm calculating the suspended load and predicting its loss through deposition along every link from the top of the basin to the sea. This calculation takes a probabilistic approach to sediment delivery through each river link encountered on the route from source to sea.

For further details on this modeling for Australian rivers, see Prosser et al. (2001).

Each catchment was assigned to a risk group based on the estimated magnitude of the increase in sediment load between 1850 and the present. The ranking groups were:

low = 1 to 5-fold; medium = 5 to 12-fold; high = > 12-fold

Sediment export *reduction factors* to be achieved by 2011 for each group were set as:

low = 1 (no change); medium = 0.67 (33% reduction); and high = 0.5 (50% reduction)

Using these *reduction factors*, sediment export targets for 2011 (ie. 10 years) were calculated by multiplying the current sediment load by the *reduction factor*. The numerical data for each catchment/river is presented in Table 5.

For the entire GBR Catchment (summing the 26 individual catchments) the 2011 target for sediment export is approximately 7,300,000 tonnes per year or 138,000 tonnes per km^3 of discharge, a 38% reduction from the current 11,700,000 tonnes per year or 220,000 tonnes per km^3.

2.2 Nitrogen

A considerable body of information regarding nitrogen concentrations in both developed and undeveloped catchment areas has been collected over the last 15 years by the Australian Institute of Marine Science (AIMS database; Appendix 1). The AIMS database was therefore used to model current and 1850 nitrogen loads for nitrogen target development. NLWRA estimates of nutrient export data are extrapolated from sediment export, with no allowance for increased dissolved nitrogen loading associated with catchment fertiliser use. Given this, the AIMS modelled exports are deemed to be more suitable for nutrient target setting than the NLWRA modelling at this stage. The techniques used for nutrient monitoring are outlined in Box 2.

To determine catchment nitrogen targets, the following risk analysis was utilised. The first risk factor was determined from individual catchment-based increases in N export from 1850 to present. The current export was divided by the 1850 export to give an 1850/current ratio. This ratio was then ranked into categories of low, medium and high (Table 6, N Risk Group 1). The ranking groups were:

low = <2-fold; medium = 2 to 4-fold; high => 4-fold

A second risk factor was based on 1990 application rates of nitrogen-based fertilisers (taken from Pulsford, 1996). The nitrogen in fertiliser is highly soluble and a significant fraction of the nitrogen is leached from the soils as dissolved inorganic nitrogen (DIN), chiefly nitrate. DIN is completely bioavailable. Other forms of nitrogen such as dissolved organic nitrogen (DON) and particulate nitrogen (PN) may also be bioavailable, but over longer time frames (Harris, 2001). Thus DIN potentially presents a higher short-term risk to ecosystem function than DON or PN. Nitrogenous-fertiliser application rates are listed in Table 6 for the major river catchments draining to the GBR.

The risk ranking scale was set so that the middle level included a moderately high level of fertiliser use, such as recorded for the Barron, Proserpine and Herbert catchments. On this basis, 0-7 kg N/ha is defined as low risk (L), 7-14 kg N/ha as medium risk (M) and >14 kg N/ha as high risk (H). Risk rankings for river catchments based on N-fertiliser application rates are listed in Table 6 (N Risk Group 2).

Significant data regarding the proportion of Total N (TN) exported as DIN from a small number of catchments is presented in Appendix 1. From this data it is evident that DIN concentrations in river discharge are correlated with nitrogen fertiliser use in the catchment area. This arises due to fertiliser being applied in highly soluble forms (such as urea, ammonia and ammonium nitrate) and losses to waterways are immediately present as DIN. Available data is shown in Table 6, DIN as a percent of TN exports.

A combined risk ranking was then determined by allocating scores to N Risk Groups 1 and 2, where low was scored as 1, medium scored as 2 and high scored as 3, and adding the two scores.

The sum of the scores for the risk ratings gives the Overall N Risk Group based on:

low = 2; medium = 3-4; high = 5-6

Nitrogen export *reduction factors* to be achieved by 2011 for each catchment were set as:

low = 1 (no change); medium = 0.67 (33% reduction); and high = 0.5 (50% reduction)

Using these *reduction factors*, nitrogen export targets for 2011 (ie. over 10 years) were calculated by multiplying the current nitrogen export flux by the *reduction factor*. The numerical data for each catchment/river is presented in Table 6.

To substantiate these rankings, there is data indicating that considerable expansion of cultivated agriculture has occurred in Queensland river catchments since 1990. From 1990 to 1999 (latest data available - Australian Sugar Year Book, 2001), the area harvested for sugarcane increased by 26% in the Northern mill region, 65% in the Herbert-Burdekin area, 22% in the Mackay region and 6% in the Bundaberg region. This recent, continued expansion of the sugar industry in the Herbert River catchment appears sufficient to justify an upgrade of this catchment from moderate to high risk. Rapid growth has also occurred in areas used for banana cultivation, though almost all of this expansion has occurred in just two river catchments. From 1990 to 1998, the area used for banana cultivation has expanded by 126%, with around 60% of this area located in the Johnstone River catchment and 40% in the Tully River catchment. From 1990 to 1999, the combined usage of nitrogenous-fertiliser for both sugarcane and bananas is estimated to have increased by 55% in the Johnstone River catchment and 118% in the Tully - Murray River catchments. This recent growth supports the assignment of both the Tully and Murray River catchments to the high risk category. Continued rapid growth of the Burdekin River Irrigation Area also supports the high risk rating given to the Haughton River catchment, the main area of expansion in the Burdekin delta region. Continued expansion of sugar acreage in the Mackay region, while somewhat less, is the basis for the ranking of the O'Connell, Pioneer and Plane River catchments.

For the entire GBR catchment (summing the 26 individual catchments), the 2011 target for aggregate nitrogen export is approximately 24,000 tonnes per year or 450 tonnes per km^3 of discharge, a 39% reduction from the current 39,300 tonnes per year or 742 tonnes per km^3.

2.3 Phosphorus

To set catchment targets for phosphorus export reduction, the following risk analysis was utilised. The first risk factor was determined from individual catchment increases in P export between 1850 and the present. The current export flux was divided by the estimated 1850 export to give an 1850/current ratio. This ratio was then ranked into categories of low, medium and high (Table 7, P Risk Group 1). The ranking groups were:

low = < 4-fold; medium = 4 to 10-fold; high => 10-fold

A second risk factor was based on 1990 application rates of phosphorus-based fertilisers in individual catchments (from Pulsford, 1996), where 0-1 kg P/ha is defined as low risk (L), 1-5 kg P/ha as medium risk (M) and >5 kg P/ha as high risk (H). The Burdekin, Fitzroy and Burnett are all large catchments with the greater part dominated by rangeland grazing but with flood plains containing fertilised cropping, sugar in the case of the Burdekin and Burnett, and cotton and grains in the Fitzroy. For this reason, classifications of these catchments have been adjusted to take into account this intensive fertiliser use by upgrading P Risk Group 2 by one category. Risk rankings for river catchments based on P-fertiliser application rates are listed in Table 7 (P Risk Group 2).

A combined risk ranking was then determined by allocating scores to P Risk Group 1 and P Risk Group 2, where low was scored as 1, medium scored as 2 and high scored as 3, and adding the two scores. The sum of the scores for the risk ratings gives the Overall P Risk Group based on:

low = 2; medium = 3-4; high = 5-6

Phosphorus export *reduction factors* to be achieved by 2011 for each catchment were set as:

low = 1 (no change); medium = 0.67 (33% reduction); and high = 0.5 (50% reduction)

Using these *reduction factors*, phosphorus export targets for 2011 (ie. over 10 years) were calculated by multiplying the current phosphorus export flux by the *reduction factor*. The numerical data for each catchment/river is presented in Table 7.

For the entire GBR Catchment (summing the 26 individual catchments) the 2011 target for aggregate phosphorus export is approximately 3,900 tonnes per year or 74 tonnes per km^3 of discharge, a 47% reduction from the current 7,400 tonnes per year or 139 tonnes per km^3.

Table 5. Sediment export risk analysis.

Catchment Name	[1]1850 sediment export (t/y)	[1]1850 sediment export (t/km³)	[1]Current sediment export (t/y)	[1]Current sediment export (t/km³)	Current divided by 1850	Sediment risk group	Overall Sediment target reduction factor	2011 Target Sediment export (t/y)	2011 Target Sediment export (t/km³)
Normanby River	540,000	109,091	1,620,279	327,273	3	L	1	1,620,279	327,273
Endeavour River	97,000	53,297	486,871	267,582	5	L	1	486,871	267,582
Daintree River	23,000	18,254	94,132	74,603	4.1	L	1	94,132	74,603
Mossman River	3,000	5,085	15,131	25,424	5	L	1	15,131	25,424
Barron River	18,000	22,222	145,877	180,247	8.1	M	0.67	97,738	120,765
Mulgrave-Russell R.	37,000	10,165	222,425	60,989	6	M	0.67	149,025	40,863
Johnstone River	10,000	2,141	305,142	65,310	30.5	H	0.5	152,571	32,655
Tully River	15,000	4,559	88,084	26,748	5.9	M	0.67	59,016	17,921
Murray River	3,000	2,830	17,098	16,038	5.7	M	0.67	11,456	10,745
Herbert River	83,000	20,698	664,787	165,835	8	M	0.67	445,407	111,109
Black River	28,000	73,684	82,887	218,421	3	L	1	82,887	218,421
Ross River	29,000	59,184	58,383	118,367	2	L	1	58,383	118,367
Haughton River	17,000	22,973	172,454	232,432	10.1	M	0.67	115,544	155,729
Burdekin River	163,000	15,841	2,443,232	237,415	15	H	0.5	1,221,616	118,708
Don River	46,000	61,333	509,528	680,000	11.1	M	0.67	341,384	455,600
Proserpine River	7,000	6,481	227,314	210,185	32.5	H	0.5	113,657	105,092
O'Connell River	8,000	5,195	366,309	237,662	45.8	H	0.5	183,155	118,831
Pioneer River	10,000	8,403	288,343	242,017	28.8	H	0.5	144,172	121,008
Plane Creek	2,000	1,342	114,860	77,181	57.4	H	0.5	57,430	38,591
Styx River	4,000	**	136,011	**	34	H	0.5	68,006	**
Fitzroy River	126,000	20,724	2,635,482	433,388	20.9	H	0.5	1,317,741	216,694
Calliope River	2,000	6,667	60,772	203,333	30.4	H	0.5	30,386	101,667
Boyne River	2,000	6,897	16,974	58,621	8.5	M	0.67	11,373	39,276
Baffle Creek	3,000	3,846	103,376	132,051	34.5	H	0.5	51,688	66,026
Kolan River	2,000	4,878	61,589	151,220	30.8	H	0.5	30,795	75,610
Burnett River	8,000	6,957	728,607	633,913	91.1	H	0.5	364,304	316,957
Total	1,286,000		11,665,944					7,324,147	

Note: ** insufficient data to calculate estimates

Source: [1] National Land and Water Resources Audit

Table 6. Nitrogen export risk analysis.

Catchment Name	[1]1850 N export (t/y)	[1]1850 N export (t/km³)	[1]Current N export (t/y)	[1]Current N export (t/km³)	[1]Current divided by 1850	N Risk group 1	[2]N fertiliser use 1990 (t)	[2]N fertiliser rate 1990 (kg/ha)	%DIN of TN	N Risk group 2	Overall N risk group	Overall N Target reduction factor	2011 Target N export (t/y)	2011 Target N export (t/km³)
Normanby River	1,206	244	1,960	396	1.6	L	n.a.	n.a.	7%	L	L	1	1,960	396
Endeavour River	245	134	721	396	2.9	M	n.a.	n.a.		L	M	0.67	483	265
Daintree River	169	134	499	396	3	M	340	1.6		L	M	0.67	334	265
Mossman River	79	134	234	396	3	M	820	16.7		H	H	0.5	117	198
Barron River	109	134	321	396	2.9	M	1,680	7.7	24%	M	M	0.67	215	265
Mulgrave-Russell R.	489	134	1,441	396	2.9	M	4,720	23.4	44%	H	H	0.5	721	198
Johnstone River	628	134	1,849	396	2.9	M	7,300	31.3	41%	H	H	0.5	925	198
Tully River	442	134	1,303	396	2.9	M	2,660	15.8	51%	H	H	0.5	652	198
Murray River	142	134	420	396	3	M	1,290	11.3	37%	M	H	0.5	210	198
Herbert River	539	134	1,588	396	2.9	M	9,800	9.7	32%	M	H	0.5	794	198
Black River	93	244	411	1,082	4.4	H	5	<0.1		L	M	0.67	275	725
Ross River	119	244	530	1,082	4.5	H	21	0.1		L	M	0.67	355	725
Haughton River	180	244	801	1,082	4.5	H	8,805	24.1		H	H	0.5	401	541
Burdekin River	2,508	244	11,134	1,082	4.4	H	3,180	0.2	21%	L	M	0.67	7,460	725
Don River	183	244	812	1,082	4.4	H	1,445	3.7		L	M	0.67	544	725
Proserpine River	263	244	1,169	1,082	4.4	H	3,040	12.2		M	H	0.5	585	541
O'Connell River	375	244	1,666	1,082	4.4	H	4,390	18		H	H	0.5	833	541
Pioneer River	160	134	471	396	2.9	M	5,490	36.9		H	H	0.5	236	198
Plane Creek	363	244	1,612	1,082	4.4	H	7,685	28.8		H	H	0.5	806	541
Styx River	145	**	642	**	4.4	H	0	0		L	M	0.67	**	**
Fitzroy River	1,482	244	6,579	1,082	4.4	H	7,290	0.5	22%	L	M	0.67	4,408	725
Calliope River	73	244	325	1,082	4.5	H	62	0.3		L	M	0.67	218	725
Boyne River	71	244	314	1,082	4.4	H	7	<0.1		L	M	0.67	210	725
Baffle Creek	190	244	844	1,082	4.4	H	405	1.1		L	M	0.67	565	725
Kolan River	100	244	444	1,082	4.4	H	1,690	5.7		L	M	0.67	297	725
Burnett River	280	244	1,244	1,082	4.4	H	4,545	1.4		L	M	0.67	833	725
Total	10,633		39,334				76,670						24,437	

Note: ** insufficient data to calculate estimates; n.a. - data is not available for fertiliser use, it is assumed to be low for these catchments.

Source: [1] Australian Institute of Marine Science; [2] Pulsford (1996).

Table 7. Phosphorus export risk analysis.

Catchment Name	[1]1850 P export (t/y)	[1]1850 P export (t/km³)	[1]Current P export (t/y)	[1]Current P export (t/km³)	[1]Current divided by 1850	P Risk group 1	[2]P fertiliser use 1990 (t)	[2]P fertiliser rate 1990 (kg/ha)	P Risk group 2	Overall P risk group	Overall P Target Reduction factor	2011 Target P Export (t/y)	2011 Target P export (t/km³)
Normanby River	60	12	208	42	3.5	L	n.a.	n.a.	L	L	1	208	42
Endeavour River	12	7	76	42	6.3	M	n.a.	n.a.	L	M	0.67	51	28
Daintree River	8	7	53	42	6.6	M	100	0.47	L	M	0.67	36	28
Mossman River	4	7	25	42	6.3	M	240	4.9	M	M	0.67	17	28
Barron River	5	7	34	42	6.8	M	625	2.87	M	M	0.67	23	28
Mulgrave-Russell R.	24	7	153	42	6.4	M	605	3	M	M	0.67	103	28
Johnstone River	31	7	196	42	6.3	M	1,700	7.3	H	H	0.5	98	21
Tully River	22	7	138	42	6.3	M	530	3.15	M	M	0.67	92	28
Murray River	7	7	45	42	6.4	M	220	1.93	M	M	0.67	30	28
Herbert River	26	7	168	42	6.5	M	1,330	1.31	M	M	0.67	113	28
Black River	5	12	90	237	18	H	0	0	L	M	0.67	60	159
Ross River	6	12	116	237	19.3	H	0	0	L	M	0.67	78	159
Haughton River	9	12	175	237	19.4	H	613	1.68	M	H	0.5	88	119
Burdekin River	126	12	2,438	237	19.3	H	256	0.02	M	H	0.5	1,219	119
Don River	9	12	178	237	19.8	H	380	1.00	M	H	0.5	89	119
Proserpine River	13	12	256	237	19.7	H	459	1.85	M	H	0.5	128	119
O'Connell River	19	12	365	237	19.2	H	539	2.21	M	H	0.5	183	119
Pioneer River	8	7	50	42	6.3	M	648	4.35	H	H	0.5	25	21
Plane Creek	18	12	353	237	19.6	H	995	3.73	M	H	0.5	177	119
Styx River	7	**	140	**	20	H	3	<0.1	L	M	0.67	**	**
Fitzroy River	74	12	1,440	237	19.5	H	786	<0.1	M	H	0.5	720	119
Calliope River	4	12	71	237	17.8	H	20	<0.1	L	M	0.67	47	159
Boyne River	4	12	69	237	17.3	H	2	<0.1	L	M	0.67	46	159
Baffle Creek	10	12	185	237	18.5	H	105	0.27	L	M	0.67	123	159
Kolan River	5	12	97	237	19.4	H	360	1.21	M	H	0.5	49	119
Burnett River	14	12	272	237	19.4	H	1,160	0.35	M	H	0.5	136	119
Total	530		7,391				11,676					3,939	

Note: ** insufficient data to calculate estimates; n.a. - data is not available for fertiliser use, it is assumed to be low for these catchments.

Source: [1] Australian Institute of Marine Science; [2] Pulsford (1996)

Box 2: Australian Institute of Marine Science river water nutrient monitoring methodology

Contemporary river nutrient exports are estimated from high intensity, wet-season (October-April) sampling carried out in five river systems (Wet – South Johnstone, Tully, Herbert; Dry – Burdekin, Fitzroy) over periods ranging between two and 13 years. To resolve the high natural flow-related variability in nutrient concentrations in North Queensland rivers, sampling was carried out at least weekly, but to the extent possible, on a daily basis over periods when significant flow was occurring. Water sampling was sporadic during the summer dry season (May-September) when discharge from all rivers is low and nutrient concentrations relatively constant. In most cases, mid-stream surface water samples were collected at a downstream bridge crossing in the freshwater section of the river.

Fluxes of individual nutrient species were integrated over the course of each sampled wet season using daily river discharge data obtained from the Queensland Dept. of Natural Resources and Mines. Nutrient concentrations on days between successive samples were estimated by linear interpolation. Integrated nutrient exports over the course of sampled wet seasons for both wet- and dry-catchment rivers were correlated with total water discharge volumes over the same interval to calculate nutrient export coefficients (tonnes N or P per km^3 of discharge). Nutrient exports (tonnes per year) from rivers not sampled (Data Confidence Index 1 and 2) were estimated by classifying them as either wet or dry catchment rivers and multiplying the mean annual discharge for the 1968-94 period (km^3) by the nutrient run-off coefficient (tonnes per km^3). Pre-1850 concentrations of suspended sediment and nutrients in GBR catchment rivers were estimated using medians of nutrient and sediment concentrations measured in a small number of tributaries of regional rivers draining undisturbed or relatively undisturbed headwater sub-catchments and one river on Cape York Peninsula (Normanby). Median pre-1850 nutrient and sediment concentrations were selected for both wet and dry catchment rivers. These concentrations were multiplied by the mean annual discharge for each river to estimate a pre-clearing nutrient and sediment export flux.

Box 3: Sediment and nutrient data confidence indices

The data confidence index is an indicator of the amount and type of data available to derive estimates of nutrient and sediment delivery from catchments. The following indices have been used to score individual catchments:

1. Basic geographical characteristics of the catchment are available. Streamflow data is available, but is sometimes sporadic. No in-stream monitoring of nutrient or sediment concentrations has taken place. Estimates of exports are derived from extrapolation of discharge-export relationships derived for catchments with similar geographical, vegetational and hydrological characteristics.
2. Basic geographical characteristics of the catchment are available. Streamflow data is available. Limited in-stream sampling of nutrient and sediment concentrations has been carried out, but data are insufficient to calculate annual exports. Estimates of exports are derived from extrapolation of discharge-export relationships derived for catchments with similar geographical, vegetational and hydrological characteristics.
3. Basic geographical characteristics of the catchment are available. Streamflow data is available. Sampling programs have been undertaken to measure suspended sediment and/or nutrient concentrations over periods of two or more years. Wet season sampling has been sufficiently intense that exports of fine sediments and/or nutrients can be reliably calculated.

Export estimates from category 3 catchments have been used to estimate exports from category 1 and 2 catchments.

3. Nearshore Marine Water Quality: Chlorophyll *a* Concentration Targets

Concentrations of the photosynthetic pigment, chlorophyll *a,* are a measure of phytoplankton biomass and a useful integrative indicator of nutrient status in the water column. Chlorophyll *a* concentrations have been measured in GBR waters as part of research programs since the 1927/28 Royal Society expeditions to Low Isles. The most comprehensive data set is that collected by AIMS scientists over the last 25 years (Haynes *et al*. 2001). Data from various AIMS projects have been published in Ikeda *et al*. (1980); Revelante and Gilmartin, (1982); Sammarco and Crenshaw, (1984); Furnas *et al.* (1990); Liston *et al.* (1992); Furnas and Brodie, (1996); Brodie *et al.* (1997); and Furnas and Mitchell, (1997). The Authority has coordinated a water quality monitoring program based on chlorophyll monitoring since 1992. Monthly samples have been collected at up to 90 stations throughout the GBR. Information from this program has been published in a number of papers and reports (eg. Brodie and Furnas, 1994; Brodie *et al.* 1997; Haynes *et al*. 1998; Steven *et al.* 1998; Devlin *et al.* in prep). The methodology for the chlorophyll monitoring programs is outlined in Box 4.

In general, the mean chlorophyll concentration in most GBR waters is close to 0.35 mg m^{-3}. There are local exceptions due to shelf break upwelling and nutrient runoff from the land. Chlorophyll concentrations in flood plumes are often highly elevated, with peak concentrations ranging from 1 to 15 mg m^{-3} due to the high concentrations of bioavailable nutrients in river flood waters (Devlin *et al.* 2001). Chlorophyll concentrations in GBR waters are also very high after cyclonic wind resuspension events. Following the transit of Cyclone Winifred across the central GBR shelf and extensive resuspension of bottom sediments under the storm track (Gagan *et al.* 1987; 1990), chlorophyll concentrations between the range 3 - 7 mg m^{-3} were measured in the central GBR within three days (Furnas, 1989). Resuspension of shallow nearshore sediments by south-easterly trade winds may also lead to locally elevated chlorophyll concentrations. In Cleveland Bay (central GBR) wind resuspension episodically lifted chlorophyll concentrations from 0.25 to 0.55 mg m^{-3} (Walker, 1981). Strong tidal currents also enhance mixing and bottom resuspension. Inshore chlorophyll concentrations in the GBR between Mackay and Port Clinton, (the area of greatest tidal range and high turbidity in the GBR (Kleypas, 1996; van Woesik, 1989) normally range between 0.4 and 4 mg m^{-3}.

Inner shelf waters adjoining the central and southern GBR coast have elevated chlorophyll concentrations compared to coastal waters in the northern GBR (Devlin *et al.* in prep). The mean of all data collected in the chlorophyll monitoring program for the northern GBR over the 1993 – 2000 period for inshore waters (< 20 km from coast) is 0.27 mg m^{-3} while means for the central and southern inshore are 0.63 and 0.59 mg m^{-3} respectively (Devlin *et al.* in prep). Values from the regions sampled are shown in Figures 3 and 4. The elevated concentrations in the southern and central inshore GBR are most likely due to enhanced nutrient delivery from developed catchments and different coastal hydrodynamic regimes. The mean chlorophyll concentration of the northern inshore GBR (about 0.3 mg m^{-3}) most likely represents the pristine condition, which prevailed throughout most of the inshore GBR. The higher present concentrations in the central and southern GBR have resulted from anthropogenic nutrient input from the land. Given the above, chlorophyll targets have been set at 0.4 mg m^{-3} for inshore areas north of Cape Upstart (Figure 1) and at 0.6 mg m^{-3} south of Cape Upstart. These targets are about 30% above probable pristine conditions in these areas.

Figure 3. Average chlorophyll results, 1993 to 2000.

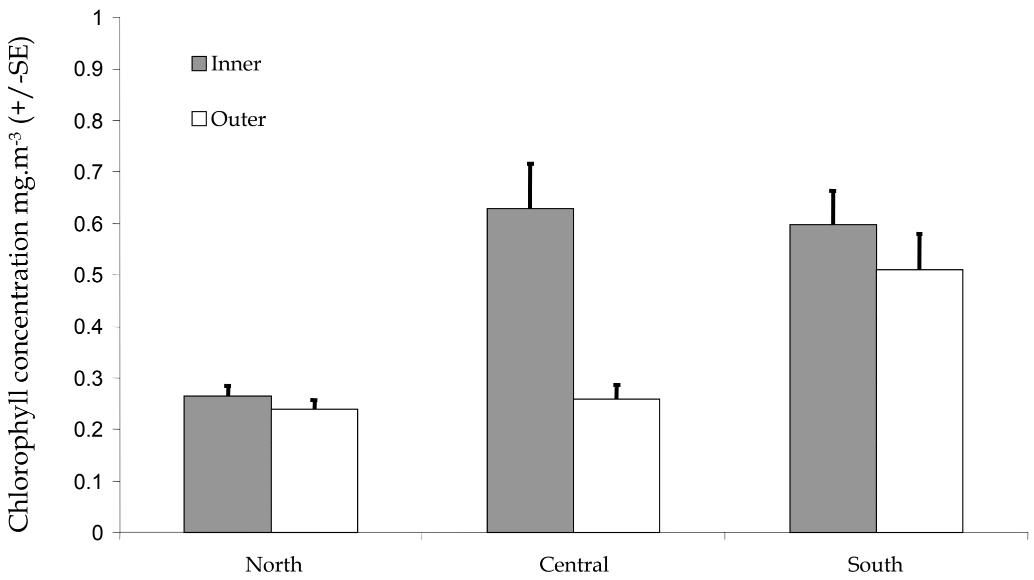
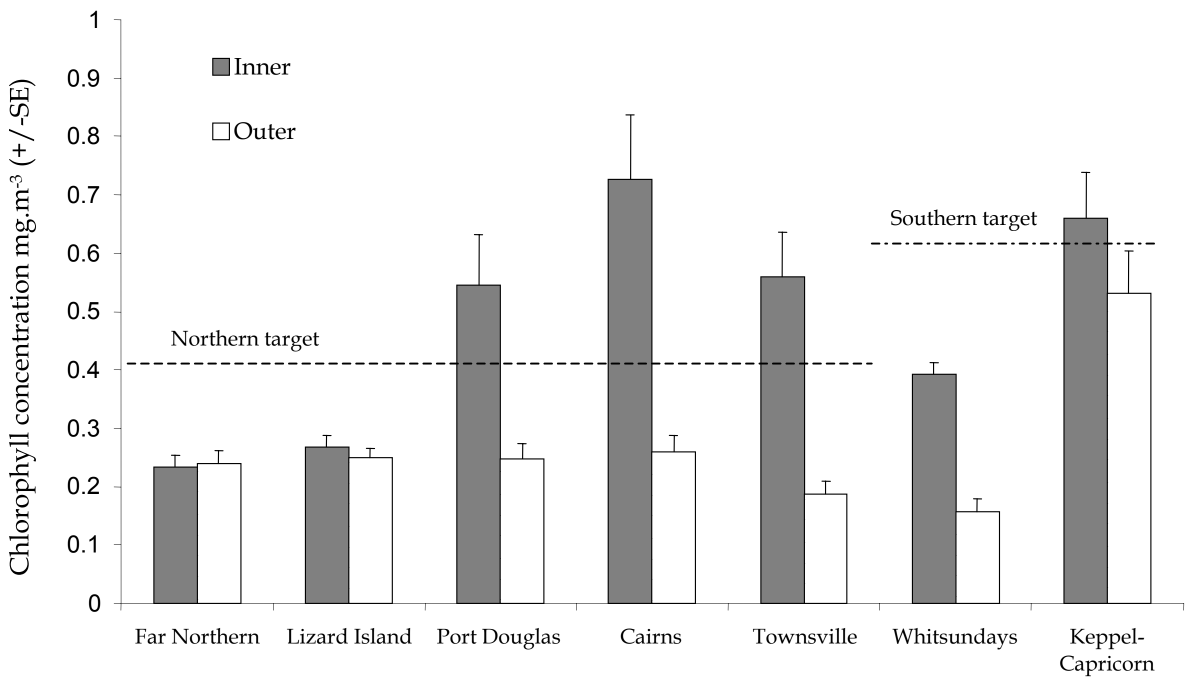


Figure 4. Average latitudinal chlorophyll results, 1993 to 2000.



Box 4: Regional Chlorophyll Statistics

Standing stocks of phytoplankton biomass in marine waters (including the GBR) are usually controlled by the quantity of nutrients (eg. N, P) available to the biota. Nutrients added to Great Barrier Reef waters through terrestrial run-off and other natural processes (upwelling, rainfall) are very rapidly taken up by phytoplankton and bacteria. Because of this demand, concentrations of nutrients in reef waters are typically very low, regardless of the level of inputs and are poor indicators of reef water nutrient status. The magnitude of the phytoplankton standing crop, as shown by the concentration of the photosynthetic pigment, chlorophyll, is a better integrative measure of the amount of nutrients held and cycling in the ecosystem.

Regional statistics for water column chlorophyll concentrations are derived from samples collected by the Australian Institute of Marine Science since the mid-1970's. Samples were collected and analysed by a relatively small number of individuals using a consistent set of methods throughout. The data set is maintained by the AIMS Biological Oceanography Group.

Water samples for the AIMS chlorophyll determinations were collected with Niskin bottles. The GBRMPA Long-Term Monitoring Program statistics are based on surface samples collected with a clean bucket. In both cases, duplicate aliquots of seawater were filtered at sea and the filters frozen (-10°C) for analysis ashore. Chlorophyll concentrations were determined at AIMS by fluorometric analysis of acetone-extracted pigments in particulate matter collected on Whatman GF/F glass fibre filters (Parsons *et al*. 1984). The filters collect particles nominally larger than 0.4 μm.

The AIMS summary statistics are calculated using depth-weighted, mean water column concentrations of chlorophyll at stations where chlorophyll samples were collected from two or more depths in the water column. Sampling stations influenced by oceanic upwelling, river plumes or the obvious presence of *Trichodesmium* were excluded.

The GBRMPA chlorophyll LTMP samples are averaged within regions. The chlorophyll concentrations therefore represent phytoplankton biomass related to the nutrients available under nominally unperturbed conditions in GBR waters.

The station data is divided into 9 latitudinal regions having nominally similar oceanographic conditions which are determined by the distribution and density of coral reefs. Within each latitudinal band, the stations are sorted by distance from the coastline. Water depths within 10 km of the coastline are generally < 20 m in depth. As a consequence, the nearshore water column is influenced by wind-forced resuspension of bottom sediments.

4. Contaminants in Subtidal Sediments

Some 26 major river catchments discharge directly into the Great Barrier Reef World Heritage Area (Moss *et al.* 1992) and the bulk of their terrigenous inputs are deposited within 10 km of the coast (Larcombe *et al.* 1996). This nearshore deposition zone containing mangroves, soft-bottom communities, seagrass and fringing reef environments is therefore most at risk from sediment-associated contaminants such as heavy metals, herbicides, pesticides and other organic compounds from anthropogenic activity in Queensland coastal catchments. These pollutants are often persistent and highly toxic. Some (eg. heavy metals) are essentially permanent additions to the environment (Clark, 1992). Pollutant concentrations in sediments usually exceed those of the overlying water column by three to five orders of magnitude (Bryan and Langston, 1992). Sediments are regarded as the ultimate sink for heavy metals discharged to the marine environment (Gibbs, 1973). Organochlorine compounds tend to rapidly bind to the fine organic matter in sediments or are bioaccumulated into lipids by living organisms (Miyamoto *et al.* 1990; Olsen *et al*. 1982). As a consequence, estuarine and nearshore terrigenous muds contain the highest concentrations of most contaminants derived from anthropogenic sources and are widely recognised as the most suitable medium for monitoring these materials in the environment. Further information on contaminants detected in GBR sediments is included in Box 5.

4.1 Sediment Contaminant Targets

Nearshore marine water column and sediment pollutant target values are presented in Table 3. The targets were derived using the following methods:

- All trace metal targets are those presented in the Australian and New Zealand guidelines for freshwater and marine water quality (ANZECC, 2000).
- Sediment target concentrations for total DDT, dieldrin and lindane are those presented as trigger values in the Australian and New Zealand guidelines for freshwater and marine water quality (ANZECC, 2000).
- Sediment target concentrations for chlorpyrifos and endosulfan were calculated based on the water concentration trigger values presented in the Australian and New Zealand guidelines for freshwater and marine water quality (ANZECC, 2000).
- Sediment target concentrations for atrazine, diuron, glyphosate and 2,4-D were calculated using water concentration toxicity data for seagrass and coral species (references cited in Table 3) using partitioning coefficients for the pollutant:

Sediment threshold=K_{ow}**Cw*(%organic fraction of the sediment).*

where K_{ow} is the partitioning coefficient between octanol and water; and C*w* is the water concentration.

4.2 Biota Sampling

The use of sediment pollutant concentration data does not fully describe potential biological risk resulting from sediment metal concentrations. This is necessary if an estimate of the toxicological and ecological significance of sediment pollutant levels to aquatic life is to be made (Anon, 1995; Long *et al.* 1995). Crabs were selected as indicator organisms for a Great Barrier Reef pollutant monitoring program as they are abundant and are relatively immobile compared with other organisms such as fish. A number of studies have shown that crabs are able to accumulate persistent organics and trace metal pollutants (Asanullah and Ying, 1993; Mortimer, 2000).

Standardised sampling is essential if temporal and spatial comparisons of the data are to be made. These include standardised sampling with respect to animal sex, length, weight, and sampled tissue (hepatopancreas). Sampling location and sampling time (i.e. pre or post monsoon season) should also be standardised over surveys.

Box 5: Contaminant Information

Organochlorines

Use of most organochlorine pesticides was banned in Queensland during the late 1980s. Compounds including lindane (γ-HCH), aldrin, heptachlor, chlordane, DDT and dieldrin were previously used extensively in Queensland agriculture for the control of insects and weeds (Hamdorf, 1992; von Westernhagen and Klumpp, 1995) in a wide range of domestic, public health and agricultural applications (Mortimer, 1998). As a consequence, these pollutants have been detected as contaminants of northern Australian estuarine sediments (Dyall and Johns, 1985; Mortimer, 1998) and marine biota (Kannan *et al.* 1995; McCloskey and Duebert, 1972; Moss and Mortimer, 1996; Olafson, 1978; von Westernhagen and Klumpp, 1995). Seafoods collected along the tropical north-eastern Australian seaboard for human consumption have been shown to be contaminated with low levels of PCBs, DDT and its metabolites, chlordane compounds and lindane isomers (Kannan *et al*. 1994). A range of pesticides has been detected in the nearshore environment along the Queensland coast (Haynes *et al.* 2000a). Organochlorine pesticides and polychlorinated biphenyls (PCBs) have been implicated in reproductive and immunological abnormalities in terrestrial bird and marine mammal populations (Boon *et al.* 1992). While the impact of organochlorines on lower invertebrates such as corals, is still unclear, their potential toxicity to immune systems and reproductive processes is of concern.

Heavy Metals

Heavy metal contaminants including arsenic, cadmium, copper, mercury, lead, nickel and zinc have been and continue to be released into the aquatic environment through urban stormwater and wastewater discharges and as a consequence of agricultural activity. Zinc and copper are used in small amounts as fertilisers in some soils. Arsenic, cadmium and mercury are constituents of some fungicides (Hunter, 1992). Arsenic, cadmium and zinc also occur as contaminants of the phosphatic fertilisers applied to Queensland soils (Rayment *et al.* 1989; Tesiram, 1995). Sugar cane fungal disease is controlled through the use of mercury-based compounds such as methylethoxymercuric chloride (MEMC) (Hamilton and Haydon 1996). Once dissolved, metals may be accumulated by marine invertebrates via passive uptake across permeable surfaces such as gills and the digestive tract (Rainbow, 1990). Cellular metal toxicity is primarily due to the chemical inactivation of cellular enzymes responsible for normal organism function (Forstner, 1989). Growth, reproduction and behaviour are potentially affected by elevated environmental metal concentrations (Langston, 1990).

Contemporary Pesticides and Herbicides

A number of triazine (atrazine), phenylurea and chlorophenoxy acid organochlorine herbicides (diuron and 2,4-D) and organophosphate pesticides (chlorpyrifos) are in wide use by the Queensland sugar cane industry (Hamilton and Haydon, 1996). Chronic herbicide run-off from agriculture has the potential to impact seagrasses and other photo-autotrophic reef organisms (Haynes *et al.* 2000b; Ralph, 2000; Vandermeulen *et al.* 1972). This includes shallow water reef-building corals that rely on symbiotic zooxanthellae for nutrition (Davies, 1991).

4.3 Future Sampling Strategies

Future sampling strategies rely on improved technology to establish reliable and less resource intensive monitoring programs. Progress has recently been made in innovative water quality sampling techniques with the introduction of semi-permeable membrane devices (SPMDs) and diffusive gradients in thin films (DGT) techniques for the analysis of water column lipophilic contaminants as well as heavy metals and nutrient species (Figure 5). SPMDs are devices that consist of a thin film of triolein sealed in a polyethylene tube (Prest *et al.* 1995). Lipophilic compounds permeate the membrane and partition into the lipid layer where they are concentrated and sequestered according to physico-chemical principals (Huckins *et al*. 1993). SPMDs have been shown to accurately reflect concentrations present in local bivalves (Prest *et al.* 1992; 1995; Rantalainen *et al.* 1998). Similarly, DGT techniques are based on a simple device that accumulates solutes on a binding agent after passage through a hydrogel, which acts as a well defined diffusion layer (Davison and Zhang, 1994; Zhang *et al.* 1998). The use of these techniques reduce some of the problems inherent in the analyses of water, sediment and biota samples for pollutants (Huckins *et al*. 1993; Prest *et al.* 1995; Zhang *et al*. 1998), and their use should be adopted as soon as practicable in the Great Barrier Reef Marine Park for routine monitoring of water column pollutants.

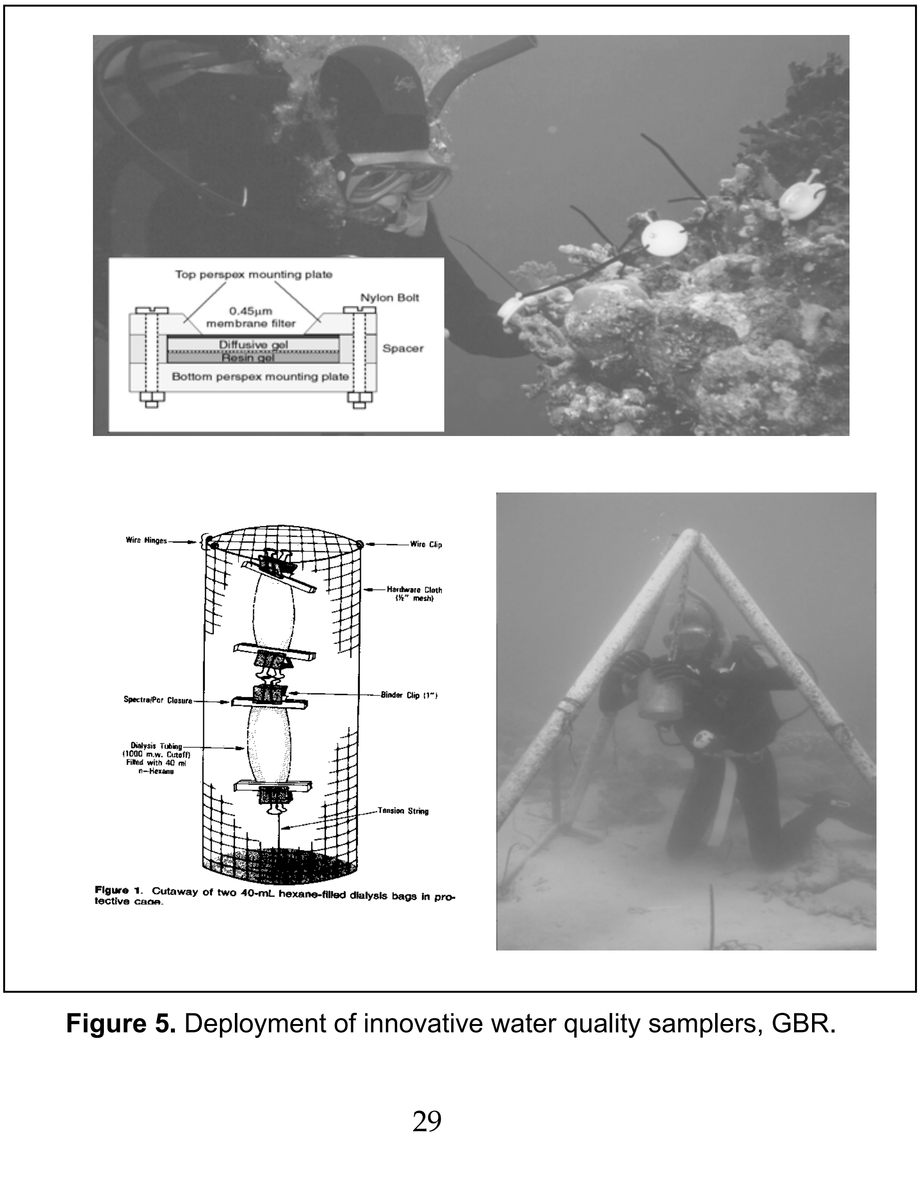


Figure 5. Deployment of innovative water quality samplers, GBR.

References

The compilation of references listed in this report are not necessarily cited in the scope of the document, but have been mentioned to provide a framework and information source for the current water quality targets and research on the Great Barrier Reef.

Abal, E. G. and Dennison, W. C. (1996). Seagrass depth range and water quality in southern Moreton Bay, Queensland, Australia. *Marine and Freshwater Research* 47, 763-771.

Agnihotri, N. P., Kulshrestha, G., Gajbhiye, V. T., Mohapatra, S. P., and Singh, S. B. (1996). Organochlorine insecticide residues in agricultural soils of the Indo-Gangetic plain. *Environmental Monitoring and Assessment* 40, 279-288.

AIMS (2001). Sediment and Nutrient Discharge Database.

Akinyemiju, O. A. (1991). Persistence of atrazine in a humid tropical soil in the early and late cropping season. *Turrilba* 41, 129-134.

Alcock, R. E., McLachlan, M. S., Johnston, A. E., and Jones, K. C. (1998). Evidence for the presence of PCDD/Fs in the environment prior to 1900 and further studies on their temporal trends. *Environmental Science and Technology* 32, 1580-1587.

Allemand, D., Tambutté., Girad, J., and Jaubert, J. (1998). Organic matrix synthesis in the scleractinian coral *Stylophora pistillata*: role in biomineralisation and potential target of the organotin tributyltin. *The Journal of Experimental Biology* 201, 2001-2009.

Alvarez Piñeiro, M. E., Simal Lozano, J., and Lage Yusty, M. A. (1995). Organochlorine compounds in mussels of the estuarine bays of Galicia (North-west Spain). *Marine Pollution Bulletin* 30, 484-487.

Alzieu, C. (1996). Biological effects of tributyltin on marine organisms. In *Tributyltin: case study of an environmental contaminant*, ed. S. J. de Mora. Cambridge University Press, Cambridge. pp. 167-211.

ANAO. (1997). *Commonwealth natural resources management and environment programs.* Australian National Audit Office, Canberra.

Anon. (1993). *The condition of river catchments in Queensland: a broad overview of catchment management issues.* Department of Primary Industries, Brisbane.

Anon. (1995). *Protocol for the derivation of Canadian sediment quality guidelines for the protection of aquatic life*. Environment Canada, Ottawa.

Anon. (1996). *Compendium of Queensland Statistics 1996*. Queensland Government.

Anon. (1997). *Marine oil pollution: its potential impact and control.* Queensland Transport, Brisbane.

Anon. (1999a). *Fish kills: A report on water quality related fish kills on the north Queensland coast between Sarina and Cardwell from August 1997 to December 1998*. Sunfish Queensland Inc., Bundall, Queensland.

Anon. (1999b). *State of the environment, Queensland 1999*. Queensland Environmental Protection Agency, Brisbane.

Anthony, K. (1999a). *Evidence for enhanced particle-feeding capacity in corals on nearshore reefs.* Unpublished report to the Great Barrier Reef Marine park Authority, Townsville.

Anthony, K. R. N. (1999b). Coral suspension feeding on fine particulate matter. *Journal of Experimental Marine Biology and Ecology* 232, 85-106.

ANZECC (2000*). Australian and New Zealand guidelines for fresh and marine water quality 2000, Vol 1. The guidelines*. Environment Australia.

Aplin, G., Mitchell, P., Cleugh, H., Pitman, A., and Rich, D. (1997). *Global environmental crisis, an Australian perspective.* Oxford University Press.

AQIS (1998). Australian ballast water program overview. www.Aqis.gov.au/docs/ballast/bprogram1.html

Asanullah, M. and Ying, W. (1993). Tidal rhythms and accumulation of cadmium from water and sediment by soldier crabs. *Marine Pollution Bulletin* 26, 29-33.

Australian Sugar Year Book, (2001). Brisbane: Strand Press, Volume 60.

Australian Water Resources Council (1987). *1985 review of Australia's water resources and water use.* Australian Government Printing Service, Canberra.

Ayling, A. M. and Ayling, A. L. (1998). *The effect of the Daintree River flood plume on Snapper Island coral reefs.* Great Barrier Reef Marine Park Authority Research Publication No. 3, Townsville.

Baldwin, C. L. (1988) (ed). *Nutrients in the Great Barrier Reef region*. GBRMPA Workshop Series No. 10. Great Barrier Reef Marine Park Authority, Townsville.

Baldwin, C. (1990). *Impacts of elevated nutrients in the Great Barrier Reef*. Great Barrier Reef Marine Park Authority Research Publication No. 20, Townsville.

Barson, M.L., Randall, L. and Bordas, V. (2000). *Landcover changes in Australia: Results of the collaborative Bureau of Rural Sciences - state agencies project on remote sensing of agricultural landcover change*. Bureau of Rural Sciences, Canberra.

Beck, C.A. and Barros, N.B. (1991). The impact of debris on the Florida Manatee. *Marine Pollution Bulletin* 22, 508–510.

Bell, P. R. F. (1991). Status of eutrophication in the Great Barrier Reef Lagoon. *Marine Pollution Bulletin* 23, 89-93.

Bell, P. R. F. and Elmetri, I. (1995). Ecological indicators of large-scale eutrophication in the Great Barrier Reef lagoon. *Ambio* 24, 208-215.

Bellamy, J. A., McDonald, G. T., Syme, G. J., and Walker, D. H. (1999). Planning and implementing integrated catchment management. In *Evaluation of integrated catchment management in a wet tropical environment,* ed. J. A. Bellamy. CSIRO, Brisbane. pp. 229-52.

Belperio, A. P. (1983). Terrigenous sedimentation in the central Great Barrier Reef lagoon: a model from the Burdekin region. *Journal of Australian Geology and Geophysics* 8, 179-190.

Bennell, N. (1979) Coastal land development - a shadow over the Great Barrier Reef. *Australian Parks and Recreation* Nov, 1979, 41-45.

Berkelmans, R. and Oliver, J. K. (1999). Large scale bleaching of corals on the Great Barrier Reef. *Coral Reefs* 18, 55-60.

Bohl, H. P., Mitchell, D. C., Penny, R. S., and Roth, C. H. (2000). Nitrogen losses via subsurface flow from sugar cane on floodplain soils in the Australian wet tropics. *Proceedings of the Australian Society of Sugar Cane Technologists* 22, 302-307.

Boon, J. P., van Arnhem, E., Jansen, S., Kannan, N., Petrick, G., Schulz, D., Duinker, J. C., Reijnders, P. J. H., and Goksoyr, A. (1992). The toxicokinetics of PCBs in marine mammals with special reference to possible interactions of individual congeners with the cytochrom P450-dependent monooxygenase system: an overview. In *Persistent pollutants in marine ecosystems,* eds. C. H. Walker and D. R. Livingstone. Pergamon Press, Oxford. pp. 119-60.

Bosselmann, K. (1996). Environmental law and tributyltin in the environment. In *Tributyltin; a case study of an environmental contaminant,* ed. S. J. de Mara. Cambridge University Press, Great Britain. pp. 237-63

Boully, L. (2000). The need for a new ICM model. *Water* 27, 26-28.

Brambilla, A., Rindone, B., Polesello, S., Galassi, S., and Balestrini, R. (1993). The fate of triazine pesticides in River Po water. *The Science of the Total Environment* 132, 339-348.

Brennan, D. (1999). Pollution control policies for Australian prawn farms. In *Proceedings of the 43rd Annual Conference of the Australian Agricultural and Resource Economics Society*. Christchurch New Zealand, January 1999.

Brodie, J. (1994). Management of sewage discharges in the Great Barrier Reef Marine Park. In *The 6th Pacific Congress on Marine Science and Technology, PACON (1994)*, ed. D. Bellwood. James Cook University, Townsville. pp 457-465.

Brodie, J. (1997). The water quality status of the Great Barrier Reef. In *State of the Great Barrier Reef World Heritage Area workshop (1995)*, eds. D. Wachenfeld, J. Oliver, and K. Davis. GBRMPA Workshop Series No. 23. Great Barrier Reef Marine Park Authority, Townsville. pp 69-96.

Brodie, J and Furnas, M. (1992). Long-term monitoring programs for eutrophication and the design of a monitoring program for the Great Barrier Reef. In *Proceedings of the Seventh International Coral Reef Symposium*, ed. R. H. Richmond Guam, 22-27 June 1992, pp. 77-84.

Brodie, J. and Furnas, M. J. (1996). Cyclones, river flood plumes and natural water quality extremes in the central Great Barrier Reef. In *Downstream Effects of Land Use*, eds. H. M. Hunter, A. G. Eyles, and G. E. Rayment. Department of Natural Resources, Brisbane. pp. 367-74.

Brodie, J., Furnas, M. J., Steven, A. D. L., Trott, L. A., Pantus, F., and Wright, M. (1997). Monitoring chlorophyll in the Great Barrier Reef lagoon: trends and variability. In *Proceedings of the 8th International Coral Reef Symposium.* pp 797-802.

Brodie, J., Devlin, M., Mitchell, A., Waterhouse, J., Audas, D., Haynes, D. and Jones, L. (in prep). Exposure of Great Barrier Reef inner-shelf reefs to river-borne contaminants. Poster paper prepared for the 2nd National Conference on Aquatic Environments, 20-23 November 2001, Townsville.

Brodie, J., Steven, A., and McGill, R. (1994). Spatial and temporal trends in chlorophyll in waters of the Great Barrier Reef Marine Park. *The 6th Pacific Congress on Marine Science and Technology, PACON (1994)*, ed. D. Bellwood. James Cook University, Townsville. pp. 77-85.

Brunskill, G. J., Pfitzner, J., Zargoskis, I., Walker, G. S., and Isdale, P. (1999). An episode of mercury contamination of Bowling Green Bay 1870-1900. In *Sources, fates and consequences of pollutants in the Great Barrier Reef and Torres Strait*, ed. Kellaway, D. Great Barrier Reef Marine Park Authority, Townsville. p 3 (abstract only).

Bryan, G. W. (1971). The effects of heavy metals (other than mercury) on marine and estuarine organisms. *Proceedings of the Ecological Society of London (B)* 177, 389-410.

Bryan, G. W. and Gibbs, P. E. (1991). Impact of low concentrations of tributyltin (TBT) on marine organisms: a review. In *Metal ecotoxicology, concepts and applications*, eds. M. C. Newman and A. W. McIntosh. Lewis Publishers Inc., USA. pp. 323-61.

Bryan, G. W. and Langston, W. J. (1992). Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review. *Environmental Pollution* 76, 89-131.

Buckland, S. J., Hannah, D. J., Taucher, J. A., Slooten, E., and Dawson, S. (1990). Polychlorinated dibenzo-p-dioxins and dibenzofurans in New Zealand's hector's dolphin. *Chemosphere* 20, 1035-1042.

Bunn, S. and Arthington, A. (1997*). Fragile future: downstream impacts of dams and flow regulation.* Centre for Catchment and In-stream Research, Griffith University.

Burrage, D., Steinberg, C., Bode, L., and Black, K. (1997). Long-term current observations in the Great Barrier Reef. In *State of the Great Barrier Reef World Heritage Area Workshop*, eds. Wachenfeld, D., Oliver, J., and Davis, K. Great Barrier Reef Marine Park Authority, Townsville. pp 21-45.

Burrows, D. and Butler, B. (1998). *Literature review and scoping study of the potential downstream impacts of the proposed Nathan Dam on the Dawson River, Fitzroy River and off shore environments.* Final report to the Great Barrier Reef Marine Park Authority, Townsville.

Capone, D. G. and Bauer, J. E. (1992). *Environmental microbiology*. Clarendon Press, Oxford.

Caruso, B.S. and Ward, R.C. (1998). Assessment of non-point source pollution from inactive mines using a watershed-based approach. *Environmental Management* 22(2), 225-243.

Cavanagh, J. E., Burns, K. A., Brunskill, G. J., and Coventry, R. J. (1999). Organochlorine pesticide residues in soils and sediments of the Herbert and Burdekin River regions, north Queensland - implications for contamination of the Great Barrier Reef. *Marine Pollution Bulletin* 39, 367-375.

Chessels, M. J., Hawker, D. W., Connell, D. W., and Papajcsik, I. A. (1988). Factors influencing the distribution of lindane and isomers in soil of an agricultural environment. *Chemosphere* 17, 1741-1749.

Church, J. A. (1987). East Australian current adjacent to the Great Barrier Reef. *Australian Journal of Marine and Freshwater Research* 38, 671-683.

Church, J. A., Andrews, J. C., and Boland, F. M. (1985). Tidal currents in the central Great Barrier Reef. *Continental Shelf Research* 5, 515-531.

Ciesiolka, C. (1987). *Catchment management in the Nogoa watershed.* Australian Water Resource Council Research Project 80/129. Queensland Department of Primary Industry, Brisbane. 204 p

Clark, R.B. (1992). *Marine Pollution*. Claredon Press, Oxford.

Clegg, D. E. (1974). Chlorinated hydrocarbon pesticide residues in oysters (*Crassostrea commercialis*) in Moreton Bay, Queensland, Australia, 1970-72. *Pesticides Monitoring Journal* 8, 162-166.

Clendening, L. D., Jury, W. A., and Ernst, F. F. (1990). A field mass balance study of pesticide volatilization, leaching and persistence. In *Long-range transport of pesticides*, ed. D. A. Kurtz. Lewis Publishers Inc., Michigan, USA. pp. 47-60.

Coates, M., Connell, D. W., Bodero, J., Miller, G.J. and Back, R. (1986). Aliphatic hydrocarbons in Great Barrier Reef organisms and environment. *Estuarine, Coastal and Shelf Science* 23, 99-113.

Coles, S. L. and Jokiel, P. L. (1992). Effects of salinity on coral reefs. In *Pollution in tropical aquatic systems*, eds. D. W. Connell and D. W. Hawker. CRC Press Inc., Boca Raton. pp. 147-68.

Congdon, R.A. and Lukacs, G.P. (1996). Water quality aspects of irrigation run-off from the Burdekin River irrigation area. In *Downstream Effects of Landuse* Hunter, eds. H.M., Eyles, A.G. and Rayment, G.E. Queensland Department of Natural Resources, Brisbane. pp 73-76.

Connell, D. W. (1990). Environmental routes leading to the bioaccumulation of lipophilic chemicals. In *Bioaccumulation of xenobiotic compounds*, ed. D. W. Connell. CRC Press, Boca Raton, Florida. pp. 47-58.

Connell, D. W. (1995). Occurrence and effects of petroleum hydrocarbons on Australia's marine environment. In *The state of the marine environment report for Australia technical annex: 2 pollution*, eds. L. P. Zann and D. C. Sutton. Great Barrier Reef Marine Park Authority: Townsville. pp. 47-52.

Cook, F. J., Hicks, W., Gardner, E. A., Carlin, G. D., and Froggatt, D. W. (2000). Export of acidity in drainage water from acid sulphate soils. *Marine Pollution Bulletin* 41, 319-326.

Corbin, C.J. and Singh, J.G. (1993). Marine debris contamination of beaches in St. Lucia and Dominica, *Marine Pollution* Bulletin 26, 325–328.

Craik, W. (1985) (ed). *Workshop on response to hazardous chemical spills in the Great Barrier Reef Region (1984).* GBRMPA Workshop Series No. 6. Great Barrier Reef Marine Park Authority, Townsville.

Craik, W. (1992). The Great Barrier Reef Marine Park: its establishment, development and current status. *Marine Pollution Bulletin* 25, 122-133.

Davies, P. S. (1991). The effect of daylight variations on the energy budgets of shallow-water corals. *Marine Biology* 108, 137-144.

Davison, W. and Zhang, H. (1994). In-situ speciation measurement of trace components in natural waters using thin-film gels. *Nature* 367, 546-548.

DCILGP (1998). *Population projections for Queensland*. Department of Communication and Information, Local Government and Planning. Brisbane.

Devlin, M., Christie, C., Waterhouse, J., Haynes, D., and Brodie, J. (in prep). *Long-term chlorophyll monitoring in the Great Barrier Reef lagoon. Status Report 2*. GBRMPA Research Publication Series, Great Barrier Reef Marine Park Authority, Townsville.

Devlin, M., Waterhouse, J., Taylor, J., and Brodie, J. (2001). *Flood plumes in the Great Barrier Reef: spatial and temporal patterns in composition and distribution*. Great Barrier Reef Marine Park Authority, Townsville.

Dixon, T.R and Dixon, T.J. (1981). Marine litter surveillance. *Marine Pollution Bulletin* 12, 289–95.

DNR (1999a). *Landcover change in Queensland 1991-1995*. A Statewide Landcover and Trees Study

(SLATS) report. Department of Natural Resources, Brisbane.

DNR (1999b). *Landcover change in Queensland 1995-1997*. A Statewide Landcover and Trees Study (SLATS) report. Department of Natural Resources, Brisbane.

DNR (2000). *Landcover change in Queensland 1997-1999*. A Statewide Landcover and Trees Study (SLATS) report. Department of Natural Resources, Brisbane.

Doherty, G., Brunskill, G. J., and Ridd, M. J. (2000). Natural and enhanced concentrations of trace metals in sediments of Cleveland Bay, Great Barrier Reef lagoon. *Marine Pollution Bulletin* 41, 337-344.

DPI (1993). *The condition of river catchments in Queensland: a broad overview of catchment management issues*. Queensland Department of Primary Industries, pp 1-84.

Dutton, I. M. (1985) (ed). *Workshop on contaminants in the waters of the Great Barrier Reef (1984).* GBRMPA Workshop Series No. 5. Great Barrier Reef Marine Park Authority, Townsville.

Dyall, R. A. and Johns, R. B. (1985). *Organochlorine pesticide levels in selected sediments of the Great Barrier Reef*. Unpublished Report, University of Melbourne.

Enell, M. and Wennberg, L. (1991). Distribution of halogenated organic compounds (AOX) - Swedish transport to surrounding sea areas and mass balance studies in five drainage systems. *Water Science and Technology* 24, 385-395.

EPA (1999). *Queensland's coast: managing its future. A position paper on coastal management in Queensland.* Environmental Protection Agency, Brisbane.

EPA (2001). Vegetation Communities and Regional Ecosystems (Ver. 3.0: June 2001). Queensland Herbarium, QEPA, Brisbane.

Eyre, B. and Davies, P. (1996). A preliminary assessment of suspended sediment and nutrient concentrations in three far north Queensland catchments. In *Downstream effects of land use,* ed. Hunter, H. M., Eyles, A. G., and Rayment, G. E. Department of Natural Resources, Brisbane. pp 57-64.

Fabricius, K.E. and Wolanski, E. (2000). Rapid smothering of coral reef organisms by muddy marine snow. *Estuarine Coastal Shelf Science* 50, 115 – 120.

Faithful, J. and Brodie, J. (1990). *Tully-Millstream hydroelectric scheme: Water quality sampling and testing program.* ACTFR Technical report No. 90/09, Australian Centre for Tropical Freshwater Research, Townsville.

Faris, J. and Hart, K. (1994). *Sea of Debris*. A Summary of the Third International Conference on Marine Debris, North Carolina Sea Grants College Program.

Finlayson, B. L. and Brizga, S. O. (1993). Anastomosing channels and arroyo development on the Nogoa River, Central Queensland, Australia. *Sedimentary Geology* 85, 179-190.

Förstner, U. (1989). *Contaminated sediments*. Springer-Verlag, Berlin.

Fowler, S. W. (1990). Critical review of selected heavy metal and chlorinated hydrocarbon concentrations in the marine environment. *Marine Environmental Research* 29, 1-64.

FRC (1999). *Pioneer Bay Environmental Monitoring Program. Third Monitoring Event, May, 1999.* Report to the Whitsunday Shire Council. FRC Coastal Resource and Environmental.

Freney, J. R., Denmead, O. T., Wood, A. W. and Saffigna, P. G. (1994). Ammonia loss following urea addition to sugar cane trash blankets. *Proceedings of the Australian Society of Sugar Cane Technologists* 16, 114-121.

Furnas, M. J. (in prep). Terrestrial runoff to the Great Barrier Reef: A synthesis.

Furnas, M. J. (1989). Cyclonic disturbance and a phytoplankton bloom in a tropical shelf ecosystem. In *Red Tides : Biology, Environmental Science, and Toxicology*. Eds. Okaichi, Anderson, and Nemoto. Elsevier Science Publishing Co., Inc. pp273-276.

Furnas, M. and Mitchell, A. (1986). Oceanographic aspects of cyclone Winifred. In Dutton, I. M. ed. *The offshore effects of cyclone Winifred*. GBRMPA Workshop Series No. 7. Great Barrier Reef Marine Park Authority, Townsville. pp 41-42.

Furnas, M. J. and Brodie, J. (1996). Current status of nutrient levels and other water quality parameters in the Great Barrier Reef. In *Downstream effects of land use*, eds. H. M. Hunter, A. G. Eyles and G. E. Rayment. Department of Natural Resources, Brisbane. pp 9-28.

Furnas, M. J. and Mitchell, A. W. (1996). Nutrient inputs into the central Great Barrier Reef (Australia) from subsurface intrusions of Coral Sea waters: a two dimensional displacement model. *Continental Shelf Research* 16, 1127-1148.

Furnas, M. J. and Mitchell, A. L. (1997). Biological oceanography of the Great Barrier Reef. In *The Great Barrier Reef: Science, use and management,* eds. N. Turia and C. Dalliston. Great Barrier Reef Marine Park Authority, Townsville. Vol. 1 pp 75-87.

Furnas, M. J. and Mitchell, A. W. (2001). Run-off of terrestrial sediment and nutrients into the Great Barrier Reef World Heritage Area. In *Oceanographic processes of coral reefs: Physical and biological links in the Great Barrier Reef.* ed E. Wolanski. CRC Press, Boca Raton. 37-52.

Furnas, M. J. Mitchell, A. W., Gilmartin, M. and Revelante, N. (1990). Phytoplankton biomass and primary production in semi-closed reef lagoons of the central Great Barrier Reef, Australia. *Coral Reefs* 9, 1-10.

Furnas, M. J., Mitchell, A. W. and Skuza, M. (1995). *Nitrogen and phosphorus budgets for the central Great Barrier Reef shelf.* Great Barrier Reef Marine Park Authority Research Publication No. 36. Great Barrier Reef Marine Park Authority Townsville.

Furnas, M. J., Mitchell, A. and Skuza, M. (1997). Shelf scale nitrogen and phosphorus budgets for the Central Great Barrier Reef (16° – 19° S). *Proceedings from the 8th International Coral Reef Symposium, Panama.*pp 809-814.

Furnas, M. J, Mitchell, A. W., Skuza, M., Ghonim, S. and Wright, M. (2001). Terrestrial nutrient and sediment export to the Great Barrier Reef – differences between wet and dry catchments. Australian Marine Sciences Association Conference, June 2001. Townsville, Australia. Abstract only.

Gagan, M. K., Sandstrom, M. W., and Chivas, A. R. (1987). Restricted terrestrial carbon input to the continental shelf during Cyclone Winifred: implications for terrestrial run-off to the Great Barrier Reef Province. *Coral Reefs* 6, 113-119.

Gagan, M. K., Chivas, A. R and Herczeg, A. L. 1990. Shelf-wide erosion, deposition and suspended sediment transport during cyclone Winifred: implications for terrestrial runoff to the Great Barrier Reef Province. *Coral Reefs* 6, 113-119.

Garrity, S.D. and Levings, S.C. (1993). Marine debris along the Caribbean coast of Panama. *Marine Pollution Bulletin* 26, 317–324.

Gaus, C., Päpke, O., Denisson, N., Haynes, D., Shaw, G., Connell, D.W. and Müller, J. F. (2001). Evidence for the presence of a widespread PCDD source in coastal sediments and soils from Queensland, Australia. *Chemosphere* (in press)

Gibbs, R. J. (1973). Mechanisms of trace metal transport in rivers. *Science* 180, 71-72.

Gilbert, M., Brodie, J., Waterhouse, J and Ramsay, M (in press). *Population and major land use in the Great Barrier Reef catchment area: spatial and temporal trends.* Great Barrier Reef Marine Park Authority, Townsville.

Glynn P. W. (1993). Coral reef bleaching and ecological perspectives. *Coral Reefs* 12, 1-17.

Glynn, P. W., Howard, L. S., Corcoran, E. and Freay, A. D. (1984). The occurrence and toxicity of herbicides in reef building corals. *Marine Pollution Bulletin* 15(10), 370-374.

Goreau, T. J. (1964). Mass expulsion of zooxanthellae from Jamaican reef communities after hurricane Flora. *Science* 145, 383-386.

Goreau, T. J. and MacFarlane, A. H. (1990). Reduced growth rate of *Montastrea annularis* following the 1987-1988 coral-bleaching event. *Coral Reefs* 8: 211-215.

Graetz, R. D., Wilson, M. A. and Campbell, S. K. (1995). Landcover disturbance over the Australian continent: a contemporary assessment. CSIRO, Canberra. Published by the Department of Environment, Sport and Territories.

Gribble, G. W. (1994). The natural production of chlorinated compounds. *Environmental Science and Technology* 28, 310A-319A.

Hall, L. W. and Anderson, R. D. (1999). A deterministic ecological risk assessment for copper in European saltwater environments. *Marine Pollution Bulletin* 38, 207-218.

Hamdorf, I. (1992). *Organochlorine termiticides: residues in fisheries products.* Fisheries Pollution and Marine Environment Committee. Australian Fisheries Council.

Hamilton, D. and Haydon, G. (1996). *Pesticides and fertilisers in the Queensland sugar industry - estimates of usage and likely environmental fate.* Department of Primary Industries, Queensland.

Harris, G. P. (2001). Biogeochemistry of nitrogen and phosphorus in Australian catchments, rivers and estuaries: effects of land use and flow regulation and comparisons with global patterns. *Marine and Freshwater Research* 52, 139-149.

Harris, J. R. W., Cleary, J. J. and Valkirs, A. O. (1996). Particle-water partitioning and the role of sediments as a sink and secondary source of TBT. In *Organotin: environmental fate and effects*, eds. M. A. Champ and P. F. Seligman. Chapman and Hall, London. pp. 459-73.

Hart, B. T., Day, G., Sharp-Paul, A. and Beer, T. (1988). Water quality variation during a flood event in the Annan river, North Queensland. *Australian Journal of Marine and Freshwater Research* 39, 225-243.

Hashimoto, S., Wakimoto, T. and Tatsukawa, R. (1995). Possible natural formation of polychlorinated dibenzo-p-dioxins as evidenced by sediment analysis from the Yellow Sea, the East China Sea and the Pacific Ocean. *Marine Pollution Bulletin* 30, 341-346.

Haynes, D. (2001) (ed) *Great Barrier Reef water quality; current issues.* Great Barrier Reef Marine Park Authority, Townsville.

Haynes, D. (1997). Marine debris on continental islands and sand cays in the far northern section of the Great Barrier Reef Marine Park, Australia. *Marine Pollution Bulletin* 34, 276-279.

Haynes, D. and Michalek-Wagner, K. (2000). Water quality in the Great Barrier Reef World Heritage Area: past perspectives, current issues and new research directions. *Marine Pollution Bulletin* 41, 428-434.

Haynes, D. and Loong, D. (2001). Antifoulant (tributyltin and copper) contamination in the Great Barrier Reef, Australia. *Marine Pollution Bulletin*, in review.

Haynes, D., Kellaway, D. and David, K. (1998). *Protection of wetlands adjacent to the Great Barrier Reef.* Great Barrier Reef Marine Park Authority, Townsville.

Haynes, D., Brodie, J. and Devlin, M. (1998). Long-term monitoring of chlorophyll concentrations in the Great Barrier Reef World Heritage Area. In *Proceedings of a workshop on sampling aquatic nutrients in aquatic ecosystems: collecting valid and representative samples,* eds. Markwort, K. N. and Maher, W. A. CRC for Freshwater Ecology, Canberra. pp115-126.

Haynes, D., Müller, J.F. and McLachlan, M.S. (1999). Polychlorinated dibenzo-*p*-dioxins and dibenzofurans in Great Barrier Reef (Australia) dugongs (*Dugong dugon*). *Chemosphere* 38, 255-262.

Haynes, D., Müller, J. and Carter, S. (2000a). Pesticide and herbicide residues in sediments and seagrass from the Great Barrier Reef World Heritage Area and Queensland coast. *Marine Pollution Bulletin* 41, 279-287.

Haynes, D., Ralph, P., Prange, J. and Dennison, W. (2000b). The impact of the herbicide diuron on photosynthesis in three species of tropical seagrass. *Marine Pollution Bulletin* 41, 288-293.

Hilliard, R.W. and Raaymakers, S. (1997). *Ballast water risk assessment, Stage 5 report.* Ecoports Monograph Series No. 14.Queensland Ports Corporation, Brisbane.

Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research* 50, 839-866.

Houghton, J. (1995). Global warming, the complete briefing. *Nature* 375 (6509), 30-31.

Huber, W. (1993). Ecotoxicological relevance of atrazine in aquatic systems. *Environmental Toxicology and Chemistry* 12, 1865-1881.

Huckins, J. N., Manuweera, G. K., Petty, J. D., Mackay, D. and Lebo, J. A. (1993). Lipid-containing semipermeable membrane devices for monitoring organic contaminants in water. *Environmental Science and Technology* 27, 2489-2496.

Huggett, J., Storrie, J. and Foster, A. (2000). *Oil-spill risk assessment for the coastal waters of Queensland and the Great Barrier Reef Marine Park*. Unpublished report, Great Barrier Reef Marine Park Authority, Townsville.

Hunter, H. M. (1992). *Agricultural contaminants in aquatic environments: a review*. Department of Primary Industries, Brisbane.

Hunter, H. M. (1997). Nutrients and suspended sediment discharged from the Johnstone River catchment during cyclone Sadie. In *Cyclone Sadie flood plumes in the Great Barrier Reef lagoon:*

Composition and consequences, ed. A. Steven. GBRMPA Workshop Series No. 22. Great Barrier Reef Marine Park Authority, Townsville. pp 1-8.

Hunter, H. M. and Walton, R. (1997). *From land to river to reef lagoon: land use impacts on water quality in the Johnstone River catchment.* Department of Natural Resources, Brisbane.

Hunter, H. M., Eyles, A. G. and Rayment, G. E. (1996). *Downstream effects of land use.* Department of Natural Resources, Brisbane.

Hunter, H. M., Walton, R. S. and Russell, D. J. (1996). Contemporary water quality in the Johnstone River catchment. In *Downstream effects of land use*, eds. H. M. Hunter, A. G. Eyles and G.E. Rayment. Department of Natural Resources, Brisbane. pp 339-345.

Hunter, H. M., Hargreaves, P. A. and Rayment, G. E (1999). Pesticide residues in surface waters of two northern Queensland catchments. In *Sources, fates and consequences of pollutants in the Great Barrier Reef and Torres Strait*, ed D. Kellaway, Great Barrier Reef Marine Park Authority, Townsville. pp 10. (Abstract only).

Hutchings, P. and Haynes, D. (2000). Sources, fates and consequences of pollutants in the Great Barrier Reef. *Marine Pollution Bulletin* 41, 265-266.

Hutchinson, J. and Simmonds, M. (1991). *A Review of the Effects of Pollution on Marine Turtles.* Greenpeace, London.

Ikeda, T., Gilmartin, M., Revelante, N., Mitchell, A. W., Carleton, J. H., Dixon, P., Hutchinson, S. M., Hing Fay, E., Boto, G. M. and Iseki, K. (1980). Biological, chemical and physical observations in inshore waters of the Great Barrier Reef, North Queensland 1975-1978. *Technical Bulletin of the Australian Institute of Marine Science (0ceanography Series No. 1)* AIMS –OS-80-1, 1-56 (Internal publication).

International Coral Reef Initiative (1999). *Renewed Call to Action: International Coral Reef Initiative 1998*. Great Barrier Reef Marine Park Authority, pp 1-40.

Iwata, H., Tanabe, S., Miyazaki, N. and Tatsukawa, R. (1994). Detection of butyltin compound residues in the blubber of marine mammals. *Marine Pollution Bulletin* 28, 607-12.

Jarman, W. M., Norstrom, R. J., Muir, D. C. G., Rosenberg, B., Simon, M. and Baird, R. W. (1996). Levels of organochlorine compounds, including PCDDs and PCDFs, in the blubber of cetaceans from the west coast of North America. *Marine Pollution Bulletin* 32, 426-436.

Johnson, D. (1996). Knowledge summary of terrigenous input to the central Great Barrier Reef. In *Great Barrier Reef: Terrigenous sediment flux and human impacts,* eds. P. Larcombe, K. Woolfe, and R. Purdon. CRC Reef Research Centre, Townsville. pp 86-90.

Johnson, A. and Bramley, R. (1996). *The natural resources of the Herbert River catchment and strategies for their management.* CSIRO, Townsville, Australia.

Johnson, A. K. L., Ebert, S. P. and Murray, A. E. (1998a). Spatial and temporal distribution of wetland and riparian zones and opportunities for their management in catchments adjacent to the Great Barrier Reef Marine Park. In *Protection of wetlands adjacent to the Great Barrier Reef,* eds. D. Haynes, D. Kellaway and K. Davis. GBRMPA Workshop Series No. 24. Great Barrier Reef Marine Park Authority, Townsville. pp 82-101.

Johnson, A. K. L., McDonald, G. T., Shrubsole, D. A. and Walker, D. H. (1998b). Natural resource use and management in the Australian sugar industry: current practice and opportunities for improved policy, planning and management. *Australian Journal of*

Environmental Management 5, 97-108.

Johnson, A. K. L., Ebert, S. P. and Murray, A. E. (2000). Land cover change and its environmental significance in the Herbert River catchment, north-east Queensland. *Australian Geographer* 31, 75-86.

Johnston, P. A., Stringer, R. L., and Santillo, D. (1996). Cetaceans and environmental pollution: the global concerns. In *The conservation of whales and dolphins*, eds. M. P. Simmonds and J. D. Hutchinson. John Wiley and Sons Ltd. pp. 219-61.

Jokiel, P. (1980). Solar ultraviolet radiation and coral reef epifauna. *Science* 207, 1069-1071.

Jones, M. M. (1995). Fishing debris in the Australian marine environment. *Marine Pollution Bulletin* 30, 25–33.

Jones, G., Broadbent, A., McDonald, M. and Curran, M. (1997). *Dimethylsulphide and dimethylsulphoniopropionate as an indicator of coral stress during the ENCORE experiment at One Tree Island.* Report to the Great Barrier Reef Marine Park Authority, Townsville.

Jones, R., Hoegh-Guldberg, O., Larkum, A. W. L. and Schrieber, U. (1998). Temperature induced bleaching of corals begins with impairment of dark metabolism in zooxanthellae. *Plant Cell and Environment* 21, 1219-1230.

Jones, R. J., Kildea, T. and Hoegh-Guldberg, O. (1999). PAM chlorophyll fluorometry: a new in situ technique for stress assessment in scleractinian corals, used to examine the effects of cyanide from cyanide fishing. *Marine Pollution Bulletin* 38, 864-874.

Kannan, K., Tanabe, S., and Tatsukawa, R. (1995). Geographical distribution and accumulation features of organochlorine residues in fish in tropical Asia and Oceania. *Environmental Science and Technology* 29, 2673-2683.

Kannan, K., Tanabe, S., Williams, R. J., and Tatsukawa, R. (1994). Persistent organochlorine residues in foodstuffs from Australia, Papua New Guinea and the Solomon Islands: contamination levels and human dietary exposure. *The Science of the Total Environment* 153, 29-49.

Kellaway, D. (1999) (ed). *Sources, fates and consequences of pollutants in the Great Barrier Reef and Torres Strait.* Great Barrier Reef Marine Park Authority, Townsville.

Kelly, J. R., Levine, S. N., Buttel, L. A., Carr, K. A., Rudnick, D. T. and Morton, R. D. (1990a). The effects of tributyltin within a *Thalassia* seagrass ecosystem. *Estuaries* 13, 301-10.

Kelly, J. R., Rudnick, D. T., Morton, R. D., Buttel, L. A., Levine, S. N. and Carr, K. A. (1990b). Tributyltin and invertebrates of a seagrass ecosystem: exposure and response of different species. *Marine Environmental Research* 29, 245-276.

Kennicutt, M. C., Wade, T. L., Presley, B. J., Requejo, A. G. and Denoux, G. J. (1994). Sediment contaminants in Casco Bay, Maine: inventories, source, and potential for biological impact. *Environmental Science and Technology* 28, 1-15.

King, B. (1995). *Hydrodynamic complexities of tropical coastal waters: a study through the application of numerical models.* PhD Thesis, James Cook University, Townsville.

Kjeller, L.-O., Jones, K. C., Johnston, A. E., and Rappe, C. (1991). Increases in polychlorinated dibenzo-p-dioxin and -furan content of soils and vegetation since the 1840s. *Environmental Science and Technology* 25, 1619-1627.

Kleypas, J. A. (1996). Coral reef development under naturally turbid conditions: fringing reefs near Broad Sound, Australia. *Coral Reefs* 15, 153-167.

Kleypas, J.A., Buddemeier, R.W., Archer, D., Gattuso, J.P., Langdon, C. and Opdyke, B.N. (1999). Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. *Science* 284, 118-120.

Klumpp, D. W., Done, T., McKinnon, A. D., Brunskill, G. J. and Robertson, A. I. (1997). *Response of nearshore reefs to nutrient enhancement: baseline information on nutrient concentrations, primary production and coral reef community structure.* Report to the Great Barrier Reef Marine Park Authority, Townsville.

Koop, K., Booth, D., Broadbent, A., Brodie, J., Bucher, D., Capone, D., Coll, J., Dennison, W., Erdmann, M., Harrison, P., Hoegh-Guldberg, O., Hutchings, P. A., Jones, G. B., Larkum, A. W. D., O'Neil, J., Steven, A., Tentori, E., Ward, S., Williamson, J. and Yellowlees, D. (2001). ENCORE: The effect of nutrient enrichment on coral reefs. Synthesis of results and conclusions. *Marine Pollution Bulletin* 42(2), 91-120.

Korpraditskul, R., Katayama, A., and Kuwatsuka, S. (1993). Chemical and microbiological degradation of atrazine in Japanese and Thai soils. *Journal of Pesticide Science* 18, 77-83.

Kubiak, T. G., Harris, H. J., Smith, L. M., Schartz, T. R., Stalling, D. L., Trick, J. A., Sileo, L., Docherty, D. E. , and Erdman, T. C. (1989). Micro-contaminants and reproductive impairment of the Foster's tern on Green Bay, Lake Michigan - 1983. *Archives of Environmental Contamination and Toxicology* 18, 706-727.

Kuiken, T., Bennett, P. M., Allchin, C. R., Kirkwood, J. K., Baker, J. R., Lockyer, C. H., Walton, M. J., and Sheldrick, M. C. (1994). PCBs, cause of death and body condition in harbour porpoises (*Phocoena phocoena*) from British waters. *Aquatic Toxicology* 28, 13-28.

Kurtz, D.A. and Atlas, E.L. (1990). Distribution of hexachlorocyclohexanes in the Pacific ocean basin, air, water, 1987. In *Long range transport of pesticides,* ed. D.A. Kurtz. Lewis Publishers, Inc., Michigan, USA. pp 143-160.

Laist, D.W. (1987). Overview of the biological effects of lost and discarded plastic debris in the marine environment. *Marine Pollution Bulletin* 18, 319–326.

Langston, W. J. (1990). Toxic effects of metals and the incidence of metals pollution in marine ecosystems. In *Heavy metals in the marine environment*, eds. R. W. Furness and P. S. Rainbow. CRC Press, Boca Raton, Florida. pp. 101-22.

Lapointe, B. E. and O'Connell, J. (1989). Nutrient enhanced growth of *Cladophora prolifera* in Harrington Sound, Bermuda: eutrophication of a confined, phosphorus limited marine ecosystem. *Estuarine, Coastal and Shelf Science* 28, 347-360.

Larcombe, P., Ridd, P.V., Prytz, A. and Wilson, B. (1995). Factors controlling suspended sediment on inner-shelf coral reefs, Townsville, Australia. *Coral Reefs* 14, 163-171.

Larcombe, P. and Woolfe, K. (1999). Increased sediment supply to the Great Barrier Reef will not increase sediment accumulation at most coral reefs. *Coral Reefs* 18, 163-169.

Larcombe, P., Woolfe, K. J., Amjad, N., Barnes, D. J., Brodie, J., Brunskill, G. J., Bryce, S., Carter, R. M., Costen, A., Crook, K. A. W., Crossland, C., Deacon, G. L., Ferland, M. A., Gorrie, A., Grindrod, J., Johnson, D. P., McIntyre, C., Neil, D. T., Okubo, C., Orpin, A. R., Purdon, R. G., Pye, K., Ridd, P. V., Shulmeister, J., Taylor, J. and Walker, G. S. (1996). Terrigenous sediment fluxes and the central Great Barrier Reef shelf: the current state of knowledge. In *Great Barrier*

Reef: terrigenous sediment flux and human impacts, eds P. Larcombe, K. Woolfe and R. Purdon. CRC Reef Research Centre, James Cook University, Townsville, Australia. 7-23.

Lawrence, P. A. and Thorburn, P. J. (1989). *Changes in hydrology, soil fertility and productivity of Brigalow catchments following clearing*. QDPI Publication RQR89002. Queensland Department of Primary Industries, Brisbane.

Leach, J. M., Howard, T. E. and Lanz, H. E. (1985). Chlorinated organics in shellfish from coastal waters. *Pulp and Paper Canada* 86, T389-T401.

Lee Long, W. J., Mellors, J. E. and Coles, R. G. (1993). Seagrasses between Cape York and Hervey Bay, Queensland, Australia. *Australian Journal of Marine and Freshwater Research* 44, 19-31.

Lewis, S. and Gardiner, J. (1996). *Proposed environmental quality standards for diuron, linuron, chlorotoluron and isoproturon in water.* National Rivers Authority, Bristol.

Liston, P., Furnas, M. J., Mitchell, A. W. and Drew, E. A. (1992). Local and mesoscale variability of surface water temperature and chlorophyll in the northern Great Barrier Reef, Australia. *Continental Shelf Research* 12 (7/8), 907-921.

Livingston, R. J. (1976). Dynamics of organochlorine pesticides in estuarine systems: effects on estuarine biota. In *Estuarine processes: uses, stresses and adaptions to the estuary*, ed. M. Wiley. Academic Press, pp. 507-22.

Lobegeiger, R. (1998). *Aquaculture production survey - Queensland 1996/1997*. QDPI Information Series Q198024.

Long E. R., MacDonald, D. D., Smith, S. L. and Calder, F. D. (1995). Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19(1), 81-97.

Lottermoser, B. G. (1997). Natural enrichment of topsoils with chromium and other heavy metals, Port Macquarie, New South Wales. *Australian Journal of Soil Research* 35, 1165-1176.

Lucas, Z. (1992). Monitoring persistent litter in the marine environment on Sable Island, Nova Scotia. *Marine Pollution Bulletin* 24, 192–199.

Lucas, P. H. C., Webb, T., Valentine, P. S., and Marsh, H. (1997). *The outstanding universal value of the Great Barrier Reef World Heritage Area*. Great Barrier Reef Marine Park Authority, Townsville.

Maguire, R. J. (1984). Butyltin compounds and inorganic tin in sediments in Ontario. *Environmental Science and Technology* 18, 291-294.

Maguire, R. (1987). Environmental aspects of tributyltin. *Applied Organometallic Chemistry* 1, 475-498.

Malcolm, H., Fontes, T. and Ashworth, T. (1999). An example of an ongoing refuse and illegal fishing problem at a popular anchorage in the Great Barrier Reef Marine Park. *Reef Research* 9, 3-5.

Marshall, P. A. and Baird, A. H. (1999). Bleaching of corals on the Central Great Barrier Reef: differential susceptibilities amoung taxa. *Coral Reefs* 19, 151-163.

McCloskey, L. R. and Duebert, K. H. (1972). Organochlorines in the seastar Acanthaster planci. *Bulletin of Environmental Contamination and Toxicology* 8, 251-256.

McCulloch, M.T., Gagan, M.K., Mortimer, G.E, Chivas, A.R. and Isdale, P. J. (1994). A high resolution Sr/Ca and $\delta^{18}O$ coral record from the Great Barrier Reef, Australia and the 1982 – 1983 El Nino. *Geochimica et Cosmochimica Acta* 58, 2747 – 2754.

McGuffog, D. R., Turrell, G., and McGuffog, I. D. (1996). *Survey of unwanted chemicals stored on farms in Queensland*. McGuffog & Co Pty Ltd, Brisbane.

McIvor, J. G., Williams, J. and Gardner, C. J. (1995). Pasture management influences run-off and soil movement in the semi-arid tropics. *Australian Journal of Experimental Agriculture* 35, 55-65.

McShane, T. J., Reghenzani, J .R., Proove, B .G., and Moody, P. W. (1993). Nutrient balances and transport from sugarcane land – a preliminary report. *Proceedings of the Australian Society of Sugar Cane Technologists 15th Conference*, 268-275.

Mercier, A., Pelletier, É., and Hamel, J. (1996). Toxicological response of the symbiotic sea anenome *Aiptasia pallida* to butyltin contamination. *Marine Ecological Progress Series* 144, 133-146.

Michalek-Wagner, K. and Willis, B. (2000a). Impacts on bleaching on the soft coral *Lophophytum compactum*. 1. Fecundity, fertilisation and offspring viability. *Coral Reefs* 19(3), 231-239.

Michalek-Wagner, K. and Willis, B. (2000b). Impacts on bleaching on the soft coral *Lophophytum compactum*.2. Biochemical changes in adults and their gametes. *Coral Reefs* 19(3), 240-246.

Mitchell, A. and Furnas. M. (1994). River inputs of N and P to the central Great Barrier Reef (16-19°S). In *Proceedings of the Conference of the Australian Society Sugar Cane Technologists*, ed. B. T. Egan. pp 30-37.

Mitchell, A. W. and Furnas, M. J. (1997). Terrestrial inputs of nutrients and suspended sediments to the Great Barrier Reef lagoon. In *The Great Barrier Reef: science, use and management,* eds. N. Turia and C. Dalliston. Great Barrier Reef Marine Park Authority, Townsville. Vol 1 pp 59-71.

Mitchell, A., Rasmussen, C., Blake, S., Congdon, R., Reghenzani, J., Saffigna, P. and Sturmey, H. (1991). Nutrient status and trends in waters of the Great Barrier Reef Marine Park. In *Landuse patterns and nutrient loading of the Great Barrier Reef region*, ed. D. Yellowlees. Proceedings of a workshop, James Cook University, November 1990. James Cook University, Townsville. pp.108-161.

Mitchell, A. W., Bramley, R. G. V., and Johnson, A. K. L. (1997). Export of nutrients and suspended sediment during a cyclone-mediated flood event in the Herbert River catchment, Australia. *Marine and Freshwater Research* 48, 79-88.

Mitchell, A. Reghenzani, J. R. and Furnas, M. (2001). Nitrogen levels in the Tully River – a long-term view. *Water Science and Technology* 43(9), 99-105.

Miyamoto, J., Mikami, N., and Takimoto, Y. (1990). The fate of pesticides in aquatic ecosystems. In *Environmental fate of pesticides*. eds. D. H. Hutson and T. R. Roberts. John Wiley and Sons, Chichester. 123-48.

Mohapatra, S. P., Kumar, M., Gajbhiye, V. T., and Agnihotri, N. P. (1995). Ground water contamination by organochlorine insecticide residues in a rural area in the Indo-Gangetic plain. *Environmental Monitoring and Assessment* 35, 155-164.

Moody, P. W., Reghenzani, J. R., Armour, J. D., Prove, B. G. and McShane, T. J. (1996). Nutrient balances and transport at farm scale- Johnstone River catchment. *In Downstream Effects of*

Landuse eds H. M. Hunter, A.G. Eyles, and G. E. Rayment. Queensland Department of Natural Resources, pp 347-351.

Mortimer, M. R. (1998). Organochlorine pesticide residues in Brisbane waterways. In *Moreton Bay and catchments*. eds. I. R. Tibbetts, N. J. Hall, and W. C. Dennison. University of Queensland: Brisbane. 241-6.

Mortimer, M. R. (2000). Pesticide and Trace Metal Concentrations in Queensland Estuarine Crabs. *Marine Pollution Bulletin* 41, 359-366.

Moss, A. and Mortimer, M. (1996). Brisbane River estuary: notes on water quality. *Workshop on water quality and environmental aspects of the Brisbane River*. Royal Australian Chemical Institute.

Moss, A. J., Rayment, G. E., Reilly, N. and Best, E. K. (1992*). Sediment and nutrient exports from Queensland coastal catchments, a desk study.* Queensland Department of Environment and Heritage, Brisbane.

Muir, D. C. G., Ford, C. A., Rosenberg, B., Norstrom, R. J., Simon, M. and Béland, P. (1996). Persistent organochlorines in beluga whales (*Deophinapterus leucas*) from the St Lawrence River estuary - I. concentrations and patterns of specific PCBs, chlorinated pesticides and polychlorinated dibenzo-p-dioxins and dibenzofurans. *Environmental Pollution* 93, 219-234.

Müller, J. F., Sutton, M., Wermuth, U. D., McLachlan, M. S., Will, S., Hawker, D. W. and Connell, D. W. (1996a). Burning sugar cane - a potential source for PAHs and PCDD/Fs. *Intersect 96*, Brisbane.

Müller, J. F., Sutton, M., Wermuth, U. D., McLachlan, M. S., Will, S., Hawker, D. W. and Connell, D. W. (1996b). Polychlorinated dibenzodioxins and polychlorinated dibenzo-furans in topsoils from northern Queensland, with a history of different trash management. In *Sugarcane: research towards efficient and sustainable production*. Eds. J. R. Wilson, D. M. Hogarth, J. A. Cambell, and A. L. Garside. CSIRO Division of Tropical Crops and Pastures, Brisbane. pp. 273-4.

Müller, J. F., Haynes, D. and McLachlan, M. S. (1998). PCDD/Fs in the Great Barrier Reef environment of Australia. *Organohalogen Compounds* 39, 105-108.

Müller, J. F., Haynes, D., McLachlan, M., Bohme, F., Will, S., Shaw, G. R., Mortimer, M., Sadlet, R. and Connell, D. W. (1999). PCDDS, PCDFS, PCBS and HCB in marine and estuarine sediments from Queensland Australia. *Chemosphere* 39, 1707-1721.

Müller, J.F., Duquesne, S., Ng, J., Shaw, G.R., Krrishnamohan, K. and Manonmanii, K. (2000). Pesticides in sediments from Queensland irrigation channels and drains. *Marine Pollution Bulletin* 41, 294-301.

Nash, R.G. and Hill, B.D. (1990). Modeling pesticide volatilization and soil decline under controlled conditions. In Long-range transport of pesticides, ed. D.A. Kurtz. Lewis Publishers, Inc., Michigan, USA. pp 17-28.

Neff, J. M. (1990). Composition and fate of petroleum and spill-treating agents in the marine environment. In *Sea mammals and oil: confronting the risks*, eds. J. R. Geraci and D. J. St.Aubin. Academic Press, Inc., San Diego, California. pp. 1-34.

Neil, D.T. (1994). *Sediment yield response to landuse intensification in humid tropical catchment: the Tully River catchment, North Queensland.* PhD Thesis, Australian National University, Canberra.

Neil, D. T. and Yu, B. (1996a). Fluvial sediment yield to the Great Barrier Reef lagoon: Spatial patterns and the effect of land use. In *Downstream effects of land use*, eds. H. M. Hunter, A. G. Eyles and G. E. Rayment. Department of Natural Resources, Brisbane. pp 281-286.

Neil, D. T. and Yu, B. (1996b). Simple climate-driven models for estimating sediment input to the Great Barrier Reef lagoon. In *Great Barrier Reef: terrigenous sediment flux and human impacts*, eds. P. Larcombe, K. Woolfe, and R. Purdon. James Cook University, Townsville. pp. 122-127.

NLWRA (2001). Great Barrier Reef Catchment Rivers Sediment and Nutrient Discharge Data, National Land and Water Resources Audit, Canberra.

Noble, R. M., Rummenie, S. K., Long, P. E., Duivenvoorden, L. J. and Fabbro, L. D. (1996). The Fitzroy River system, monitoring of water quality and biota. In *Downstream effects of land use*, eds. H. M. Hunter, A. G. Eyles and G. E. Rayment. Department of Natural Resources, Brisbane. pp 10 (Abstract only).

Norstrom, R. J., Simon, M. and Muir, D. C. G. (1990). Polychlorinated dibenzo-p-dioxins and dibenzofurans in marine mammals in the Canadian north. *Environmental Pollution* 66, 1-19.

Obien, S. R. and Green, R. E. (1969). Degradation of atrazine in four Hawaiian soils. *Weed Science* 17, 509-514.

Oehme, M., Schlabach, M., Hummert, K., Luckas, B. and Nordøy, E. S. (1995). Determination of levels of polychlorinated dibenzo-p-dioxins, dibenzofurans, biphenyls and pesticides in harp seals from the Greenland Sea. *The Science of the Total Environment* 162, 75-91.

Olafson, R. W. (1978). Effect of agricultural activity on levels of organochlorine pesticides in hard corals, fish and molluscs from the Great Barrier Reef. *Marine Environmental Research* 1, 87-107.

Olsen, C. R., Cutshall, N. H. and Larsen, I. L. (1982). Pollutant-particle associations and dynamics in coastal marine environments: a review. *Marine Chemistry* 11, 501-533.

Olsen, H. F. (1983). *Biological resources of Trinity Inlet and Bay, Queensland.* Queensland Department of Primary Industries Bulletin [QB83004].

Olsgard, F. (1999). Effects of copper contamination on recolonisation of subtidal marine soft sediments - an experimental field study. *Marine Pollution Bulletin* 38, 448-462.

Parsons, T. R., Maita, Y. and Lalli, C. M. (1984*). A Manual of Chemical and Biological Methods for Seawater Analysis.* Pergamon, New York.

Peters, E. C., Gassman, N. J., Firman, J. C., Richmonds, R. H. and Power, E. A. (1997). Ecotoxicology of tropical marine ecosystems. *Environmental Toxicology and Chemistry* 16, 12-40.

Pitts, D. (1998). *Preliminary study of potential impacts on the Great Barrier Reef World Heritage Area from coastal urban development: a scoping study to identify projects suitable for future funding proposals.* Great Barrier Reef Marine Park Authority, Townsville.

Platten, J. R. (1997). *The influence of the Fitzroy River discharge on fishery catch rates in central Queensland waters.* Central Queensland University, Rockhampton.

Powell, B. and Ahern, C. (1999). Nature, origin and distribution of acid sulfate soils: Issues for Queensland. In *Acid Sulfate Soils and their Management in Coastal Queensland: Forum and Technical Pape*rs, eds. K.M. Hey, C.R. Ahern, V.J. Eldershaw, J.M. Anorov and K.M. Watling, QASSIT and Department of Natural Resources, Brisbane. pp. 1-11.

Preen, A. R., Lee Long, W. J., and Coles, R. G. (1995). Flood and cyclone related loss, and partial recovery, of more than 1000km^2 of seagrass in Hervey Bay, Queensland, Australia. *Aquatic Botany* 52, 3-17.

Prest, H. F., Jarman, W. M., Burns, S. A., Weismueller, T., Martin, M. and Huckins, J. N. (1992). Passive water sampling via semipermeable membrane devices (SPMDs) in concert with bivalves in the Sacramento/San Joaquin River delta. *Chemosphere* 37, 1119-1138.

Prest, H. F., Richardson, B. J., Jacobson, L. A., Vedder, J. and Martin, M. (1995). Monitoring organochlorines with semi-permeable membrane devices (SPMDs) and mussels (*Mytilus edulis*) in Corio Bay, Victoria, Australia. *Marine Pollution Bulletin* 30, 543-554.

Prinsloo, J. F., Roets, W., Theron, J., Hoffman, L. C. and Schoonbee, H.J. (1999). Changes in some water quality conditions in recycling water used in three types of biofiltration systems during the production of the sharptooth catfish *Clarias gariepinus* (Burchell). *Water SA* (Pretoria) 25, 239-252.

Prosser, I. P., Rutherford, I. D., Olley, J. M., Young, W. J., Wallbrink, P. J. and Moran, C. J. (2001). Large-scale patterns of erosion and sediment transport in river networks, with examples from Australia. *Marine and Freshwater Research* 52, 81-99.

Prove, B. G., and Hicks, W. S. (1991). Soil and nutrient movements from rural lands of north Queensland. In *Land Use Patterns and Nutrient Loading of the Great Barrier Reef Region,* ed. Yellowlees, D. James Cook University of North Queensland, Townsville. pp 67-76.

Prove, B., Moody, P. and Reganzani, J. (1997). *Nutrient balances and transport from agricultural and rainforest lands: a case study in the Johnstone River catchment.* Report to Great Barrier Reef Marine Park Authority. Townsville

Pulsford, J. S. (1996). *Historical nutrient usage in coastal Queensland river catchments adjacent to the Great Barrier Reef Marine Park.* Research Publication No. 40, Great Barrier Reef Marine Park Authority, Townsville.

QDEH (1994). *Curtis coast study resource report.* Queensland Department of Environment and Heritage, Brisbane.

Rainbow, P. S. (1990). Heavy metals in marine invertebrates. In *Heavy metals in the marine environment,* eds. R. W. Furness and P. S. Rainbow. CRC Press, Boca Raton, Florida. pp. 67-80.

Rainer, S.F. (1995). *Potential for the introduction and translocation of exotic species by hull fouling: a preliminary assessment.* Centre for Research on Introduced Marine Pests Technical Report 1.

Ralph, P. J. (2000). Herbicide toxicity of *Halophila ovalis* assessed by chlorophyll *a* fluorescence. *Aquatic Botany* 66, 141-152.

Ralph, P. J. and Burchett, M. D. (1998). Photosynthetic response of *Halophila ovalis* to heavy metal stress. *Environmental Pollution* 103, 91-101.

Ramsay, M. (in prep). *Coastal wetlands adjacent to the Great Barrier Reef: Current status and management guidelines.* Great Barrier Reef Marine Park Authority, Townsville.

Rantalainen, A. L., Ilkonomou, M. G., and Rogers, I. H. (1998). Lipid-containing semipermiable membrane devices (SPMDs) as concentrators of toxic chemicals in the Lower Fraser River, Vancouver, British Colombia. *Chemosphere* 16, 1603-1618.

Rayment, G. E. and Neil, D. T. (1997). Sources of material in river discharge. In *The Great Barrier*

Reef: Science, use and management, eds. N. Turia and C. Dalliston. Great Barrier Reef Marine Park Authority, Townsville. Vol 1 pp 42-58.

Rayment, G. E., Best, E. K. and Hamilton, D. J. (1989). Cadmium in fertilisers and soil amendments. *Chemistry International, 10th Australian Symposium Analytical Chemistry.*

Rayment, G. E., Moss, A., Mortimer, M. and Haynes, D. (1997). *Monitoring pesticides in Queensland's aquatic environment and in the Great Barrier Reef Marine Park*. Downstream Effects of Agricultural Practices (DEAP) Committee 97- 1.

Reganzani, J. R. and Armour, J. D. (2000). Management to minimise nutrient export from canelands. In *Environmental short course for sustainable sugar production*, eds R. C. Bruce, M. Johnston and G. E. Rayment. CRC for Sustainable sugar production, James Cook University, Townsville. pp 117-122.

Reganzani, J.R., Armour, J.D., Prove, B.G., Moody P.W., and McShane, T. (1996). Nitrogen balances for sugarcane plant and first ratoon crops in the wet tropics. In *Sugarcane research towards efficient and sustainable production*, eds J. R. Wilson, D. M. Hogarth, J. A. Campbell and A. L. Garside. CSIRO Division of Tropical Crops and Pasture, Brisbane. pp 275-277.

Reicheld-Brushett, A. J. and Harrison, P. L. (1999). The effect of copper, zinc and cadmium on fertilization success of gametes from scleractinian reef corals. *Marine Pollution Bulletin* 38, 182-187.

Revelante, N. and Gilmartin, M. (1982). Dynamics of phytoplankton in the Great Barrier Reef lagoon. *Journal of Plankton Research* 4, 47-76.

Richardson, B. J. (1995). The problem of chlorinated compounds in Australia's marine environment. In *The State of the Marine Environment Report for Australia, Technical Annex: 2,* eds. L. P. Zann and D. C. Sutton. Great Barrier Reef Marine Park Authority, Townsville. pp. 53-61.

Ridd, M. (1999). An historical record of cadmium input into the Herbert Estuary. In *Sources, fates and consequences of pollutants in the Great Barrier Reef and Torres Strait,* ed. D. Kellaway. Great Barrier Reef Marine Park Authority, Townsville. p 10. (Abstract only).

Robertson, F. A. and Thornburn, P. J. (2000). Trash management – consequences for soil carbon and nitrogen. *Proceedings of the Australian Society of Sugar Cane Technologists* 22, 225-229.

Rogers, C. S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series* 62, 185-202.

Ross, J. B., Parker, R. and Strickland, M. (1991). A survey of shoreline litter in Halifax Harbour 1989. *Marine Pollution Bull*etin 22, 245–248.

Russell, D. J. and Hales, P. W. (1994). *Stream habitat and fisheries resources of the Johnstone River catchment.* Queensland Department of Primary Industries, Cairns.

Russell, D. J., Hales, P. W. and Helmke, S. A. (1996a). *Fish resources and stream habitat of the Moresby River catchment.* Department of Primary Industries. Information series.

Russell, D. J., Hales, P. W. and Helmke, S. A. (1996b). *Stream habitat and fish resources in the Russell and Mulgrave River catchments.* Department of Primary Industries. Information series.

Russell, D. J., Hales, P. W. and Moss, A. (1996c). Pesticide residues in aquatic biota from north-east Queensland coastal streams. *Proceedings of the Royal Society of Queensland* 106, 23-30.

Sammarco, P. and Crenshaw, H. (1984). Plankton Community Dynamics of the central Great Barrier Reef lagoon: analysis of data from Ikeda *et al*. *Marine Biology* 82, 167-180.

Sammut, J. and Lines-Kelly, R. (1996). *An introduction to acid sulfate soils, Ballina, NSW.* Department of the Environment, Sport and Territories.

Sammut, J., White, I. and Melville, M. D. (1994). Stratification in acidified coastal floodplain drains. *Wetlands (Australia)* 13, 49-64.

Schroeder, B.L., Wood, A.W. and Kingston, G. (1998). Re-evaluation of the basis for fertiliser recommendations in the Australian sugar industry. *Proceedings of the Australian Society of Sugar Cane Technologists* 20, 239-247.

Seligman, P. F., Maguire, R. J., Lee, R. F., Hinga, K. R., Valkirs, A. O. and Stang, P. M. (1996). Persistence and fate of tributyltin in aquatic ecosystems. In *Organotin: Environmental Fate and Effects*, eds. M. A. Champ and P. F. Seligman. Chapman and Hall, London. pp. 429-57.

Shepherd, S. A., McComb, A. J., Bulthuis, D. A., Neverauskas, V., Steffensen, D. A., and West, R. (1989). Decline of seagrasses. In *Biology of seagrasses: a treatise on the biology of seagrasses with special reference to the Australian region*, eds. A. W. D. Larkum, A. J. McComb, and S. A. Shepherd. Elsevier, Amsterdam. pp. 346-93.

Skull, S. (1996). *Habitat clearing and fragmentation in tropical lowlands*, PhD thesis, James Cook University, Townsville.

Slip, D.J. and Burton, H.R. (1991), Accumulation of fishing debris, plastic litter and other artefacts on Heard and Macquarie Islands in the Southern Ocean, *Environmental Conservation* 18, 249–254.

Smith, (1993). Prawn farming in Australia-sediment is a major issue. *Australian Fisheries* Dec, 29-32.

Smith, V. S., Kimmerer, W. J., Laws, E. A., Brock, R. E. and Walsh, T. W. (1981). Kaneohe Bay sewage diversion experiment: perspectives on ecosystem responses to nutritional perturbation. *Pacific Science* 35, 279-340.

Steven, A.D. and van Woesik, R. (1990). *A Multi-disciplinary Examination of the Hayman Island Fringing Reef: Influence of a Secondary Sewage Discharge.* Report to the Great Barrier Reef Marine Park Authority, Townsville.

Steven, A.D.L., Pantus, F., Brooks, D. and Trott, L. (1998). *Long-term chlorophyll monitoring in the Great Barrier Reef Lagoon: Status Report 1, 1993-1995.* Great Barrier Reef Marine Park Authority, Townsville.

Tarasova, E. N., Mamonlov, A. A., Mamontova, E. A., Klasmeier, J. and McLachlan, M. S. (1997). Polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) in Baikal seal. *Chemosphere* 34, 2419-2427.

Tatsukawa, R., Yamaguchi, Y., Kawano, M., Kannan, N. and Tanabe, S. (1990). Global monitoring of organochlorine insecticides- an 11-year case study (1975-1985) of HCHs and DDTs in the open ocean atmosphere and hydrosphere. In *Long range transport of pesticides*, ed. D. A. Kurtz. Lewis Publishers Inc, Michigan, USA. pp. 127-41.

Tesiram, Y. A. (1995). *The use of cadmium, uranium and arsenic as indicators of anthropogenic input into the Herbert River estuary, central Great Barrier Reef.* Honours Thesis, James Cook University, Townsville.

Thompson, D. R. (1990). Metal levels in marine vertebrates. In *Heavy metals in the marine environment*, eds. R. W. Furness and P. S. Rainbow. CRC Press Inc., Boca Raton, Florida. pp. 143-82.

Thompson, A., Allen, J. R., Dodoo, D., Hunter, J., Hawkins, S. J. and Wolff, G. A. (1996). Distribution of chlorinated biphenyls in mussels and sediments from Great Britain and the Irish Sea Coast. *Marine Pollution Bulletin* 32, 232-237.

Thoms, M. and Sheldon, F. (2000). Channel processes and environmental flow requirements for the Barwon-Darling River. *Rivers for the Future* 12, 10-19.

Thorburn, P.J., Keating, B.A., Robertson, F.A. and Wood, A.W. (2000). Long-term changes in soil carbonand nitrogen under trash blanketing. *Proceedings of the Australian Society of Sugar Cane Technologists* 22, 217-224.

Thorrold, S. R. and McKinnon, A. D. (1995). Responses of larval assemblages to a riverine plume in coastal waters of the central Great Barrier Reef. *Limnology and Oceanography* 40, 177-181.

Tomascik, T. and Sander, F. (1985). Effects of eutrophication on reef-building corals. I. Growth rates of the reef-building coral *Montastera annularis*. *Marine Biology* 87, 143-155.

Toyne, P. and Farley, R. (2000). *The decade of landcare*. The Australia Institute, Discussion Paper No. 30.

Troell, M., Ronnback, P., Halling, C., Kautsky, N. and Buschmann, A. (1999). Ecological engineering in aquaculture: use of seaweeds for removing nutrients from intensive mariculture. *Journal of Applied Phycology* 11, 89-97.

Trott, L. and Alongi, D. (1999). Presentation to the Annual International Conference and Exposition of the World Aquaculture Society, April 1999, Sydney, Australia.

Udy, J. W., Dennison, W. C., Lee Long, W. and McKenzie, L. J. (1999). Responses of seagrass to nutrients in the Great Barrier Reef, Australia. *Marine Ecological Progress Series* 185, 257-271.

Vandermeulen, J. H., Davis, N. D. and Muscatine, L. (1972). The effect of photosynthesis on zooxanthellae in corals and other marine invertebrates. *Marine Biology* 16, 185-191.

van Woesik, R. (1989). *A preliminary examination of the sedimentology, reef growth and hydrography of Green Island*. Report to the Great Barrier Reef Marine Park Authority, Townsville.

van Woesik, R. S., DeVantiers, S. M. and Glazebrook, J. S. (1995). Effects of cyclone Joy on nearshore coral communities of the Great Barrier Reef. *Marine Ecology Progress Series* 128, 261-270.

van Woesik, R. and Done, T. J. (1997). Coral communities and reef growth in the southern Great Barrier Reef. *Coral Reefs* 16, 103-115.

van Woesik, R., Tomascik, T. and Blake, S. (1999). Coral assemblages and physico-chemical characteristics of the Whitsunday Islands: evidence of recent community changes. *Marine and Freshwater Research* 50, 427-440.

von Westernhagen, H. and Klumpp, D. W. (1995). Xenobiotics in fish from Australian tropical coastal waters, including the Great Barrier Reef. *Marine Pollution Bulletin* 30, 166-169.

Wachenfeld, D. R., Oliver, J. K., and Morrisey, J. I. (1998) (eds). *State of the Great Barrier Reef*

World Heritage Area 1998. Great Barrier Reef Marine Park Authority, Townsville.

Waldichuk, M. (1985). Biological availability of metals to marine organisms. *Marine Pollution Bulletin* 16, 7-11.

Walker, T.A. (1981). Dependence of phytoplankton chlorophyll on bottom resuspension in Cleveland Bay, northern Queensland. *Australian Journal of Marine and Freshwater Research* 32, 981-986.

Walker, D., Dennison, W. and Edgar, G. (1999). Status of Australian seagrass research and knowledge . In *Seagrass in Australia. Strategic review and development of an R&D plan*, eds. A. J. Butler and P. Jernakoff. Commonwealth Scientific and Industrial Research Organisation. pp. 1-24.

Walker, D.I. and Ormond, R.F.G. (1982). Coral death from sewage and phosphate pollution at Aqaba, Red Sea. *Marine Pollution Bulletin* 13, 21-25.

Walker, D. I. and McComb, A. J. (1992). Seagrass degradation in Australian coastal waters. *Marine Pollution Bulletin* 25, 191-195.

Walker, G. S. and Brunskill, G. J. (1997). Detection of anthropogenic and natural mercury in sediments from the Great Barrier Reef. In *The Great Barrier Reef: Science, Use and Management,* eds. J. Campbell and C. Dalliston. Great Barrier Reef Marine Park Authority, Townsville. Vol 2 pp 30-36.

Walker, T. A. and O'Donnell, G. (1981). Observations on nitrate, phosphate and silicate in Cleveland Bay, Northern Queensland. *Australian Journal of Marine and Freshwater Research* 32, 877-87.

Ward, S. and Harrison, P. L. (1997). The effect of elevated nutrient levels on the settlement of coral larvae during the ENCORE experiment, Great Barrier Reef, Australia. In *Proceedings of the Eighth International Coral Reef Symposium,* eds. Lessios, H. A. and McIntyre, I. G. pp. 890-896.

Wasson, R. (1997). Run-off from the land to the rivers to the sea. In *The Great Barrier Reef: Science, use and management,* ed. N. Turia, and C. Dalliston. Great Barrier Reef Marine Park Authority, Townsville. Vol 1 pp 23-41.

Waterhouse, J. and Johnson, J. (2001). *Status of island sewage systems review of island sewage treatment facilities in the Great Barrier Reef World Heritage Area.* Australian Marine Sciences Association Conference, June 2001. Townsville, Australia. Abstract only.

Weier, K. L., McEwan, C. W., Vallis, I., Catchpoole, V. R. and Myers, J. R. (1996). Potential for biological denitrification of fertiliser N in sugarcane soils. *Australian Journal of Agriculture Research* 47, 67-79.

White, I., Melville, M. D., Wilson, B. P. and Bowman, G. M. (1996). Downstream impacts from acid sulphate soils. In *Downstream effects of landuse* eds. Hunter, H. M., Eyles, A. G. and Rayment, G. E. Department of Natural Resources, Brisbane. pp 165-172.

White, I., Melville, M. D., Wilson, B. P. and Sammut, J. (1997). Reducing acidic discharges from coastal wetlands in eastern Australia. *Wetlands Ecology and Management* 5, 55-72.

Wilkinson, C.R. (1996). Global climate change and coral reefs: impacts on reefs, economies and human cultures. *Global Change Biology* 2, 547-558.

Wilkinson, C.R. (1999). Global and local threats to coral reef functioning and existence: review and predictions. *Marine and Freshwater Research* 50, 867-878.

Wilkinson, C., Linden, O., Cesar, H., Hodgson, G., Rubens, J. and Strong, A. E. (1999). Ecological and Socioeconomic Impacts of 1998 Coral Mortality in the Indian Ocean: An ENSO Impact and a Warning of Future Change? *Royal Swedish Academy of Sciences* 28, 188-196.

Witney, E. (1989). *TBT in antifouling paints - a Queensland perspective*. Queensland Department of Primary Industries, Information Series.

Wolanski, E. and Bennett, A. F. (1983). Continental shelf waves and their circulation around the Great Barrier Reef. *Australian Journal of Marine and Freshwater Research* 34, 23-47.

Wolanski, E. and Pickard, G. L. (1985). Long-term observations of curents on the central Great Barrier Reef continental shelf. *Coral Reefs* 4, 47-57.

Woolfe, K. J., Larcombe, P., Orpin, A. R., Purdon, R. G., Michaelsen, P., McIntyre, C. M. and Amjad, N. (1998). Controls upon inner-shelf sedimentation, Cape York Peninsula, in the region of 12°S. *Australian Journal of Earth Sciences* 45, 611-621.

Yellowlees, D. (1991). *Land use patterns and nutrient loading of the Great Barrier Reef region*. Workshop proceedings, James Cook University, Townsville.

Yonge, C. M. and Nichols, A. G. (1931). Studies on the physiology of corals: V. The effect of starvation in light and in darkness on the relationship between corals and zooxanthellae. *Scientific Report of the Great Barrier Reef Expedition* 1, 177-211.

Zhang, H., Davison, W., Gadi, R. and Kobayashi, T. (1998). In situ measurement of dissolved phosphorus in natural waters using DGT. *Analytica Chemica Acta* 370, 29-38.

Appendix 1. Summary of AIMS River Monitoring Data

Note: Median values in data set; D = Downstream freshwater section, U = Upstream freshwater section, E = Estuarine section, I = Intermediate freshwater section with relatively little development upstream

River	Section	Location	NO_3 µM	DIN µM	DON µM	PN µM	TN µM	DIN %	DON %	PN %	PO_4 µM	DOP µM	PP µM	TP µM	PO_4 %	DOP %	PP %	SS mg L^{-1}
Barron	E	Highway	6.79	9.84	10.28	7.22	27.34	0.36	0.38	0.26	0.51	0.29	0.57	1.37	0.37	0.21	0.42	12.30
Barron	D	Kamerunga	3.74	6.86	11.82	7.21	25.89	0.27	0.46	0.28	0.09	0.18	0.35	0.62	0.15	0.29	0.56	9.81
Burdekin	D	Highway	7.91	10.80	9.40	22.41	42.62	0.25	0.22	0.53	0.56	0.13	2.43	3.12	0.18	0.04	0.78	269.88
Fitzroy	D	Barrage	14.97	15.96	11.85	25.01	52.82	0.30	0.22	0.47	1.64	0.12	4.23	6.00	0.27	0.02	0.71	526.15
Herbert	D	Highway	7.69	9.34	7.36	7.27	23.96	0.39	0.31	0.30	0.07	0.15	0.50	0.71	0.09	0.20	0.70	47.30
Herbert	U	Yamani	0.76	1.74	9.78	7.00	18.53	0.09	0.53	0.38	0.01	0.18	0.30	0.50	0.03	0.36	0.61	32.13
Mulgrave	D	Lower	8.02	9.95	5.48	3.94	19.37	0.51	0.28	0.20	0.10	0.09	0.23	0.42	0.24	0.21	0.55	3.94
Mulgrave	I	Highway	1.67	4.29	5.65	3.69	13.62	0.31	0.41	0.27	0.08	0.14	0.18	0.40	0.20	0.35	0.45	2.27
Murray	D	Highway	5.14	7.61	7.24	6.53	21.38	0.36	0.34	0.31	0.12	0.22	0.37	0.71	0.17	0.31	0.52	8.40
Normanby	D	Lakefield	1.07	2.85	15.80	15.17	33.81	0.08	0.47	0.45	0.35	0.02	0.96	1.33	0.26	0.02	0.73	89.10
N. Johnstone	D	Highway	3.01	7.73	4.99	4.17	16.90	0.46	0.30	0.25	0.09	0.22	0.28	0.59	0.16	0.37	0.47	4.25
Russell	I	Highway	3.99	5.98	4.02	3.73	13.73	0.44	0.29	0.27	0.05	0.09	0.18	0.32	0.17	0.28	0.55	2.82
S. Johnstone	D	Bridge	7.06	9.48	4.56	7.24	21.29	0.45	0.21	0.34	0.16	0.13	0.37	0.66	0.25	0.19	0.56	6.00
Tully	D	Highway	10.15	11.69	3.66	5.65	21.00	0.56	0.17	0.27	0.10	0.09	0.38	0.57	0.18	0.15	0.67	19.35
Tully	U	Upper	2.68	4.64	5.97	2.94	13.55	0.34	0.44	0.22	0.04	0.09	0.18	0.31	0.13	0.29	0.58	4.20

Note: 14 µg L^{-1} N = 1µM; 14 µg L^{-1} P = 1µM

Appendix 2. National Land and Water Resources Audit - Sediment catchment modelling methodology

The only practical framework within which to assess sediment and nutrient delivery across a large complex area such as the Burdekin River catchment is spatial modelling. There are few direct measurements of sediment transport processes in regional catchments. It is unrealistic to initiate sampling programs of the processes now and expect results within a decade. Furthermore, collation and integration of existing data has to be put within an overall assessment framework, and a large-scale spatial model of sediment transport is the most effective use of that data.

The assessment of sediment transport within catchments is divided into three parts: hillslope erosion as a source of sediment; gully erosion as a source of sediment; and river links as a further source, receiver and propagator of the sediment. The methods used in each aspect of the spatial model are outlined below in brief. They were developed concurrently with support from the National Land and Water Resources Audit project on sediment budgets and reference is made to supporting technical documentation which contains details of the approach.

Hillslope Erosion Hazard

The controls on hillslope erosion by surface wash and rill erosion are well understood and there are several models which incorporate these factors. The best known model and the only type that can be applied across large regions is the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978) or its derivatives such as the Revised USLE (RUSLE; Renard *et al*. 1997), Soiloss (USLE factors for NSW; Rosewell, 1993) and PERFECT (Littleboy *et al*. 1992). Research on the mechanics of hillslope erosion has resulted in more detailed models of the mechanics of sediment detachment and transport but these cannot be used at regional scales because they require detailed data which is not available beyond limited experimental conditions. Support for the USLE is given by studies which show that its empirical form is consistent with the mechanics of sediment detachment and transport included in the more detailed models (Moore and Burch, 1986; McCool *et al*. 1989).

The RUSLE calculates mean annual soil loss (Y, tonnes/ha/y) as a product of six factors: rainfall erosivity factor (R), soil erodibility factor (K), hillslope length factor (L), hillslope gradient factor (S), ground cover factor (C) and land use practice factor (P):

$$Y = RKLSCP \qquad (1)$$

The factors included in the RUSLE can vary strongly across the diverse range of topographies, vegetation types and soils found in catchments such as the Burdekin, providing a method for estimating the spatial patterns of erosion using available spatial information for each factor.

The precise form of each factor is based on soil loss measurements on hillslope plots, mainly in the USA. Plot scale measurements of erosion have been undertaken in the

Burdekin area (McIvor *et al.* 1995; Scanlan *et al.* 1996) allowing limited local calibration of the RUSLE factors, particularly the *C* factor.

The RUSLE is directly applicable for hillslopes up to 300 m in length. For longer hillslopes the relationship based on expected runoff patterns cane be extrapolated. The *L* factor represents the increase in storm runoff volume with increasing hillslope length, and the increased propensity for rill erosion with increasing runoff. In native grasslands, woodlands and forests there is evidence that runoff volume grows only weakly or not at all with hillslope length (Bonell and Williams, 1987; Prosser and Williams, 1998). In these landscapes there are patches of runoff generation and patches of runoff adsorption and longer hillslopes do not necessarily yield more sediment than short ones. Thus the *L* factor was removed from the analysis in these areas and only applied to areas with cropping or improved pastures. Similarly, there are few land use practises such as tillage and construction of contour banks in extensive savanna grazing lands so the *P* factor was also removed from the spatial analysis.

Mean annual values for rainfall erosivity and the cover factor are often used in direct application of Equation (1) to calculate mean annual hillslope erosion. This neglects often important seasonal patterns of rainfall erosivity and cover. High intensity rains for example occur during seasonal periods of low ground cover. To incorporate these effects the product of mean monthly cover (C_m) and the proportion of annual rainfall erosivity for each month (R_m/R) was used. The monthly values of $C_m R_m/R$ are then summed to give mean annual soil loss. It can be shown that incorporation of seasonal effects reduces predicted mean annual soil loss in Australia's tropics by a factor of 1.5. The modifications of Equation (1) discussed above yield

$$Y = KLS \sum_{m=1}^{m=12} C_m \frac{R_m}{R} . \qquad (2)$$

Twenty years (1980-1999) of daily rainfall data mapped across Australia and 13 years (1981-1994) of satellite vegetation data were used to apply Equation (2). Incorporation of seasonal effects reduces predicted mean annual soil loss in Australia's tropics by a factor of 1.5. Details of the use of this data are given in Lu *et al*. (2001). The soil erodibility factor (K) was derived from the Australian Soil Resources Information System (as detailed in Lu *et al*. 2001). The length and slope factors (L, S) were derived from the national 9" digital elevation model (DEM; approximately 250 m grid resolution) and scaling rules determined from comparison with higher resolution DEMs (see Gallant 2001 for details). This transformation was needed because the raw values in the 9" DEM do not accurately reflect the topographic details of hillslopes and valleys which are at a similar or finer scale than the resolution of the DEM.

The predictions of sheetwash erosion under present land use need to be put in context of erosion under natural vegetation cover, for many areas have naturally high sheetwash erosion. Natural erosion using the same procedure as above was predicted using a cover factor for native vegetation and keeping the other factors of soil erodibility, rainfall erosivity and topography as for the present day.

The cover factor for native vegetation was obtained by assessing reserve areas in each of Australia's native vegetations where cover is retained. In the reserves, the RUSLE C factor was determined from remote sensing data as part of the assessment of current soil loss. The native vegetation cover of these reserve areas was extrapolated across other areas using an empirical decision tree model based on climatic, topographic, and geological factors. The acceleration of current mean annual soil loss above natural rates was predicted as the ratio of the current to pre-European mean annual soil loss predictions.

Further details are given in Lu *et al.* (2001).

Gully Erosion Hazard

As it is an expensive and time consuming effort to measure all the gullies within catchments (eg. the Burdekin), the extent of gullies was estimated by aerial photograph interpretation of a number of sampled areas. These were used to generate an empirical model of gully density based on various environmental attributes for which there is catchment-wide coverage.

Sample sites were selected in each of the major geology types, slopes and rainfall zones. To ensure satisfactory representation of the different terrains each major land system is represented by a number of photographs. The photographs covered all geographical areas of the catchment. There is a bias towards the central part of the catchment since suitable air photos were more readily available for this region. A total of 63 pairs of photos were used. Eroded gullies were mapped from the aerial photographs using a stereoscope and then scanned and digitized into a geographical information system (GIS). Each image is then geo-referenced using 5 to 6 control points, which were obtained from 1:100,000 topographic maps. For each air photo, the mapped gullies were grouped into areas (or polygons) of similar geology, land-use and slope. Each aerial photograph is then divided into regions blocks based upon land use, geology and relief. Each region, thus delineated, is allocated the gully density (km of eroded gully per km^2 of area) measured across that whole region. The gully density is then calculated by dividing the total length of gully by the area of the polygon, to give a value in km of eroded gully per km^2 of area.

To build a spatial model of gully density, a grid resolution of 1.25 km was selected. We consider this to be the smallest scale at which gully prediction is feasible using the variables available. It is also the approximate scale at which the original aerial photograph interpretation was done. The gully erosion model was built using 75% of pixels for which there was aerial photograph interpreted gully density. The predictor environmental variables were also sampled over the same locations. These included climatic parameters such as mean annual rainfall; various soil attributes derived from the Atlas of Australian Soils and McKenzie *et al.* (2000); geology; land use; terrain attributes derived from the 9" DEM, and remote sensing data of MSS bands. A number of training sets were used by varying the random sampling of pixel locations, and by varying the predictor variables. This ensured that the model was not sensitive to the precise choice of measured sites, and used the best combination of predictor variables.

Sets of gully density rules were determined using CUBIST decision tree software which is a data mining tool for generating rule-based predictive models for large volume of data. The basic model building methods of CUBIST can be found in Quinlan (1993). CUBIST builds a model of gully erosion based on piece-wise linear multiple regression of the predictor variables. The remaining 25% of measured gully pixels were used to test the quality of the model. The best model was selected on the basis of the highest correlation coefficient, smallest absolute and relative error, and consistent statistical figures between training set and testing set. Finally, a gully density map was produced by applying the rules generated by the decision tree to the predictor variables mapped over the entire catchment. Hughes *et al*. (2001) contains further details of the method but it should be noted that the work reported here used a separate model built solely from the Burdekin catchment aerial photograph data.

Sediment Delivery Through the River Network

Hillslope and gully erosion, together with erosion of streambanks, supplies sediment to the stream network (the network of creeks and rivers in a catchment). The sediment supplied to a reach of river is then either deposited within the river, and its surrounding floodplain or is transmitted to the next reach downstream. There is also substantial deposition in reservoirs.

A river sediment budget was constructed to calculate the supply of sediment, its deposition and its delivery downstream. We calculated budgets for two types of sediment: suspended sediment and bedload. A suite of ArcInfo™ programs were used to define river networks and their sub-catchments; import required data; implement the model; and compile the results. These are referred to collectively as the SedNet model: the Sediment River Network Model. Details of the model and its application to regional catchments in Australia is given in Prosser *et al*. (2001). That document describes all the equations and input data used. Here we give a brief descriptive summary of the approach.

The SedNet model calculates, among other things:

- the mean annual suspended sediment output from each river link;
- the depth of sediment accumulated on the river bed in historical times;
- the relative supply of sediment from sheetwash, gully and bank erosion processes;
- the mean annual rate of sediment accumulation in reservoirs;
- the mean annual export of sediment to the coast; and
- the contribution of each sub-catchment to that export.

For this project, suspended sediment is characterised as fine textured sediment carried at relatively uniform concentration through the water column during large flows. Its transport is generally limited by the supply of sediment to rivers rather than by the sediment transport capacity (Olive and Walker, 1982; Williams, 1989). The main process for net deposition of suspended sediment is overbank deposition on floodplains (e.g. Walling *et al*. 1992). The amount of deposition depends upon the residence time of water on the floodplain and the sediment concentration of flood flows. The velocities of suspended material within channels are relatively high so we can assume that its residence time is low; that there is negligible transient deposition of suspended sediment; and that steady state conditions have been reached since European settlement increased the supply of sediment. Suspended sediment is sourced from surface wash erosion of hillslopes, gully erosion and riverbank erosion. The sediment budget is reported as mean annual values for either the current land use or for pre-European native vegetation cover.

Bedload is sediment transported in greatest proportions near the bed of a river. It may be transported by rolling, saltation, or for short periods of time, by suspension. Transport occurs during periods of high flow, over distances of hundreds to thousands of metres (Nicholas *et al*. 1995). Residence times of coarse sediment in river networks are relatively long so there is transient deposition on the bed as the sediment works its way through the river network. In addition to that deposition, an increase in sediment supply from accelerated post-European erosion can cause the total supply of sediment in historical times to exceed the capacity of a river reach to transport sediment downstream. The excess sediment will be stored on the bed and the river will have aggraded over historical times (Trimble, 1981; Meade 1982). There has been a significant increase in supply of sand and fine gravel to rivers in historical times and deposition of this bedload has formed sand slugs: extensive, flat sheets of sand deposited over previously diverse benthic habitat (Nicholas *et al*. 1995; Rutherfurd, 1996). The bedload budget aims to predict the formation of these sand slugs.

The basic unit of calculation for constructing the sediment budgets is a link in a river network. A link is the stretch of river between any two stream junctions (or nodes; Figure 1). Each link has an internal sub-catchment, from which sediment is delivered to the river network by hillslope and gully erosion processes. The internal catchment area is the catchment area added to the link between its upper and lower limits (Figure 1). For the purpose of the model, the internal catchment area of first order streams is the entire catchment area of the river link. Additional sediment is supplied from bank erosion along the link and from any tributaries to the link.

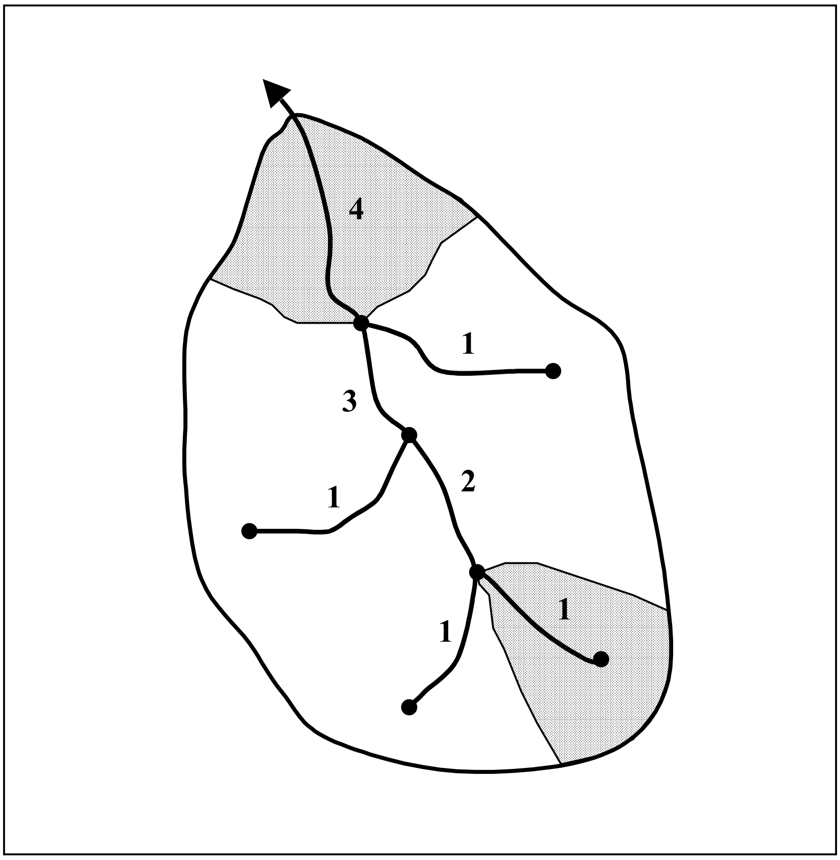


Figure 1: A river network showing links, nodes, Shreve magnitude of each link (Shreve, 1966) and internal catchment area of a magnitude one and a magnitude four link.

A branching network of river links joined by nodes was defined from the AUSLIG 9" digital elevation model (DEM) of Australia. The river network was defined as beginning at a catchment area of 50 km^2. This was an arbitrary choice used to limit the number of links across the assessment area, while still representing all large streams. The physical stream network extends well upstream of the limit in most areas and these areas are treated as part of the internal catchment area contributing material to the river link. Short links, where the catchment area had reached less than 75 km^2 by the downstream node were removed. Links were further separated by nodes at the entry to and exit from reservoirs and lakes. Internal catchment areas for each link were also determined from the 9" DEM.

A sediment mass budget for bedload was calculated for each river link (x) in the network, working from the top of the basin to the sea (Figure 2). The aim was to define those links subject to net deposition because the historical supply of bedload has exceeded sediment transport capacity. The total mean annual load supplied to the outlet of the link at any time is compared with the mean annual sediment transport capacity at that point. If the load is in excess of capacity, the excess is deposited and the yield to the link immediately downstream equals the sediment transport capacity. If the loading to the outlet is less than the sediment transport capacity there is no net deposition and the yield downstream equals the loading to the outlet.

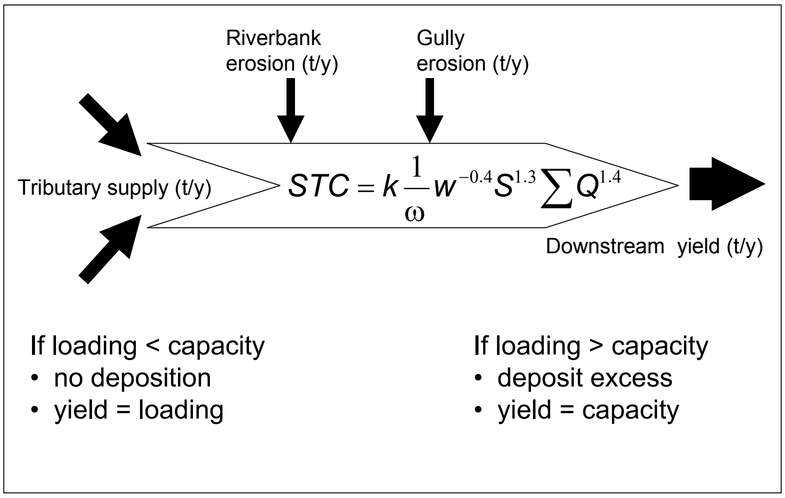


Figure 2: Conceptual diagram of the bedload sediment budget for a river link. The equation is used to calculate sediment transport capacity (STC), where k is a constant, ω is sediment settling velocity, w is river width, S is river slope and sigmaQ1.4 is the mean annual sum of daily discharge

Bedload is supplied to a river link from tributary links and from gully and riverbank erosion in the internal catchment area of the link. Half the sediment derived from riverbank and gully erosion contributed to the bedload budget and the other half contributed to the suspended load budget. This reflects observed sediment budgets (Dietrich and Dunne, 1978) and particle size of the bank materials.

The prediction of gully erosion extent was described above. Gully density was converted to a mean annual mass of sediment derived from gully erosion by assuming development of gullies over 100 y and a mean gully cross-sectional area of 10 m^2.

The supply of sediment from riverbank erosion was calculated from the results of a global review of river bank migration data (Rutherfurd, 2000). The best predictor of bank erosion rate (*BE*; m/y) was found by Rutherfurd to be bankfull discharge. This was modified in the project to account for the condition of riparian vegetation. It was assumed that the bank erosion rate was negligible on rivers with intact native riparian vegetation. The presence or absence of native riparian vegetation was determined from the Australian Land Cover Change project which mapped vegetation present in 1995 at a resolution of 100 m (BRS, 2000). This is the best available data but is still a crude measure of riparian condition. The 100 m resolution fails to identify narrow bands of remnant riparian vegetation in cleared areas but it also fails to identify narrow valleys of cleared land penetrating otherwise uncleared land.

Once calculated, the total supply of bedload to a river link is compared to sediment transport capacity (STC_x). Sediment transport capacity is a function of the river width (w_x), slope (S_x), discharge (Q_x), particle size of sediment and hydraulic roughness of the channel. Yang (1972) found strong relationships between unit stream power and *STC*. Using Yang's (1972) equation, and average value for Manning's roughness coefficient of 0.025, we predicted sediment transport capacity in a river link (t/y) from:

$$STC_x = \frac{86 S_x^{1.3} \sum Q_x^{1.4}}{\omega w_x^{0.4}} \qquad (9)$$

where ω is the settling velocity of the bedload particles (m/s). $\Sigma Q_x^{1.4}$ represents mean annual sum of daily flows raised to a power of 1.4 ($Ml^{1.4}/y$). This represents the disproportionate increase in sediment transport capacity with increasing discharge.

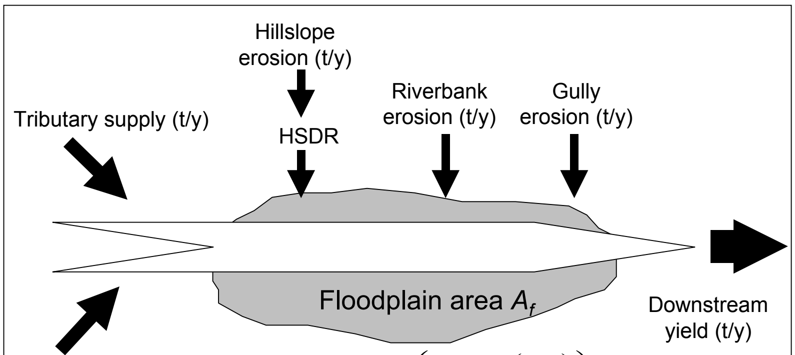
The suspended sediment loads of Australian rivers, and rivers in general, are supply limited (Olive and Walker, 1982; Williams, 1989). That is, rivers have a very high capacity to transport suspended sediment and sediment yields are limited by the amount of sediment delivered to the streams, not discharge of the river itself. Consequently, if sediment delivery increases, sediment yields increase proportionally. Deposition is still a significant process, however. This can be illustrated by plots of suspended sediment yield data against catchment area (Figure 3). These plots show a reduction in sediment yield per unit area with increasing catchment area (that is the exponent on area is less than one).

Suspended sediment is supplied to a river link from four sources: river bank erosion, gully erosion, hillslope erosion and tributary suspended sediment yield. Prediction of sheetwash and rill erosion was described above but only a small proportion of sediment moving on hillslopes is delivered to streams. The difference occurs for two reasons. First the RUSLE is calibrated against hillslope plots considerably smaller than the scale of hillslopes. Much of the sediment recorded in the trough of the plots may only travel a short distance (less than the plot length and much less than the hillslope length) so that plot results cannot be easily scaled up to hillslope predictions. Second, there are features of hillslopes, not represented by erosion plots, which may trap a large proportion of sediment. These include farm dams, contour banks, depressions, fences, and riparian zones. The most common way of representing the difference between plot and hillslope sediment yields is to apply a hillslope sediment delivery ratio (*SDR*) to the RUSLE results (e.g. Williams, 1977; Van Dijk and Kwaad, 1998). This ratio represents the proportion of sediment moving on hillslopes that reaches the stream.

The main location for deposition of suspended sediment is on floodplains A relatively simple conceptualisation of floodplain deposition is to consider that the proportion of suspended sediment load that is available for deposition is equal to the fraction of total discharge that goes overbank. This assumes uniform concentration of suspended sediment with depth.

The actual deposition of material that goes overbank can be predicted as a function of the residence time of water on floodplain. The longer water sits on the floodplain the greater the proportion of the suspended load that is deposited. The residence time of water on floodplains increases with floodplain area and decreases with floodplain discharge. Floodplain area was mapped from the DEM using a flood routing model as described in Pickup and Marks (2001).

An increase in supply of fine sediment from upstream results in a concomitant increase in mean sediment concentration and mean annual suspended sediment yield. Thus increases in fine sediment supply have relatively strong downstream influences on suspended sediment loads. Sediment deposition in reservoirs is incorporated in the model as a function of the mean annual inflow into the reservoir and its total storage capacity (Heinemann, 1981).



$$D_x = I_x \frac{Q_f}{Q_t}\left(1 - e^{-\left(\frac{vA_f}{Q_f}\right)}\right)$$

Figure 3: Conceptual diagram for the suspended sediment budget of a river link. HSDR is hillslope sediment delivery ratio. The equation is for the amount of sediment deposited on the floodplain (t/y), where Ix is the sediment load input to the link, Qf/Qt is the proportion of flow that goes overbank, Af/Qf is the ratio of floodplain area to floodplain discharge and ν is the sediment settling velocity.

The procedures above were applied in sequence to each river link from the top of the basin to the sea, adding suspended load and predicting its loss through deposition along the way. The final calculation is of mean annual suspended sediment export to the sea.

Contribution of Sediment to the Coast

One of the strongest interests in suspended sediment transport at present is the potential river export to estuaries and the coast. Because of the extensive opportunities for floodplain deposition along the way, not all suspended sediment delivered to rivers is exported to the coast. There will be strong spatial patterns in sediment delivery to the coast because some tributaries are confined in narrow valleys with little opportunity for deposition, while others may have extensive open floodplains. There will also be strong, but different patterns in sediment delivery to streams. Differentiation of subcatchments, which contribute strongly to coastal sediment loads, is important because of the very large catchments involved in Australia; the Burdekin River drains an area of 130,000 km^2 for example. It is not possible, or sensible, to implement erosion control works effectively across such large areas.

The contribution of each sub-catchment to the mean annual suspended sediment export from the river basin was calculated. The sub-catchments are the link internal areas described in Figure 1. The calculations were made once the mean annual suspended sediment export was calculated. The method tracks back upstream calculating from where the sediment load in each link is derived. The calculation takes a probabilistic approach to sediment delivery through each river link encountered on the route from source to sea.

Each internal link catchment area delivers a mean annual load of suspended sediment (LF_x) to the river network. This is the sum of gully, hillslope and riverbank erosion delivered from that sub-catchment. The sub-catchment delivery contributes to the load of suspended sediment (TIF_x;) received by each river link. Each link yields some fraction of that load (YF_x). The rest is deposited. The ratio of TIF_x/YF_x is the proportion of suspended sediment that passes through each link. It can also be viewed as the probability of any individual grain of suspended sediment passing through the link. The suspended load delivered from each sub-catchment will pass through a number of links on route to the catchment mouth. The amount delivered to the mouth is the product of the loading LF_x and the probability of passing through each river link on the way:

$$CO_x = LF_x x \frac{TIF_x}{YF_x} x \frac{TIF_{x+1}}{YF_{x+1}} x......x \frac{TIF_n}{YF_n} \qquad (28)$$

where n is the number of links on the route to the outlet. Dividing this by the internal catchment area expresses CO_x as an erosion rate (t/ha/y). The proportion of suspended sediment passing through each river link is ≤ 1. A consequence of Equation (28) is that all factors being equal the further a sub-catchment is from the mouth the lower the probability of sediment reaching the mouth. This behaviour is modified though by differences in source erosion rate and deposition intensity between links.

Suspended Sediment Budget Under Natural Conditions

There are naturally strong differences in suspended sediment load across diverse environments. To assess the extent to which the current sediment loads reflect the natural circumstances, and to what extent they reflect accelerated sediment supply, requires prediction of natural sediment loads. This is necessarily a fairly speculative process as there is limited knowledge of natural conditions, and no sediment load data other than for a few small catchments which remain relatively undisturbed. Methods to estimate the natural rate of hillslope erosion were described above. The delivery of this sediment to streams was determined using the same hillslope sediment delivery ratio as for present conditions. The natural rate of gully and riverbank erosion are negligible compared to current rates and were not included in the analysis, thus all sediment is supplied from hillslopes. Deposition of suspended sediment was modelled as described above assuming no changes to flood flow. Reservoir deposition was, of course, omitted.

Hydrology

Several hydrological parameters are used in the river sediment budget methods. These need to be predicted for each river link across the river basin. The variables needed are:

- the mean annual flow
- the mean annual sum of $Q^{1.4}$ for calculating mean annual sediment transport capacity;
- the bankfull discharge; and
- a representative flood discharge form floodplain deposition.

Values for mean annual flow were derived from available gauging records and a simple empirical rule based upon rainfall and catchment area was used to predict values in ungauged river links. The same approach was used for the mean annual sum of $Q^{1.4}$ The other two hydrological parameters were also derived from gauging records by regression against mean annual flow.

PART 3: Catchment Statistics

Statistics for each catchment considered in this report are detailed in this section. The primary data source for each component is shown in the table below. It should be noted that the figures provided for land use are intended as a guide only. Data is extracted from a range of sources and is collected at various scales, with varying levels of accuracy. In all instances, the original data was not prepared specifically for the purpose of this report. In addition, datasets are not considered to be exhaustive and some of the datasets are not complete for the entire extent of the 26 catchments considered in this report. Where the data is not available for a catchment, the symbol N/A is shown. The Authority intends to update this information as it becomes available. The maps produced in this report have been prepared by the Information Coordination Analysis Unit of the Authority.

Further information on datasets can be obtained by contacting the Authority's GIS Manager at gis@gbrmpa.gov.au.

Area (km^2)	Derived from Department of Natural Resources basin coverage (1994).
% Gauged	Furnas, (in prep). Terrestrial runoff to the Great Barrier Reef: A synthesis.
Mean Discharge Per Year (km^3)	Furnas, (in prep). Terrestrial runoff to the Great Barrier Reef: A synthesis.
Rainfall (mm)	Data provided by Bureau of Meteorology (2000). Estimates of rainfall for each catchment were calculated using spatial analysis in ARCINFO by combining rainfall data with DNR basin boundaries.
Runoff (mm/km^2)	Furnas, (in prep). Terrestrial runoff to the Great Barrier Reef: A synthesis.
Runoff/Rainfall Ratio	Furnas, (in prep). Terrestrial runoff to the Great Barrier Reef: A synthesis.
Population	Australian Bureau of Statistics Census Data (1996). Estimates of population for each catchment were calculated using spatial analysis in ARCINFO by combining census data with DNR basin boundaries. Differences between basin boundaries and statistical division boundaries may result in some over-estimations in the population figures for each catchment.
Clearing (km^2)	Graetz *et al*. (1995). Estimates of the area of each catchment that is cleared were calculated using spatial analysis in ARCINFO by combining cleared data with DNR basin boundaries. The figures shown are the sum of the "cleared" and "thinned" categories. Refer to Box 6.
% Cleared	The estimated percentage of each catchment that is cleared is based on the above figure for clearing.
Area under Grazing (km^2)	Estimation based on the subtraction of the available land use data from the total catchment area. Where more accurate data sources are available, these are cited.
Area under Sugar (km^2)	Data provided by Department of Natural Resources (1994). Derived from visual interpretation of Landsat TM Satellite Imagery and field validation. Imagery ranging from 1991 to 1994. Note that this data does not cover the entire Great Barrier Reef catchment. Estimates of the area of sugar in each catchment were calculated using spatial analysis in ARCINFO by combining sugar data with DNR basin boundaries. Where more accurate data sources are available, these are cited.
Area under Horticulture (km^2)	Data provided by Department of Natural Resources (1994). Derived from visual interpretation of Landsat TM Satellite Imagery and field validation. Imagery ranging from 1991 to 1994. Note that this data does not cover the entire Great Barrier Reef catchment. Estimates of the area of horticulture in each catchment were calculated using spatial analysis in ARCINFO by combining horticultural data with DNR basin boundaries.

Pesticide Application (kg active ingredient/year)	Hamilton and Haydon (1996). *Pesticides and fertilisers in the Queensland sugar industry - estimates of usage and likely environmental fate.* Department of Primary Industries, Queensland.
Sediment Exports	1850 and current data: National Land and Water Resources Audit. Risk Group and Targets: Scientific Working Group – Refer to Part 2, Section 2.1.
Nitrogen and Phosphorus Exports	1850 and current data: Australian Institute of Marine Science. Risk Group and Targets: Scientific Working Group – Refer to Part 2, Sections 2.2 and 2.3.
Stateforest and Timber Reserves (km^2)	Data provided by Department of Natural Resources and Auslig P/L (1996). Estimates of the area of stateforest and timber reserve in each catchment were calculated using spatial analysis in ARCINFO by combining forest data with DNR basin boundaries.
Protected Areas (km^2)	Data provided by Queensland Department of Environment (1996) and includes National Parks, Conservation Parks, National Parks (Scientific) and Resource Reserves. Estimates of the area of protected areas in each catchment were calculated using spatial analysis in ARCINFO by combining protected area data with DNR basin boundaries.
Wet Tropics World Heritage Area (km^2)	Data provided by Wet Tropics Management Authority (2001). Estimates of the area of the Wet Tropics World Heritage Area in each catchment were calculated using spatial analysis in ARCINFO by combining Wet Tropics data with DNR basin boundaries.

Box 6: Estimates of land clearing in the GBR catchment

The extent and thickness of vegetation cover in a landscape is a major factor influencing soil erosion and nutrient loss. Several attempts have been made to estimate the extent of vegetation clearing in areas that include the GBR catchment (Graetz *et al*. 1995; Barson *et al*. 2000; Qld. EPA, 2000 and 2001). These efforts involve different approaches with different technologies, cover slightly different areas and are based on different assumptions in the interpretation of the data. Not surprisingly, the three approaches cited above yield different estimates of the extent of clearing. In all cases, definitions of clearing refer to the removal of the dominant over-storey vegetation (tree cover) and do not attempt to comprehensively quantify the relative cover of under-storey vegetation and grasses which have a major effect upon soil erosion rates at the paddock scale.

Two of the three approaches (Graetz *et al*. 1995, Barson *et al*. 2000) are largely based on the interpretation of satellite imagery, in conjunction with ground truthing. The third (EPA, 2000 and 2001) is based on the interpretation of several types of imagery in conjunction with statewide remnant vegetation mapping. Graetz *et al*. (1995) analysed Landsat MSS imagery and classified the vegetation as being: cleared, thinned, uncleared and indeterminate. In the landuse classification produced by the Bureau of Rural Science (Barson *et al*. 2000), landcover imagery (Landsat TM) was classified in a variety of categories, which included: native forest and rainforest (nominally uncleared), native and sparse grazing land (nominally uncleared), crops and grazing (cleared) and bare (cleared). The EPA mapping included a specific category of cleared land based on the absence of native vegetation consistent with the observed remnant vegetation community.

As an example of the range of results produced, the data of Graetz *et al*. (1995) classifies 73 percent of the Burdekin River catchment as having been "cleared" or "thinned". The Bureau of Rural Science study (Barson *et al*. 2000) estimates that 35% of the Burdekin River catchment has a landcover type which involves clearing. In the case of the Queensland EPA vegetation mapping, 24% of the extent of the Burdekin River catchment mapped to date (close to 90%) is classified as cleared. A rigorous examination of the spatial relationships between these clearing estimates has not been published, so it is not possible at present to assess the accuracy or appropriateness of the various measures.

In this report, catchment-scale estimates of clearing derived from the Graetz *et al*. (1995) data set are presented. Furnas, (in prep) includes further detail of all of the data sets.

Normanby River Catchment

Catchment Information

Description

Area (km²)	24408
% Gauged	33
Mean Discharge Yr (km³)	4.9
Rainfall (mm)	1185
Runoff (mm/m²)	203
Runoff/Rainfall Ratio	17

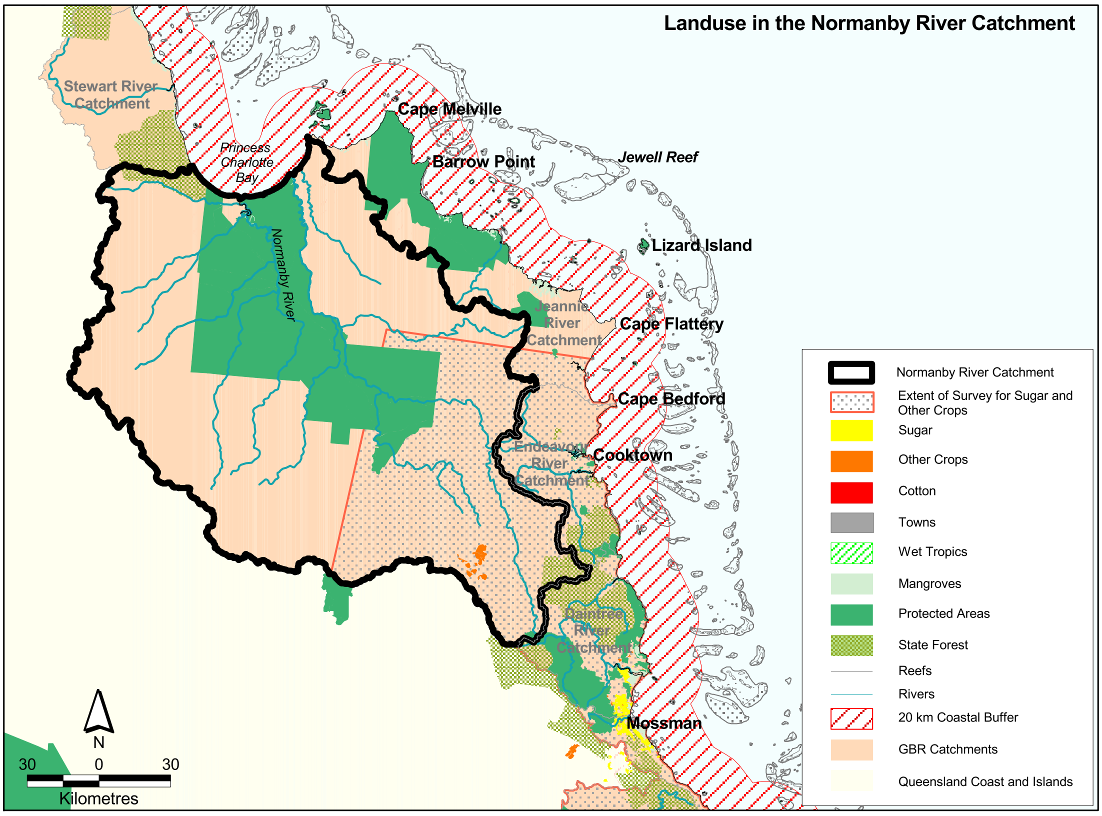
Land Use

Population	N/A
Clearing (km²)	140
% Cleared	1
Area under Grazing (km²)	18495
Area under Sugar (km²)	N/A
Area under Horticulture (km²)	35

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	540000	1620279	327273	3	0	1620279	327273
Total N Export	12064	1960	396	1	0	1960	396
Total P Export	60	208	42	3.5	0	208	42

Data Confidence Index = 2



Normanby River Catchment

The Normanby River catchment covers an area of 24408 km^2. The catchment is one of the few relatively undisturbed areas of the Great Barrier Reef Catchment Area. Grazing is the dominant land use approximately18495 km^2 and is characterised by low stocking rates associated with open-range grazing. Other land uses include 35 km^2 of horticulture. State forests and timber reserves occupy 407 km^2 and protected areas cover 5470 km^2. Sediment, total nitrogen and total phosphorus exports are classified as low risk in the Normanby River Catchment.

Issues in the catchment:

- Soils are prone to erosion when cleared. More fertile soils are suitable for cropping areas.
- Potential effects of mining and exploration activities on water quality, erosion and siltation will continue to be an important concern.
- Some fauna species are threatened in the catchment.
- Grazing is conducted in the majority of the catchment.
- Limited land clearing to date.
- 22% of the catchment is within protected areas
- Significant inshore reefal areas.
- Commercial fishery.

Water sampling was conducted by AIMS in the Normanby River during the 1999 and 2000 wet seasons. An AIMS river logger has been deployed in the Normanby River for two years.

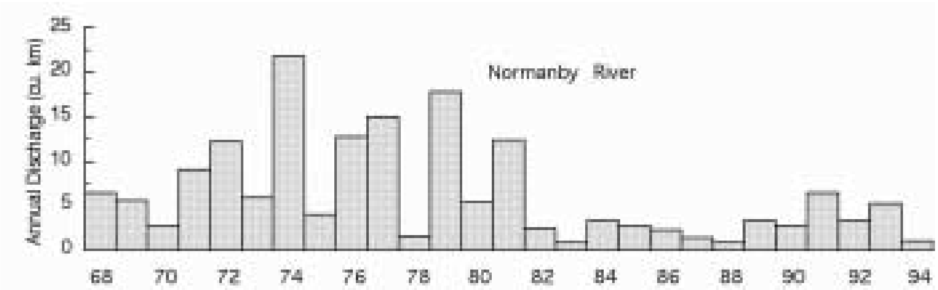


Figure 6. Water discharge patterns in the Normanby River.

Endeavour River Catchment

Catchment Information

Description

Area (km²)	2104
% Gauged	28
Mean Discharge Yr (km³)	1.8
Rainfall (mm)	1939
Runoff (mm/m²)	865
Runoff/Rainfall Ratio	45

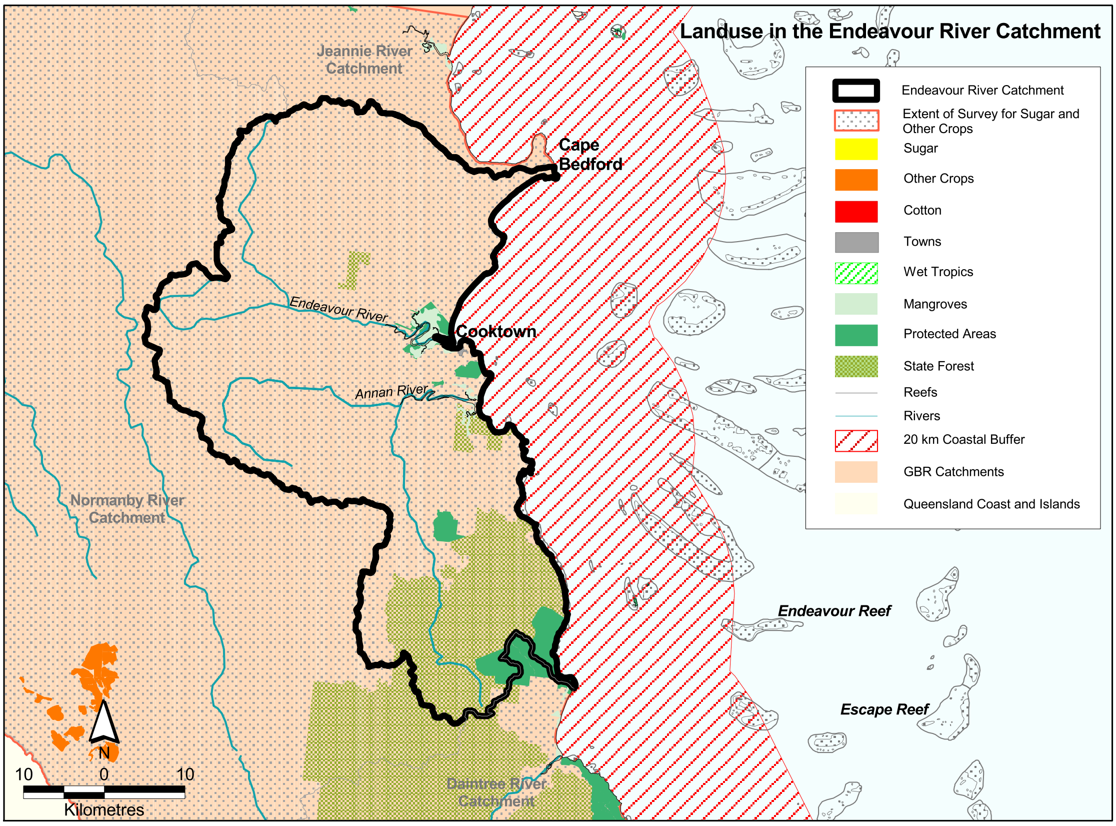
Land Use

Population	1344
Clearing (km²)	0
% Cleared	0
Area under Grazing (km²)	1768
Area under Sugar (km²)	N/A
Area under Horticulture (km²)	N/A

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	97000	486871	267582	5	0	486871	267582
Total N Export	245	721	396	2.9	33	483	265
Total P Export	12	76	42	6.3	33	51	28

Data Confidence Index = 1



Endeavour River Catchment

The Endeavour River catchment covers an area of 2104 km^2. Grazing occupies 1768 km^2. State forests and timber reserves occupy 330 km^2 and protected areas cover 300 km^2, including 264 km^2 in the Wet Tropics World Heritage Area. Sediment export is classified as low risk, and total nitrogen and total phosphorus exports are classified as medium risk in the Endeavour River catchment.

Issues in the catchment

- There are potential growth areas around Cooktown and the Endeavour River for cultivation, tourism and small hobby farm acreage.
- Some fauna species are threatened in the catchment.
- Limited clearing to date.
- Only 14% of the catchment is within protected areas.
- Significant inshore reefal areas.
- Commercial fishery.

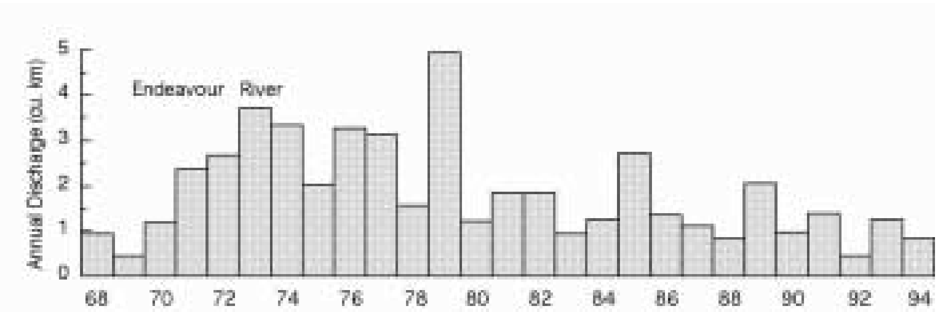


Figure 7. Water discharge patterns in the Endeavour River

Daintree River Catchment

Catchment Information

Description

Area (km^2)	2192
% Gauged	39
Mean Discharge Yr (km^3)	1.26
Rainfall (mm)	2492
Runoff (mm/m^2)	575
Runoff/Rainfall Ratio	23

Source: *Russell et al., 1998

Land Use

Population	738
Clearing (km^2)	11
% Cleared	1
Area under Grazing (km^2)	45*
Area under Sugar (km^2)	48*
Area under Horticulture (km^2)	<1

Pesticide Application

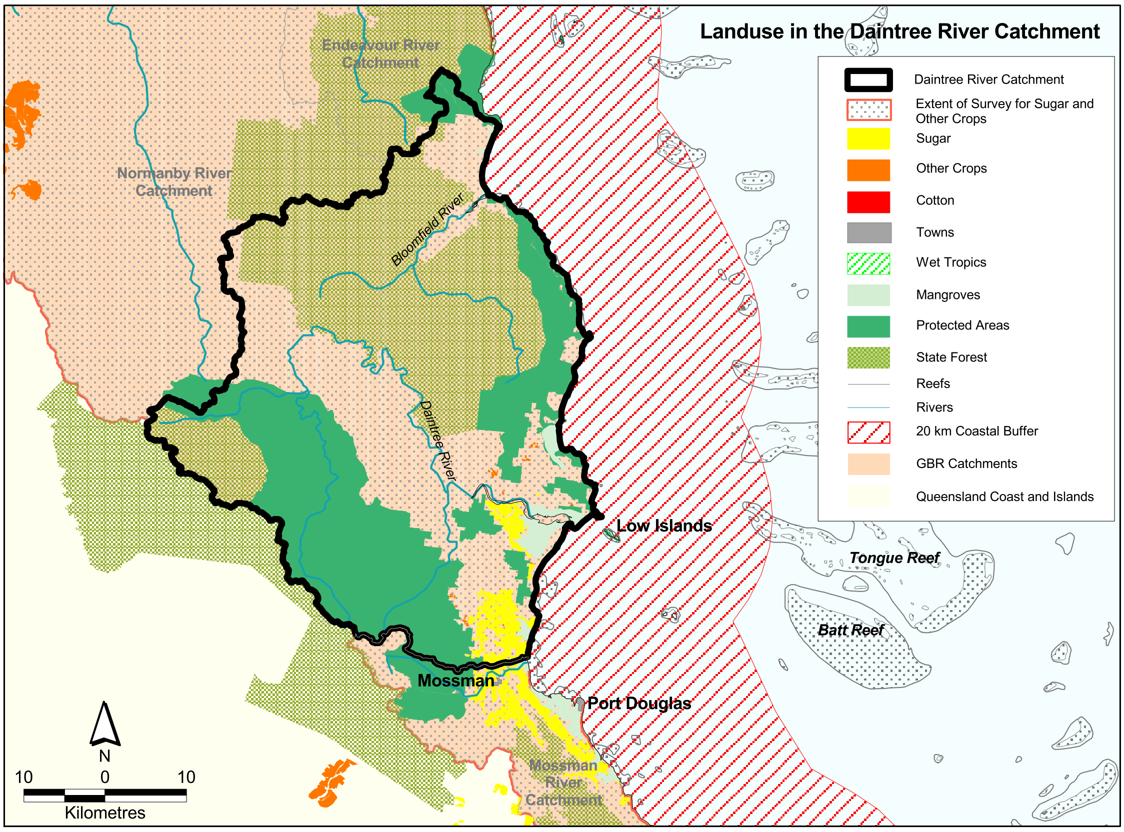
(Kg Active Ingredient/Yr)

Atrazine	3368
Diuron	2378
2-4D	1804
Chlorpyrifos	1319
MEMC	20

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km^3	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km^3 Target
Sediment Export	2300	94132	74603	4.1	0	94132	74603
Total N Export	169	499	396	2.9	33	334	265
Total P Export	8	53	42	6.6	33	36	28

Data Confidence Index = 1



Daintree River Catchment

The Daintree River catchment covers an area of 2192 km^2. Approximately 1780 km^2 of the catchment is in the Wet Tropics World Heritage Area. State forests and timber reserves occupy 784 km^2. Grazing occupies 45 km^2. Other land uses include sugarcane 48 km^2 with less than <1 km^2 of horticultural land. Sediment export is classified as low risk, and total nitrogen and total phosphorus exports are classified as medium risk in the Daintree River catchment.

Issues in the catchment:

- Small areas of significant erosion in cropping lands.
- Clearing of land in the lower Daintree has resulted in significant streambank erosion and siltation problems.
- In areas where vegetation has not been disturbed, streams are in a relatively pristine condition.
- The area is becoming a significant tourist destination with urban facilities developing in agricultural land and undisturbed forests.
- Some fauna species are threatened.
- Approximately 81% of the catchment is within protected areas.
- Small area cleared for cropping with increasing pesticide usage.
- Close proximity to inshore reef areas.
- Commercial and recreational fishery.
- Extensive marine tourism.

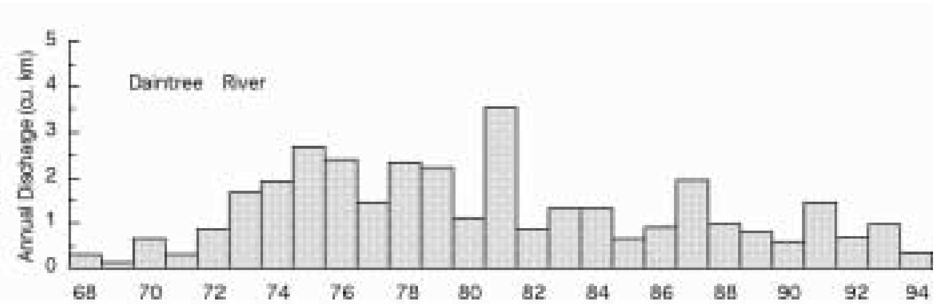


Figure 8. Water discharge patterns in the Daintree River.

Mossman River Catchment

Catchment Information

Description

Area (km²)	466
% Gauged	12
Mean Discharge Yr (km³)	0.6
Rainfall (mm)	2208
Runoff (mm/m²)	1265
Runoff/Rainfall Ratio	57

Land Use

Population	17177
Clearing (km²)	19
% Cleared	4
Area under Grazing (km²)	15*
Area under Sugar (km²)	57*
Area under Horticulture (km²)	<1

Source: *Russell et al., 1998

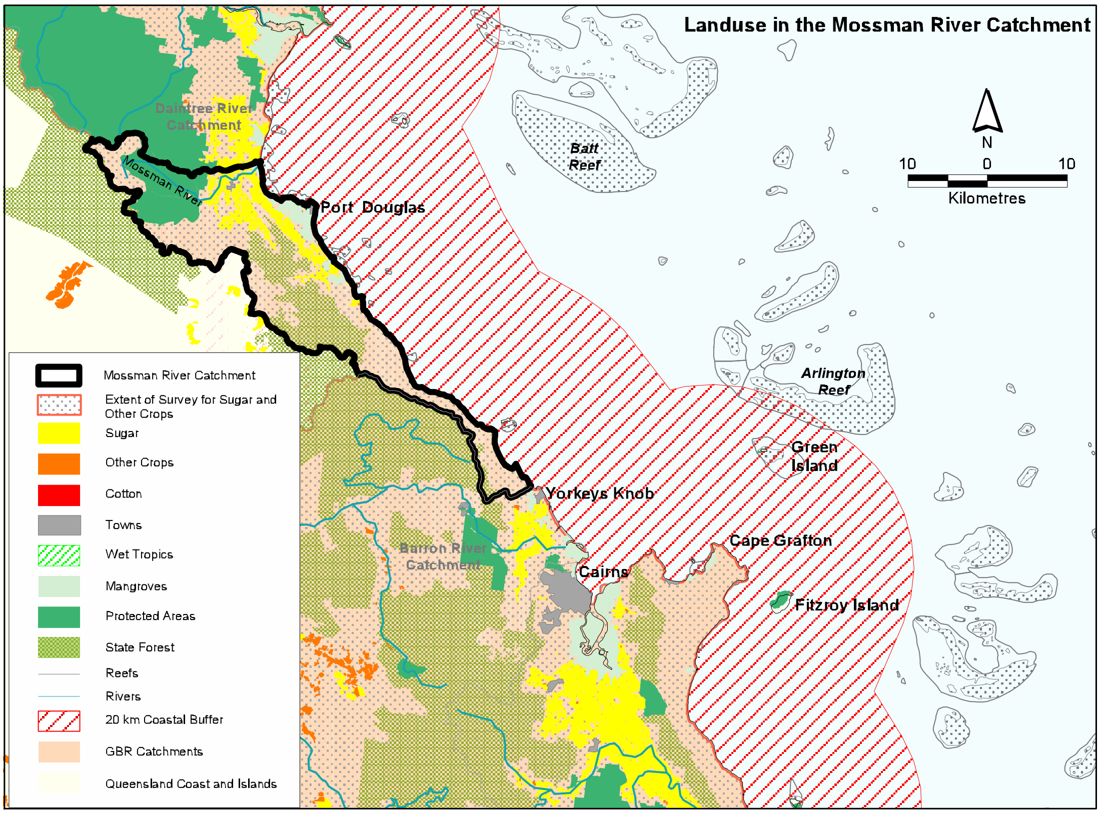
Pesticide Application
(Kg Active Ingredient/Yr)

Atrazine	5241
Diuron	3278
2-4D	2737
Chlorpyrifos	1978
MEMC	31

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	3000	15131	25424	5	0	15131	25424
Total N Export	79	231	396	2.9	50	117	198
Total P Export	4	25	42	6.3	33	17	28

Data Confidence Index = 1



Mossman River Catchment

The Mossman River catchment covers an area of 466 km^2. Approximately 285 km^2 of the catchment is in the Wet Tropics World Heritage Area. State forests and timber reserves occupy 126 km^2. Grazing occupies 15 km^2. Other land uses include sugarcane 57 km^2 with less than <1 km^2 of horticultural land. Sediment export is classified as low risk, whilst total phosphorus export is classified as medium risk and total nitrogen export is classified as high risk in the Mossman River catchment.

Issues in the catchment:

- Use of agricultural chemicals in the production of crops is a concern for discharge of runoff to the Mossman River.
- Sugar production dominates cultivated cropping in the catchment.
- The area is becoming a significant tourist destination with urban facilities developing in agricultural land and undisturbed forests.
- Approximately 61% of the catchment is within protected areas.
- Close proximity to inshore reefal areas.
- Some fauna species are threatened.
- Commercial and recreational fishery.
- Land based and marine tourism.

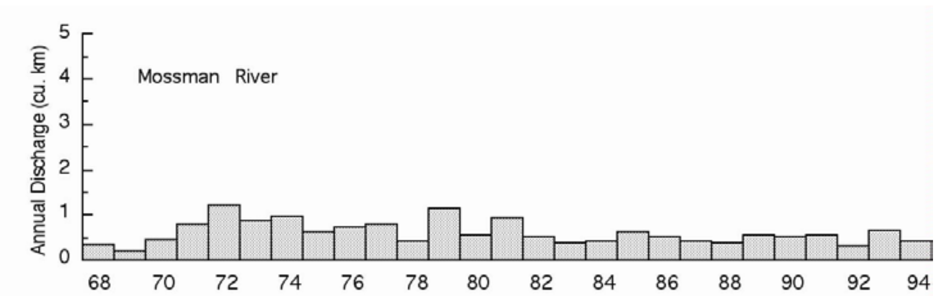


Figure 9. Water discharge patterns in the Mossman River.

Barron River Catchment

Catchment Information

Description

Area (km^2)	2902
% Gauged	89
Mean Discharge Yr (km^3)	0.8
Rainfall (mm)	1453
Runoff (mm/m^2)	279
Runoff/Rainfall Ratio	19

Land Use

Population	23814
Clearing (km^2)	130
% Cleared	6
Area under Grazing (km^2)	227*
Area under Sugar (km^2)	76*
Area under Horticulture (km^2)	117

Source: *Cogle et al., 2000

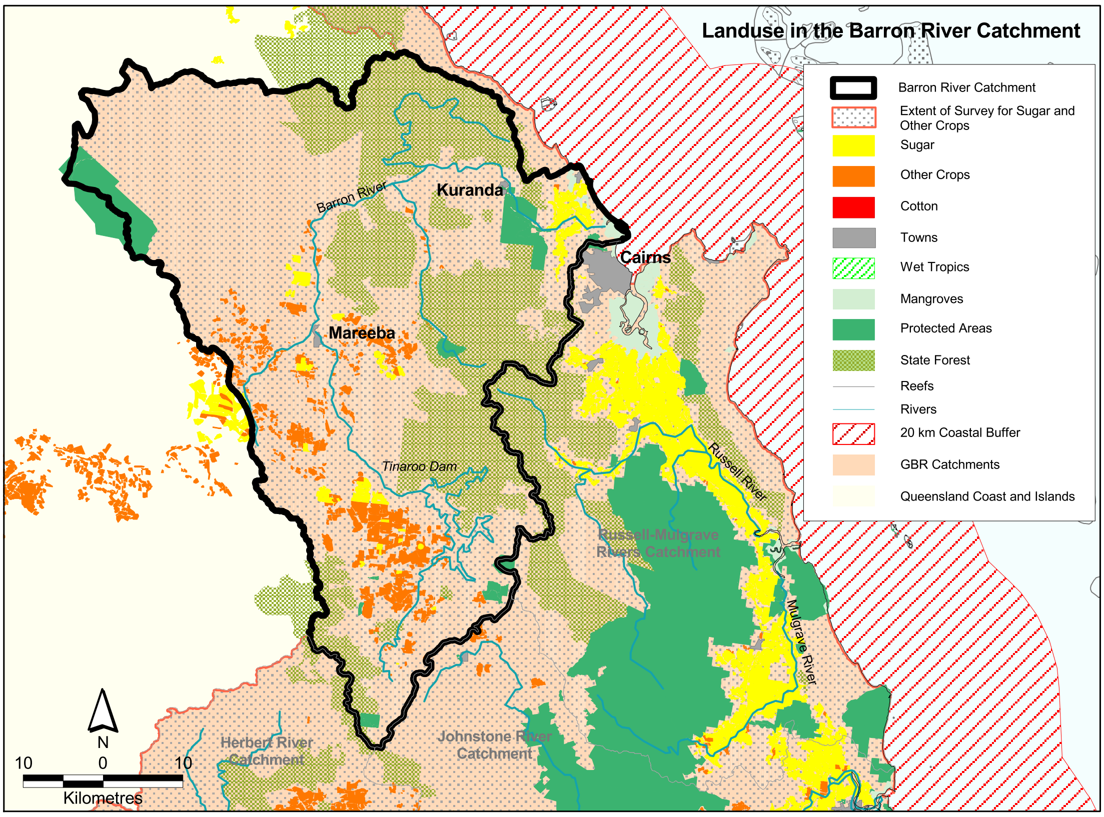
Pesticide Application
(Kg Active Ingredient/Yr)

Atrazine	5756
Diuron	835
2-4D	2637
Chlorpyrifos	1858
MEMC	37

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km^3	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km^3 Target
Sediment Export	18000	45877	180247	8.1	33	97738	120765
Total N Export	109	321	396	2.9	33	215	265
Total P Export	5	34	42	6.8	33	23	28

Data Confidence Index = 2



Barron River Catchment

The Barron River catchment covers an area of 2902 km^2 which contains the Barron River in two distinct areas, the Atherton Tableland and the coastal plain. Approximately 476 km^2 of the catchment is in the Wet Tropics World Heritage Area. State forests and timber reserves occupy 831 km^2. Grazing occupies 227 km^2. Other land uses include sugarcane 76 km^2 and 117 km^2 of horticultural land. Sediment, total nitrogen and total phosphorus exports are classified as medium risk in the Barron River catchment.

Issues in the catchment:

- Erosion of cropping lands due to high intensity rainfall is of concern.
- Weeds are a problem in some areas within the catchment.
- Significant loads of nutrient and pesticide to the receiving waters.
- Significant alteration of the river has occurred through very large extractions of sand and gravel to supply construction sites at Cairns and hydroelectricity and water storages.
- Dredging of the Barron delta has caused the stream banks to be modified and siltation to be carried out into the estuary.
- Large areas of mangrove and wetlands have been removed.
- Approximately 16% of the catchment is within protected areas.
- Extensive agricultural cropping.
- Close proximity to inshore reefal areas.
- Commercial and recreational fishery.
- The major centre for marine tourism for the Great Barrier Reef.
- Land based tourism.
- Commercial port.

Water sampling by AIMS was conducted upstream at the Kamerunga bridge and downstream at the highway bridge between 1989 and 1995. An AIMS river logger has been deployed at the Kamerunga bridge for two years.

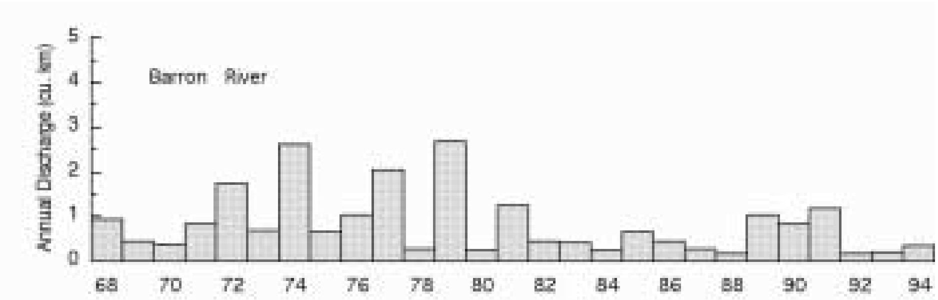


Figure 10. Water discharge patterns in the Barron River.

Russell - Mulgrave Rivers Catchment

Catchment Information

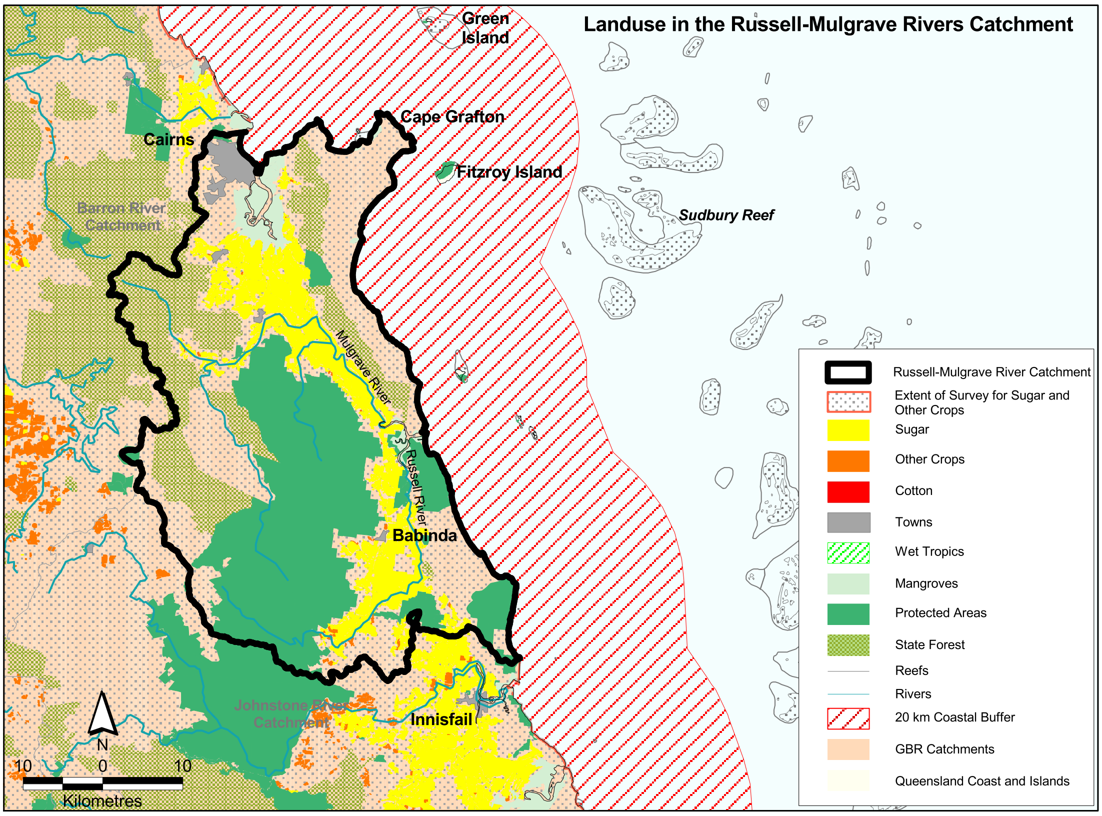
Description		Land Use		Pesticide Application (Kg Active Ingredient/Yr)	
Area (km²)	1983	**Population**	75400	**Atrazine**	34068
% Gauged	48	**Clearing (km²)**	277	**Diuron**	4702
Mean Discharge Yr (km³)	3.6	**% Cleared**	14	**2-4D**	13937
Rainfall (mm)	3016	**Area under Grazing (km²)**	55*	**Chlorpyrifos**	9021
Runoff (mm/m²)	1836	**Area under Sugar (km²)**	232*	**MEMC**	202
Runoff/Rainfall Ratio	61	**Area under Horticulture (km²)**	8		

Source: *Russell et al., 1996a

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	37000	222425	60989	6	33	149025	40863
Total N Export	489	1441	396	2.9	50	721	198
Total P Export	24	153	42	6.4	33	103	28

Data Confidence Index = 2



Russell - Mulgrave Rivers Catchment

The Russell-Mulgrave Rivers catchment covers an area of 1983 km^2. Approximately 1137 km^2 of the catchment is in the Wet Tropics World Heritage Area. State forests and timber reserves occupy 346 km^2 and protected areas cover approximately 1200 km^2. Other land uses include sugarcane 232 km^2 and 8 km^2 of horticultural land. Grazing occupies a small proportion of the catchment, approximately 55 km^2. Sediment and total phosphorus exports are classified as medium risk whilst total nitrogen export is classified as high risk in the Russell-Mulgrave catchment.

Issues in the catchment:

- Cultivation land has a high risk of erosion and losses of nutrient and pesticides.
- Cultivated areas dominated by sugar production
- Approximately 60% loss of coastal wetlands.
- High contribution on nutrient and pesticides.
- There is significant pressure on the sand resources of the Mulgrave River.
- Concerns existing within the catchment area include flooding siltation, drainage of wetland, river course management techniques, de-snagging and channel straightening.
- Fauna species are threatened in the catchment.
- Approximately 60% of the catchment is within protected areas.
- Close proximity to inshore reefal areas.
- Commercial and recreational fisheries.
- Marine tourism.
- Growing land based tourism.

Opportunistic water sampling was conducted by AIMS at upstream and downstream sites on both the Russell and Mulgrave Rivers, from 1989 to 1995. The Great Barrier Reef Marine Park Authority sampled the rivers in the late 1990's.

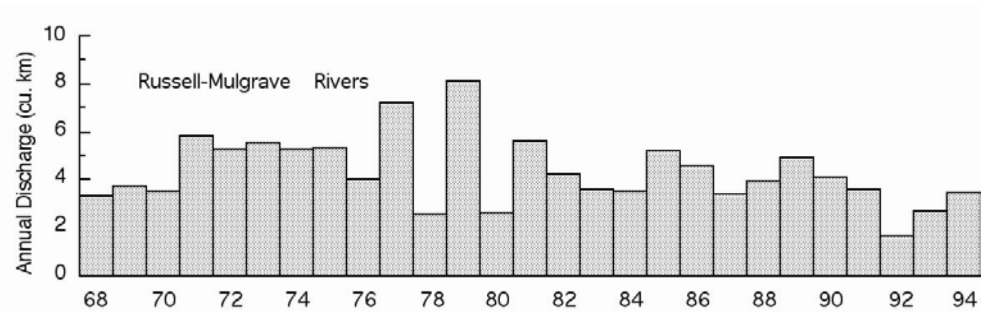


Figure 11. Water discharge patterns in the Russell- Mulgrave Rivers

Johnstone River Catchment

Catchment Information

Description

Area (km^2)	2325
% Gauged	59
Mean Discharge Yr (km^3)	4.7
Rainfall (mm)	2996
Runoff (mm/m^2)	2009
Runoff/Rainfall Ratio	67

Land Use

Population	13428
Clearing (km^2)	406
% Cleared	17
Area under Grazing (km^2)	493*
Area under Sugar (km^2)	394*
Area under Horticulture (km^2)	44*

Pesticide Application
(Kg Active Ingredient/Yr)

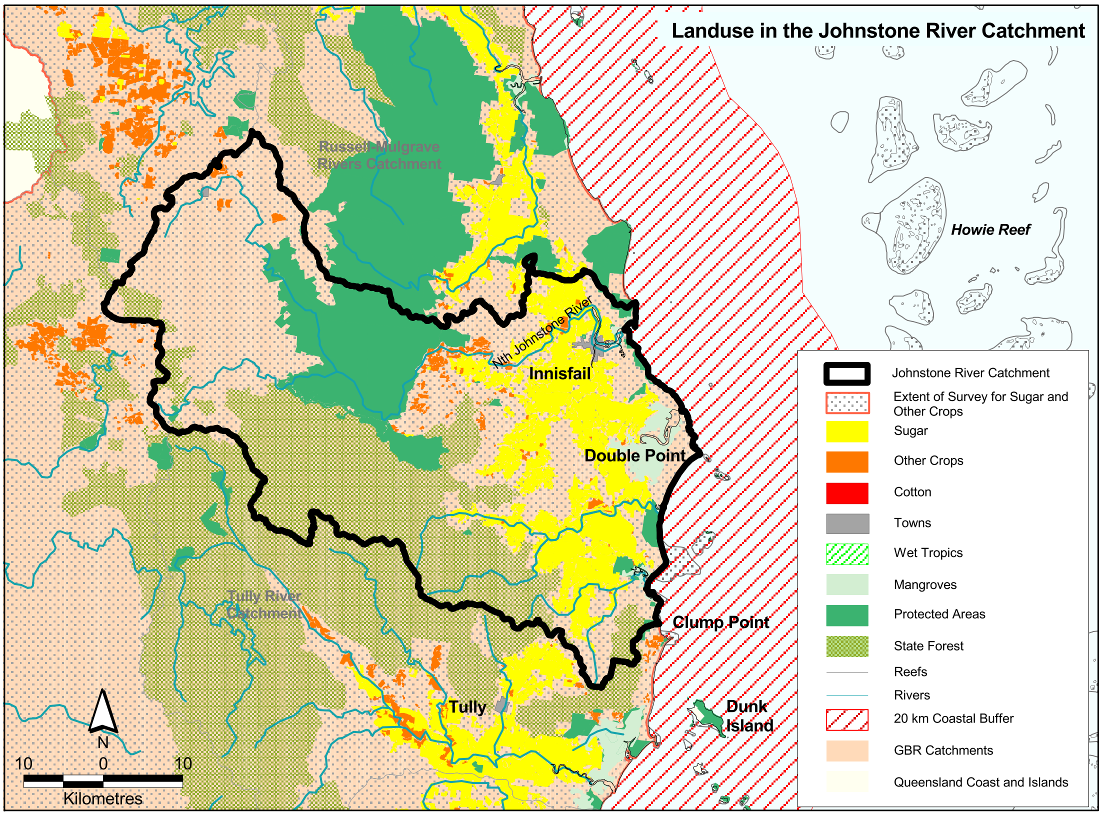
Atrazine	25284
Diuron	17353
2-4D	14938
Chlorpyrifos	6313
MEMC	251

Source: * Russell and Hales, 1997 ; Russell et al., 1996b ; Russell and Hales, 1993

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km^3	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km^3 Target
Sediment Export	10000	305142	65310	30.5	50	152571	32655
Total N Export	628	1849	396	2.9	50	925	198
Total P Export	31	196	42	6.5	50	98	21

Data Confidence Index = 3



Johnstone River Catchment

The Johnstone River catchment covers an area of 2325 km^2 which contains the North and South Johnstone Rivers. Approximately 985 km^2 of the catchment is in the Wet Tropics World Heritage Area. State forests and timber reserves occupy 613 km^2 and protected areas, including the Wet Tropics World Heritage Area, cover approximately 1000 km^2. Grazing occupies approximately 493 km^2, mainly occurring in central areas of the catchment. The lower river flood plain and coastal areas are used intensively for cultivation particularly sugarcane which occupies 394 km^2 and horticulture 44 km^2. Sediment, total nitrogen and total phosphorus exports are classified as high risk in the Johnstone River catchment.

Issues in the catchment:

- On grazing land erosion is reasonably stable with isolated areas of poor management causing erosion and weed infestation of pastures.
- Cropping land is prone to erosion due to the high intensity, long duration rainfall and steep slopes.
- High contribution of nutrients (particularly nitrates) and pesticides from cropping lands.
- The catchment has been put under pressure through changed and lost habitat with some species threatened.
- Approximately 43% of the catchment is within protected areas.
- Approximately 65% loss of coastal wetlands.
- Commercial and recreational fishery.
- Close proximity to inshore reefal areas.
- Recreation marine use.
- Commercial port.

AIMS conducted water sampling at a downstream site in the South Johnstone River from 1989-1992, with help from staff at QDPI Research Station. A high frequency of sampling maintained over significant rainfall events such as the "first flush" has provided valuable insights on nutrient dynamics in a wet tropical catchment. In 1992, DNR initiated a comprehensive water sampling program over the entire Johnstone catchment. This study continued until 1997. An AIMS river logger has been deployed on the highway bridge of the North Johnstone River for two years.

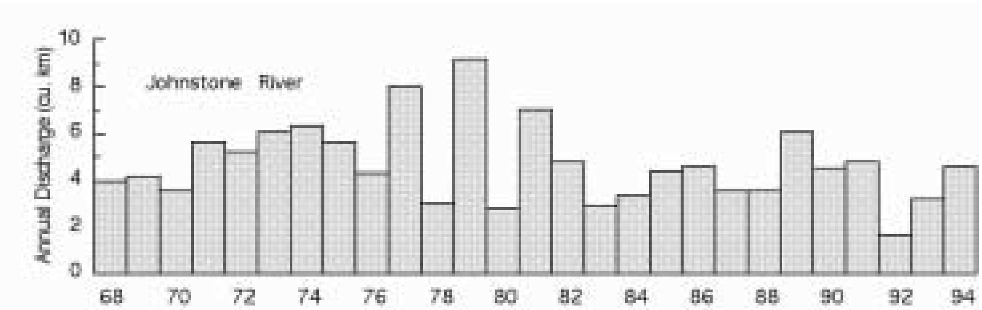


Figure 12. Water discharge patterns in the Johnstone River.

Tully River Catchment

Catchment Information

Description

Area (km²)	1683
% Gauged	88
Mean Discharge Yr (km³)	3.3
Rainfall (mm)	2855
Runoff (mm/m²)	1954
Runoff/Rainfall Ratio	68

Land Use

Population	5585
Clearing (km²)	256
% Cleared	15
Area under Grazing (km²)	316
Area under Sugar (km²)	247
Area under Horticulture (km²)	26

Pesticide Application

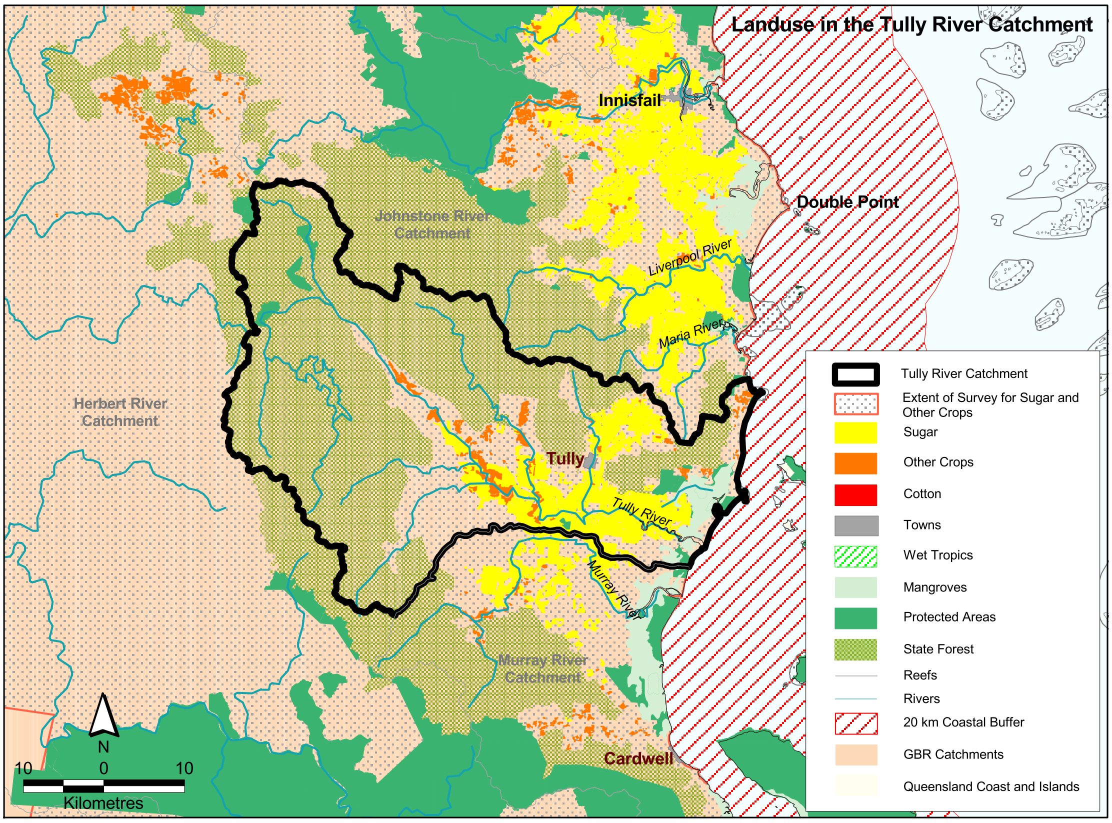
(Kg Active Ingredient/Yr)

Atrazine	22364
Diuron	2768
2-4D	9187
Chlorpyrifos	2941
MEMC	115

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	15000	88084	26748	5.9	33	59016	17921
Total N Export	442	1303	396	2.9	50	652	198
Total P Export	22	138	42	6.3	33	92	28

Data Confidence Index = 3



Tully River Catchment

The Tully River catchment covers an area of 1683 km^2. Approximately 1093 km^2 of the catchment is in the Wet Tropics World Heritage Area. State forests and timber reserves occupy 1030 km^2. Grazing occupies approximately 316 km^2. Other land uses include 247 km^2 sugarcane and 26 km^2 of horticultural land. Sediment and total phosphorus exports are classified as medium risk and total nitrogen export is classified as high risk in the Tully River catchment.

Issues in the catchment:

- The Tully River is subjected to frequent flooding. This has resulted in over-bank flows creating severe erosion problems on the lower and middle reaches of the rivers.
- Hydrological modification of the flood plain.
- Approximately 65% loss of coastal wetlands.
- Approximately 65% of the catchment is within protected areas.
- High contribution of nutrient (particularly nitrates) and pesticides.
- Close proximity to inshore reefal areas.
- Commercial and recreational fishery.
- Marine and land based tourism.

A collaborative program with the Tully Bureau of Sugar Experiment Stations (BSES) office was initiated in 1987 to measure nutrient levels at an upstream and downstream site in the Tully River, and at four further sites on Jarra, Boulder and Bauyan Creeks within the Tully catchment. Sampling was conducted at regular, monthly intervals and at periods through the wet season following large rainfall events. Sampling in the main river channel was continued for thirteen years to 2000 whilst other catchment sampling was terminated after eight years. This sampling program has provided valuable data on catchment inputs and allowed changes over time to be investigated. An AIMS river logger has been deployed at the Bruce Highway bridge over a number of wet seasons.

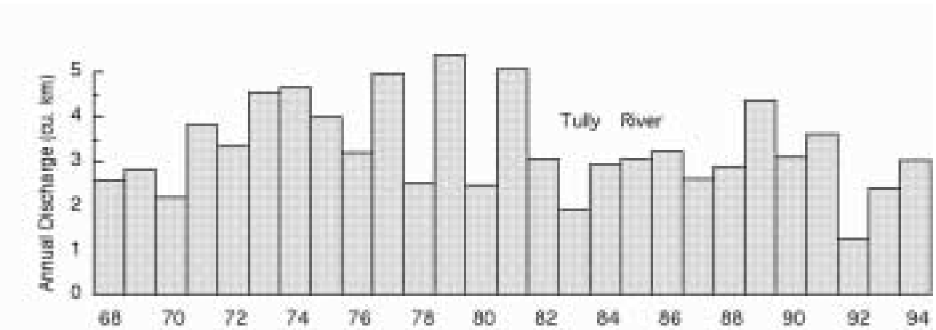


Figure 13. Water discharge patterns in the Tully River.

Murray River Catchment

Catchment Information

Description

Area (km²)	1107
% Gauged	14
Mean Discharge Yr (km³)	1.1
Rainfall (mm)	2098
Runoff (mm/m²)	958
Runoff/Rainfall Ratio	46

Land Use

Population	1296
Clearing (km²)	166
% Cleared	15
Area under Grazing (km²)	520
Area under Sugar (km²)	58
Area under Horticulture (km²)	<10

Pesticide Application

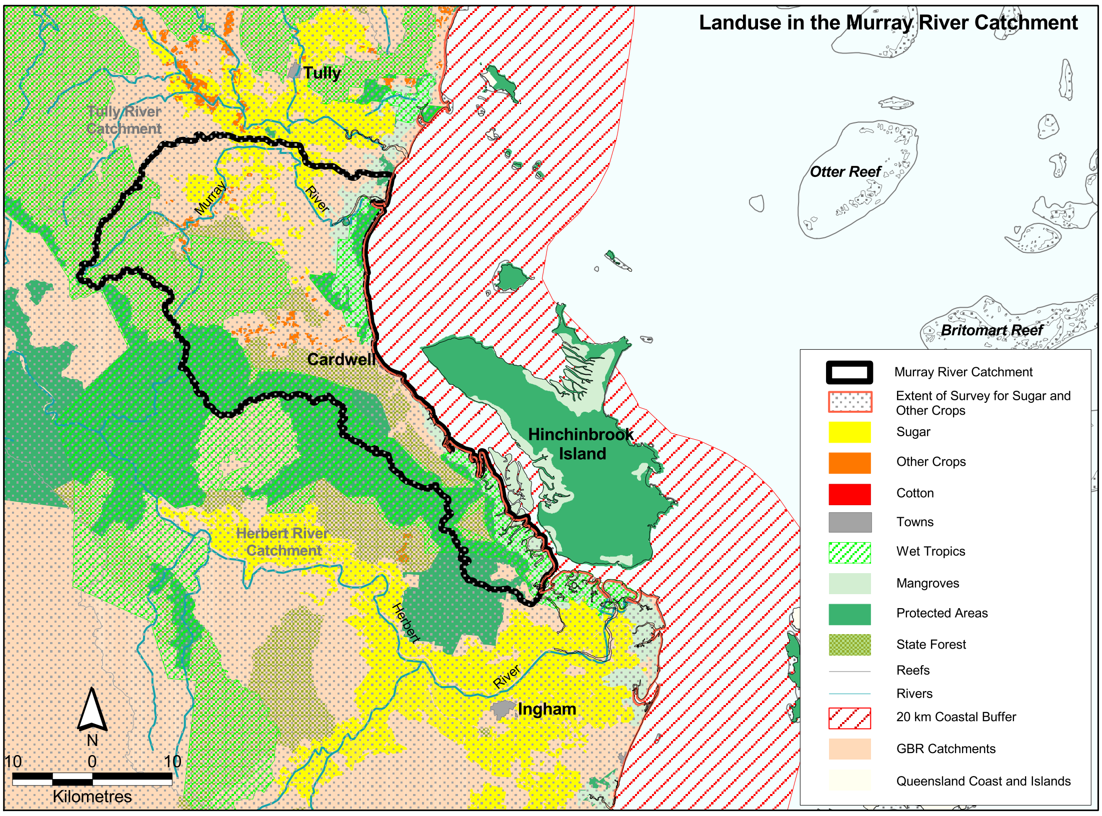
(Kg Active Ingredient/Yr)

Atrazine	8672
Diuron	1252
2-4D	3168
Chlorpyrifos	1166
MEMC	50

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	3000	17098	16038	5.7	33	11455	10745
Total N Export	142	440	396	2.9	50	210	198
Total P Export	7	45	42	6.4	33	30	28

Data Confidence Index = 1



Murray River Catchment

The Murray River catchment covers an area of 1107 km^2. Grazing occupies a large proportion of the catchment with 520 km^2. Approximately 518 km^2 is within the Wet Tropics World Heritage Area. Other land uses include 58 km^2 of sugarcane and <10 km^2 of horticulture. State forests and timber reserves occupy 361 km^2 and protected areas cover 518 km^2, including the Wet Tropics World Heritage Area. Sediment and total phosphorus exports are classified as medium risk, and total nitrogen export is classified as high risk in the Murray River catchment.

Issues in the catchment:

- The Murray River is subjected to frequent flooding. This has resulted in over-bank flows creating severe erosion problems on the lower and middle reaches of the rivers.
- Recent significant expansions in cultivated cropping.
- Increasing contribution of nutrient and pesticides.
- Close proximity to inshore reefal areas including Hinchinbrook Island.
- Recent significant losses of coastal wetlands.
- Approximately 47% of the catchment is within protected areas.
- Commercial and recreational fisheries.
- Increasing marine tourism.

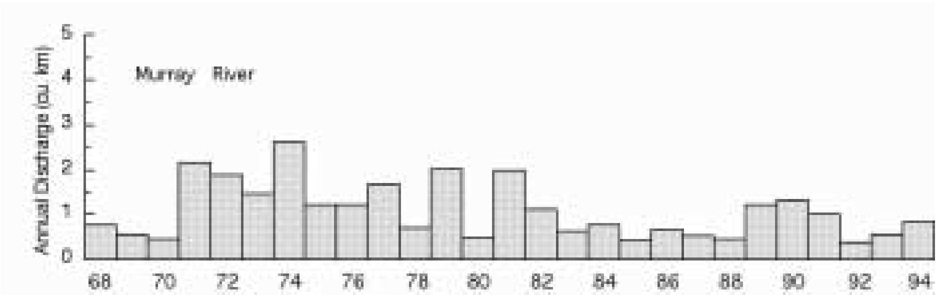


Figure 14. Water discharge patterns in the Murray River.

Herbert River Catchment

Catchment Information

Description

Area (km²)	9843
% Gauged	87
Mean Discharge Yr (km³)	4
Rainfall (mm)	1506
Runoff (mm/m²)	407
Runoff/Rainfall Ratio	27

Land Use

Population	8778
Clearing (km²)	1434
% Cleared	15
Area under Grazing (km²)	7330
Area under Sugar (km²)	691
Area under Horticulture (km²)	35

Pesticide Application

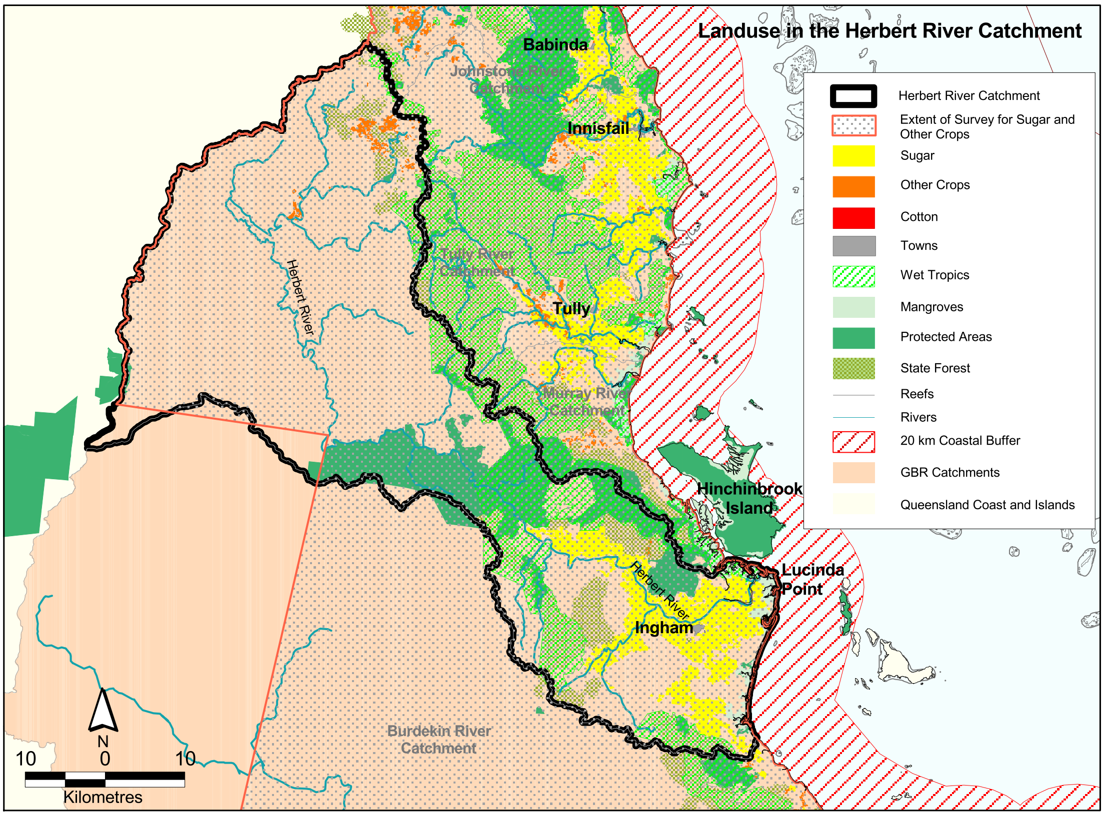
(Kg Active Ingredient/Yr)

Atrazine	33601
Diuron	16618
2-4D	28068
Chlorpyrifos	3084
MEMC	397

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	83000	664787	165835	8	33	445407	111109
Total N Export	539	1588	396	2.9	50	794	198
Total P Export	26	168	42	6.5	33	113	28

Data Confidence Index = 3



Herbert River Catchment

The Herbert River catchment covers an area of 9843 km^2. Grazing is the dominant land use including 7330 km^2, with cultivation of sugarcane on the lower river and coastal plains covering 691 km^2 and horticulture occupying 35 km^2. Approximately 1417 km^2 of the catchment is in the Wet Tropics World Heritage Area. State forests and timber reserves occupy 990 km^2 and total protected areas cover approximately 1825 km^2. Sediment and total phosphorus exports are classified as medium risk, and total nitrogen export is classified as high risk in the Herbert River catchment.

Issues in the catchment:

- Grazing land is the dominant land use.
- Regular floods in the lower catchment areas cause some erosion of croplands and flooding.
- Approximately 70% loss of coastal wetlands.
- Significant hydrological modification of the flood plain.
- High contribution of nutrient (particularly nitrates) and pesticides.
- Fauna species have been affected by changes in land use.
- Approximately 19% of the catchment is within protected areas.
- Commercial and recreational fishery.
- Marine and land based tourism.
- Close proximity to seagrass beds and dugong protection areas.

AIMS conducted sampling in the Herbert River between 1989 and 1995. Three sites were sampled down the freshwater section of the river from just below the gorge, at Abergowrie and at the John Row bridge, Ingham. Dalrymple Creek, a tributary of the Herbert River was sampled at upstream and downstream sites in collaboration with the Bureau of Sugar Experiment Stations (BSES) office at Ingham between 1993 and 1995. An AIMS river logger has been deployed on the Gairlock bridge for the past 6 years to obtain continuous turbidity measurements through each wet season.

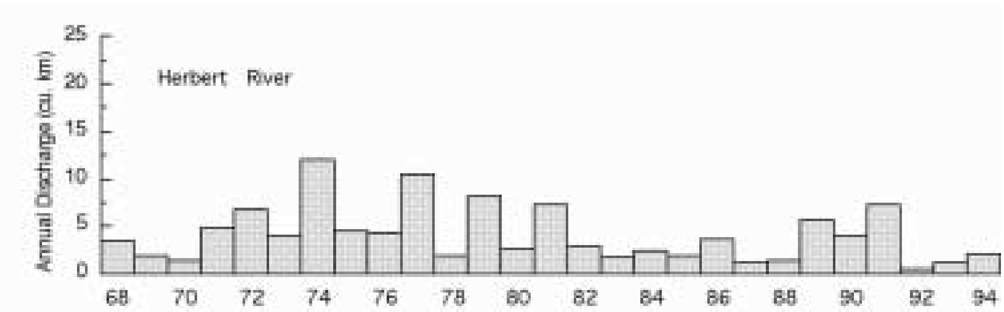


Figure 15. Water discharge patterns in the Herbert River.

Black River Catchment

Catchment Information

Description

Area (km^2)	1057
% Gauged	33
Mean Discharge Yr (km^3)	0.4
Rainfall (mm)	1538
Runoff (mm/m^2)	360
Runoff/Rainfall Ratio	23

Land Use

Population	1579
Clearing (km^2)	501
% Cleared	47
Area under Grazing (km^2)	802
Area under Sugar (km^2)	9.7
Area under Horticulture (km^2)	4.2

Pesticide Application

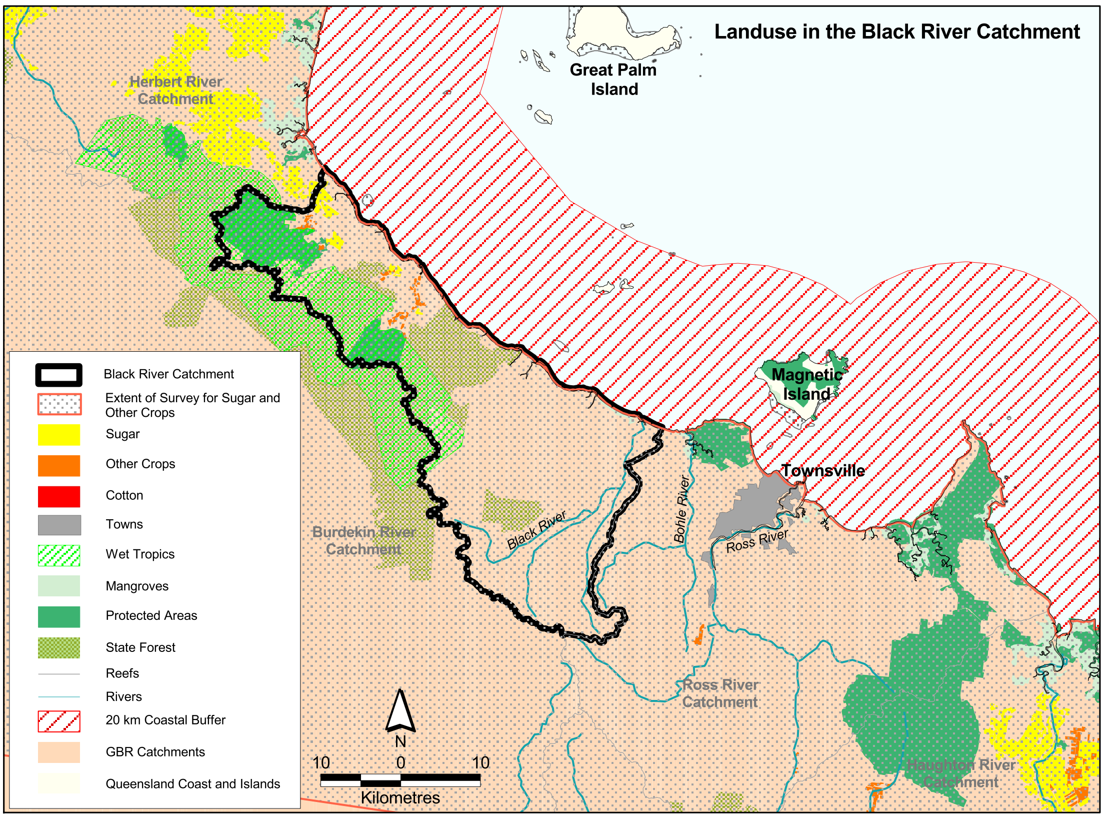
(Kg Active Ingredient/Yr)

Atrazine	203
Diuron	100
2-4D	169
Chlorpyrifos	20
MEMC	3

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km^3	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km^3 Target
Sediment Export	28000	82887	218421	2	0	82887	218421
Total N Export	93	411	1082	4.4	33	275	725
Total P Export	5	90	237	18	33	60	159

Data Confidence Index = 1



Black River Catchment

The Black River catchment covers an area of 1057 km^2. Grazing is the dominant land use occupying 802 km^2. Other land uses are sugarcane farming covers approximately 10 km^2 and horticulture 4 km^2. Total forests occupy 220 km^2 and protected areas, including the Wet Tropics World Heritage Area, cover 231 km^2. Sediment export is classified as low risk, and total nitrogen and total phosphorus exports are classified as medium risk in the Black River catchment.

Issues in the catchment:

- There are problems of ground water supplies in the Black River.
- Significant quantities of sand and gravel are extracted from the Black River for the Townsville market, creating an in-stream environmental impact.
- The riverbanks are severely eroded.
- Significant area of the Catchment has been cleared for grazing.
- Some fauna species have been subjected to pressure in the catchment.
- Approximately 22% of the catchment is within protected areas.
- Expansion of cultivated agriculture.
- Increasing contribution of nutrient and pesticides.
- Commercial and recreational fishery.
- Recreational marine use.

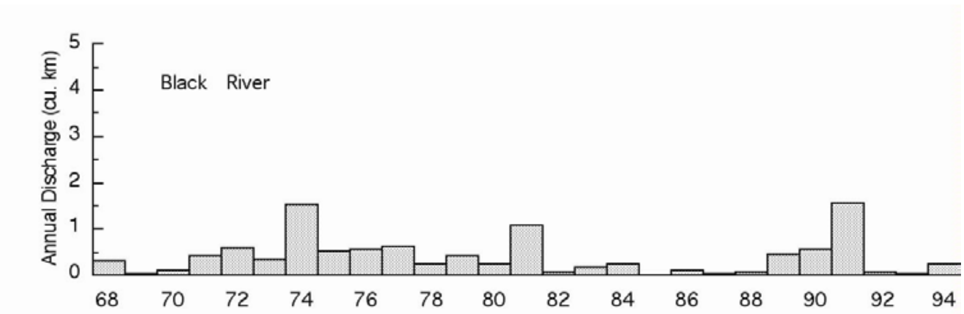


Figure 16. Water discharge patterns in the Black River.

Ross River Catchment

Catchment Information

Description

Area (km²)	1707
% Gauged	56
Mean Discharge Yr (km³)	0.5
Rainfall (mm)	1027
Runoff (mm/m²)	287
Runoff/Rainfall Ratio	28

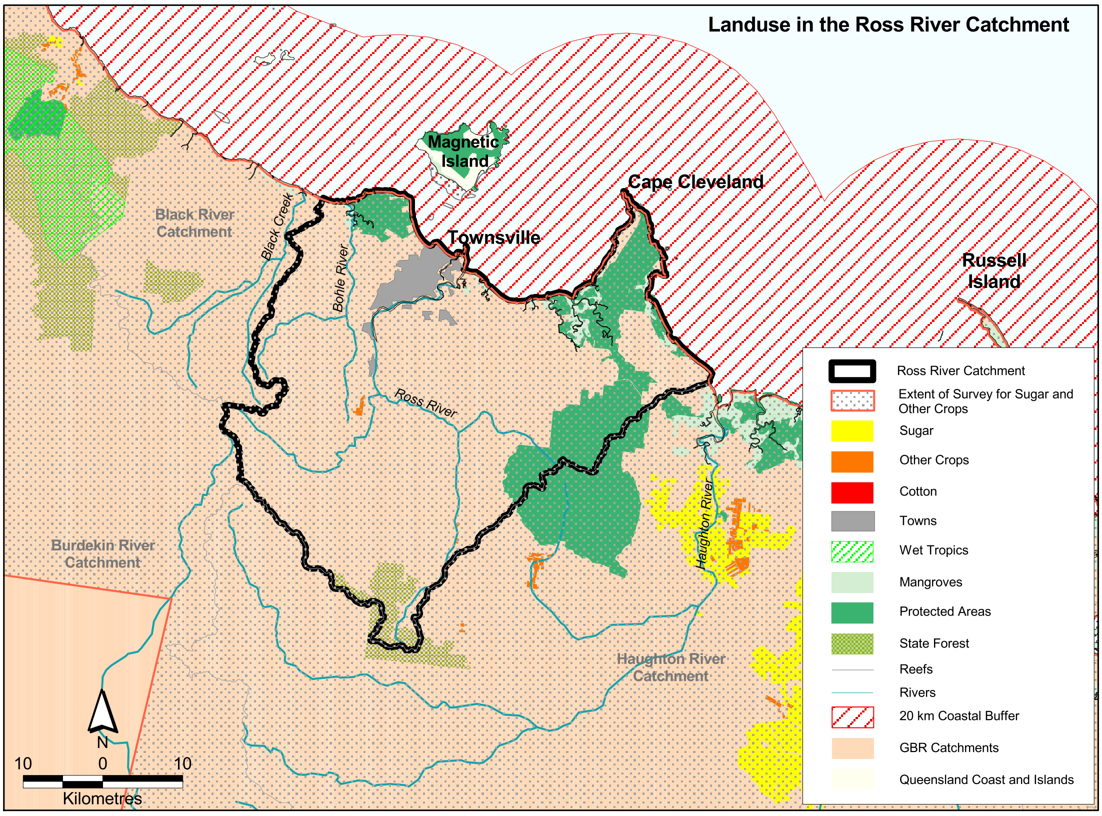
Land Use

Population	106445
Clearing (km²)	1229
% Cleared	72
Area under Grazing (km²)	1481
Area under Sugar (km²)	<10
Area under Horticulture (km²)	<10

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	29000	58383	118367	2	0	58383	118367
Total N Export	119	530	1082	4.5	33	355	725
Total P Export	6	116	237	19.3	33	78	159

Data Confidence Index = 2



Ross River Catchment

The Ross River catchment covers an area of 1707 km^2. Grazing is the dominant land use occupying 1481 km^2. State forests and timber reserves occupy 48 km^2 and protected areas cover 245 km^2. Other land uses at a much smaller scale include horticulture and sugarcane (both less than 10 km^2). Sediment export is classified as low risk, whilst total nitrogen and total phosphorus exports are classified as medium risk in the Ross River catchment.

Issues in the catchment:

- Grazing lands are in reasonably good condition with only minor gully and sheet erosion.
- Most native grasses are still present.
- The Ross River Dam is a major source of the Townsville water supply.
- The catchment contains the heavily urbanised City of Townsville and its small surrounds and small areas of sugarcane where suitable soils permit.
- Significant alteration of the river has occurred through extractions of sand and gravel to supply construction sites in Townsville and for water storage.
- Presence of heavy industry.
- Significant area of the catchment has been cleared for grazing.
- Approximately 14% of the catchment is within protected areas.
- Some fauna species have been subjected to pressure in the catchment.
- Commercial and recreational fishery.
- Marine tourism.
- Commercial port.
- Close proximity to seagrass and dugong protection areas.

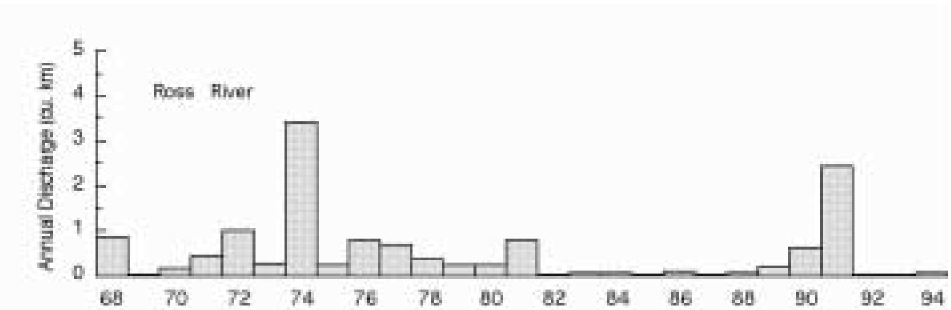


Figure 17. Water discharge patterns in the Ross River.

Haughton River Catchment

Catchment Information

Description

Area (km^2)	4044
% Gauged	68
Mean Discharge Yr (km^3)	0.7
Rainfall (mm)	888
Runoff (mm/m^2)	183
Runoff/Rainfall Ratio	21

Land Use

Population	10343
Clearing (km^2)	3120
% Cleared	77
Area under Grazing (km^2)	3441
Area under Sugar (km^2)	528
Area under Horticulture (km^2)	21

Pesticide Application

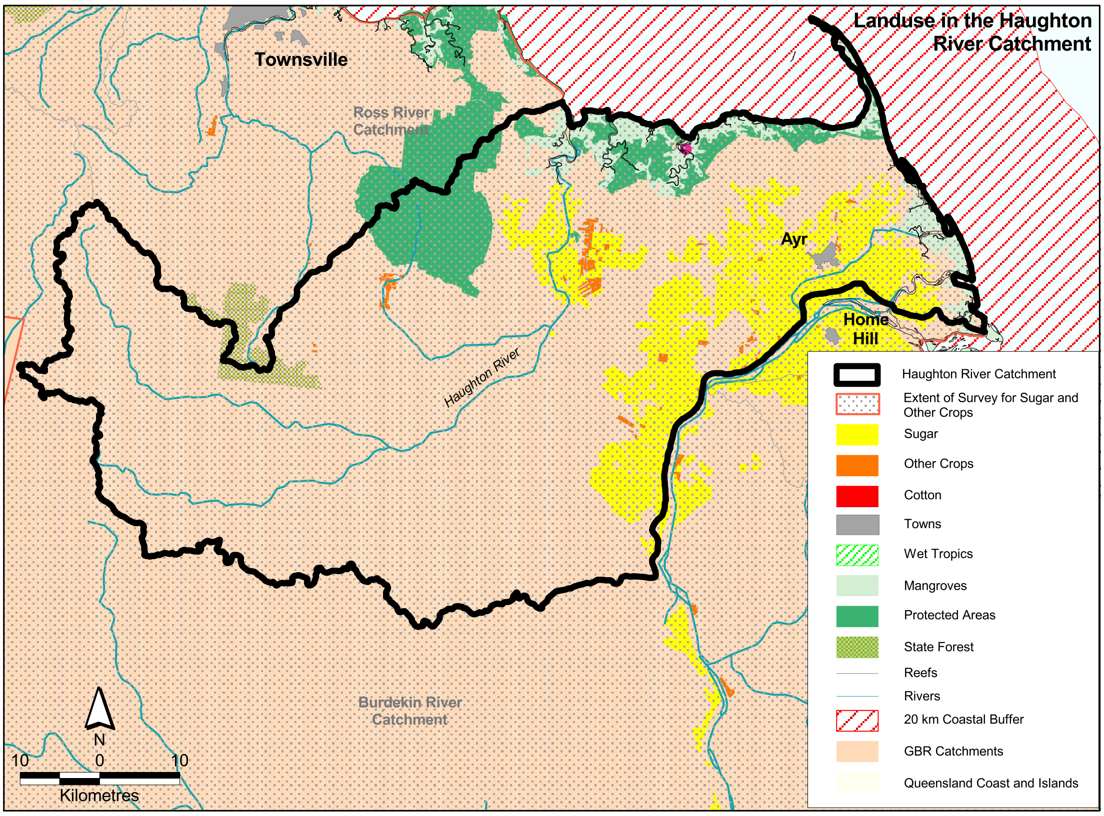
(Kg Active Ingredient/Yr)

Atrazine	24299
Diuron	4123
2-4D	6887
Chlorpyrifos	285
MEMC	247

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km^3	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km^3 Target
Sediment Export	17000	172454	232432	10.1	33	115544	155729
Total N Export	180	801	1082	4.5	50	401	541
Total P Export	9	175	237	19.4	50	88	119

Data Confidence Index = 1



Haughton River Catchment

The Haughton River catchment covers an area of 4044 km^2. Grazing is the dominant land use 3441 km^2. Other land uses are sugarcane farming 528 km^2 and horticulture 21 km^2. State forests and timber reserves occupy 30 km^2 and protected areas cover 328 km^2. Sediment export is classified as medium risk, and total nitrogen and total phosphorus exports are classified as high risk in the Haughton River catchment.

Issues in the catchment:

- Soil erosion is widespread.
- Potential salinity problems occur in some areas as a result from extensive clearing.
- Invasion of exotic weeds along waterways, disturbed clay and/or soil areas.
- Significant contribution of nutrient and pesticides from the flood plain.
- Most cultivation occurs on the river delta.
- Many fauna species are threatened in the catchment.
- Approximately 80% of the catchment has been cleared for grazing.
- Approximately 8% of the catchment is within protected areas.
- Commercial and recreational fishery.
- Close proximity to significant seagrass beds/dugong protection areas.
- Recreational marine use.

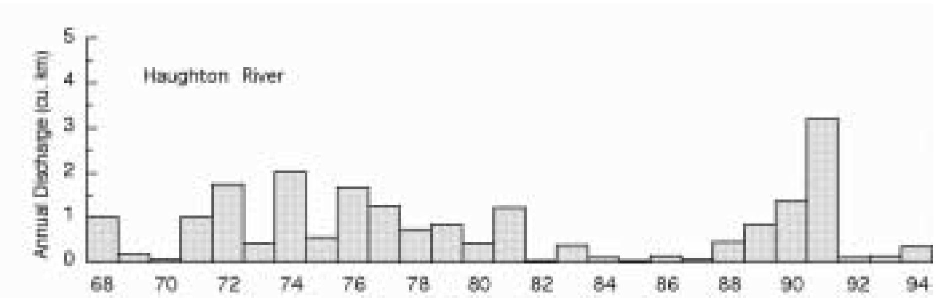


Figure 18. Water discharge patterns in the Haughton River.

Burdekin River Catchment

Catchment Information

Description

Area (km²)	130126
% Gauged	100
Mean Discharge Yr (km³)	10.3
Rainfall (mm)	727
Runoff (mm/m²)	79
Runoff/Rainfall Ratio	11

Land Use

Population	17497
Clearing (km²)	94890
% Cleared	73
Area under Grazing (km²)	128640
Area under Sugar (km²)	193
Area under Horticulture (km²)	3.9

Pesticide Application

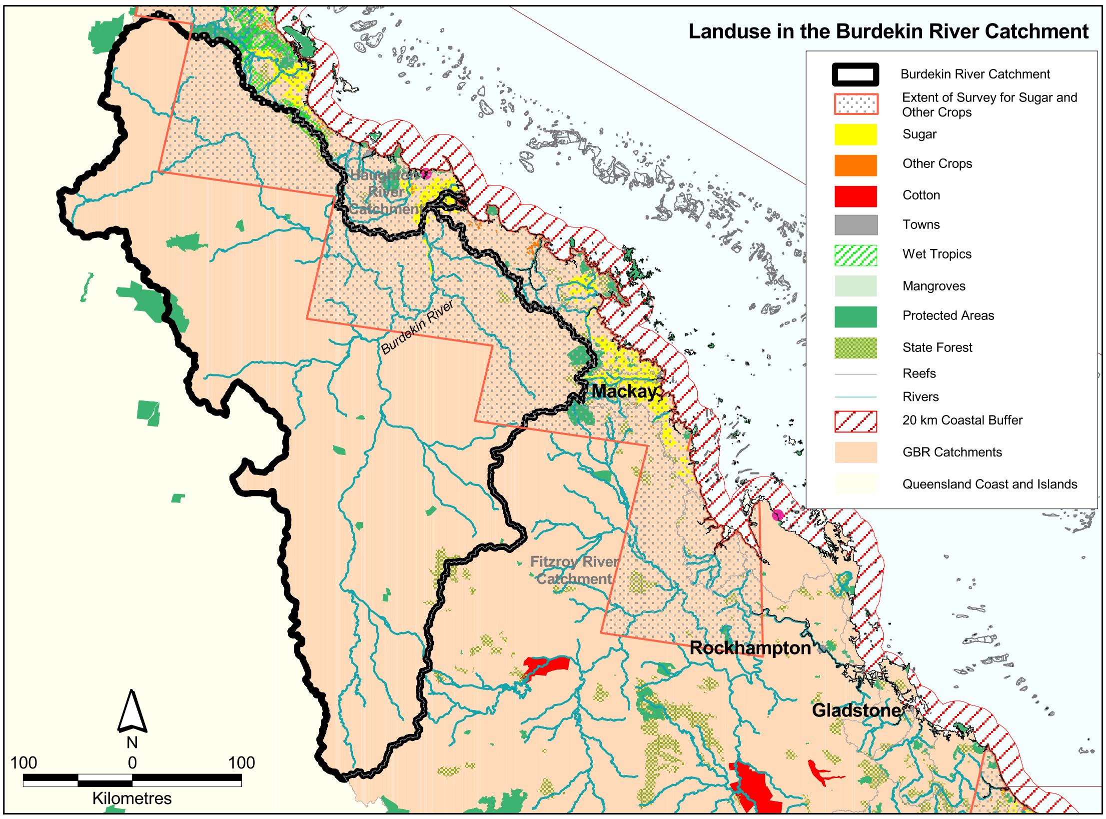
(Kg Active Ingredient/Yr)

Atrazine	19300
Diuron	3272
2-4D	5465
Chlorpyrifos	207
MEMC	196

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	163000	2443232	237415	15	50	1221616	118708
Total N Export	2508	11134	1082	4.4	33	7460	725
Total P Export	126	2438	237	19.3	50	1219	119

Data Confidence Index = 3



Burdekin River Catchment

The Burdekin River catchment covers an area of 130126 km^2. Grazing is the most dominant land use occupying 128640 km^2. Other land uses include 193 km^2 of sugarcane with a small proportion, approximately 4 km^2, of horticulture. State forests and timber reserves occupy 1219 km^2 and protected areas cover 1315 km^2. Sediment and total phosphorus export are classified as high risk and total nitrogen is classified as medium risk in the Burdekin River catchment.

Issues in the catchment:

- Flood plain contains intensive fertilised cropping, predominantly sugar.
- Soil erosion is widespread.
- Potential salinity problems occur in some areas as a result from extensive clearing.
- Invasion of exotic weeds along waterways, disturbed clay and/or soil areas.
- Grazing has contributed to the degradation of instream habitat and stream channel stability.
- Native pasture has declined.
- Impacts on the Burdekin River Irrigation Scheme experience on the flood plain.
- Approximately 70-80% loss of coastal wetlands.
- Significant alteration of the river has occurred through extraction of sand and gravel to supply construction sites in nearby towns and for water storage.
- Significant flooding of rural and urban areas still occurs.
- Significant mining activities occur in the catchment.
- Many fauna species are threatened in the catchment.
- Only 1% of the catchment is within protected areas.
- Approximately 73% of the catchment has been cleared mostly for grazing.
- Commercial and recreational fishery
- Recreational marine use.
- Proximity to seagrass beds and dugong protection areas.

Early water sampling was conducted in the Burdekin River by DNR in collaboration with AIMS between 1988 and 1991. AIMS further conducted water sampling in the Burdekin River through wet season periods from 1991-2000. An AIMS river logger has been deployed at the Inkerman bridge for four years.

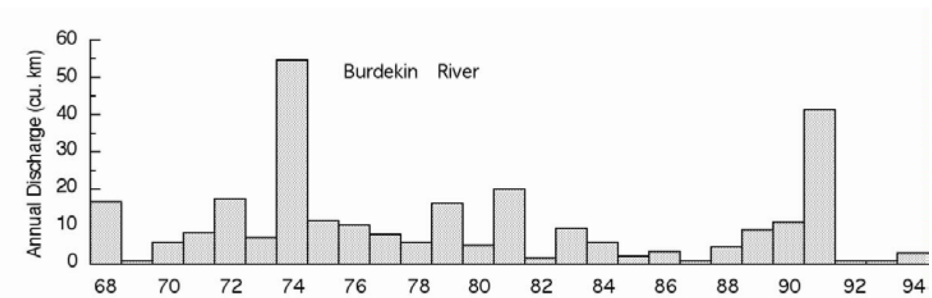


Figure 19. Water discharge patterns in the Burdekin River.

Don River Catchment

Catchment Information

Description

Area (km²)	3695
% Gauged	16
Mean Discharge Yr (km³)	0.75
Rainfall (mm)	1045
Runoff (mm/m²)	203
Runoff/Rainfall Ratio	19

Land Use

Population	237
Clearing (km²)	3395
% Cleared	92
Area under Grazing (km²)	3582
Area under Sugar (km²)	47
Area under Horticulture (km²)	63

Pesticide Application

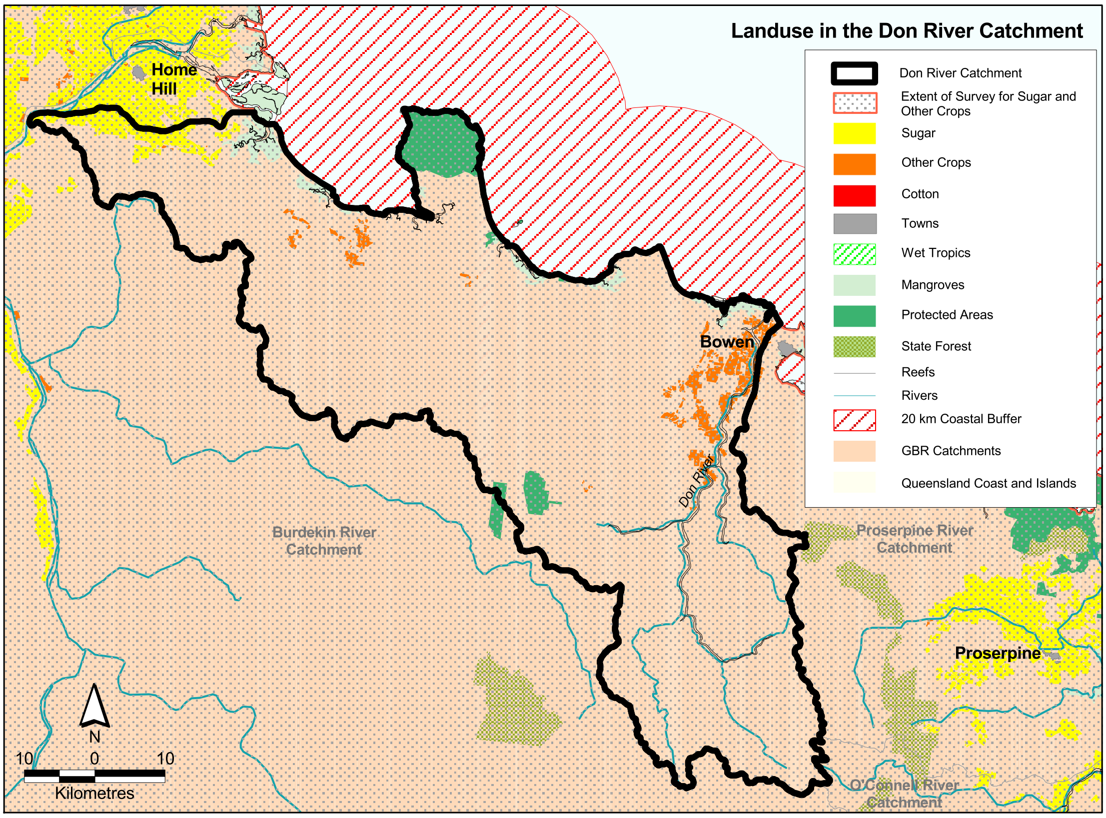
(Kg Active Ingredient/Yr)

Atrazine	2881
Diuron	489
2-4D	816
Chlorpyrifos	45
MEMC	29

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	46000	509528	680000	11.1	33	341384	455600
Total N Export	183	812	1082	4.4	33	544	725
Total P Export	9	178	237	19.8	50	89	119

Data Confidence Index = 1



Don River Catchment

The Don River catchment covers an area of 3695 km^2. Grazing is the dominant land use occupying 3582 km^2. Other land uses include 47 km^2 of sugarcane and 63 km^2 of horticulture. Protected areas cover 100 km^2, and state forests and timber reserves occupy less than 1 km^2. Sediment and total nitrogen exports are classified as medium risk, and total phosphorus export is classified as high risk in the Don River catchment.

Issues in the catchment:

- Soil erosion on the river delta and flats is significant which is caused predominantly from growing horticultural crops.
- Intensive agriculture and extensive use of chemicals have potential to cause contamination of soils and water.
- Intensive groundwater use.
- Grazing lands have isolated severe gully erosion in cleared areas.
- Major stream modifications have occurred in the catchment.
- Approximately 92% of the catchment has been cleared.
- Only 3% of the catchment is within protected areas.
- Proximity to seagrass beds and dugong protection areas
- Commercial and recreational fishery.
- Recreational marine use.
- Commercial port.

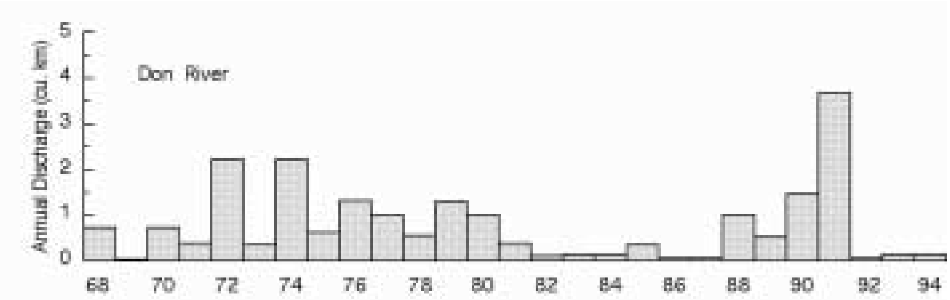


Figure 20. Water discharge patterns in the Don River.

Proserpine River Catchment

Catchment Information

Description

Area (km²)	2535
% Gauged	13
Mean Discharge Yr (km³)	1.1
Rainfall (mm)	1360
Runoff (mm/m²)	426
Runoff/Rainfall Ratio	31

Land Use

Population	16286
Clearing (km²)	1514
% Cleared	60
Area under Grazing (km²)	2070
Area under Sugar (km²)	196
Area under Horticulture (km²)	2.5

Pesticide Application

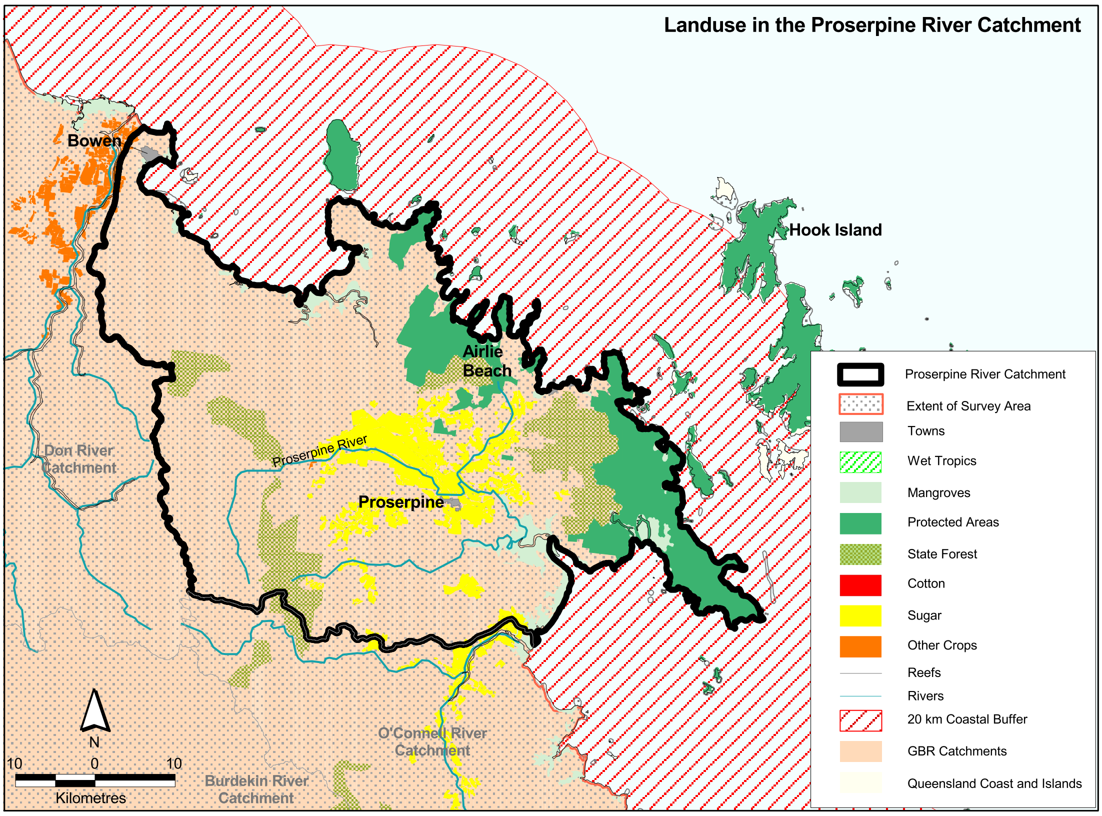
(Kg Active Ingredient/Yr)

Atrazine	9404
Diuron	9281
2-4D	5705
Chlorpyrifos	2608
MEMC	3

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	7000	227314	210185	32.5	50	113657	105092
Total N Export	263	1169	1082	4.4	50	585	541
Total P Export	13	256	237	19.7	50	128	119

Data Confidence Index = 1



Proserpine River Catchment

The Proserpine River catchment covers an area of 2535 km^2. Grazing is the dominant land use occupying approximately 2070km^2. Other land uses include 196 km^2 of sugarcane farming with a small area, 2.5 km^2, of horticultural landuses. State forests and timber reserves occupy 232 km^2 and protected areas cover 317 km^2. Sediment, total nitrogen and total phosphorus exports are classified as high risk in the Proserpine River catchment.

Issues in the catchment:

- Two types of development occur in the catchment agricultural/grazing land use and intense tourism development.
- Approximately 61% of the Catchment has been cleared mostly for grazing.
- Extensive cultivated agriculture (mostly sugar).
- High contribution of nutrient (particularly nitrates) and pesticides.
- Grazing prone to erosion.
- Approximately 13% of the catchment is within protected areas.
- Commercial and recreational fishery.
- Significant marine tourism.
- Proximity to inshore reefal areas.
- Proximity to seagrass and dugong protection areas.

Water quality studies in the late 1980's/early 1990's by James Cook University showed very high nutrient concentrations in the Proserpine River during high flow conditions.

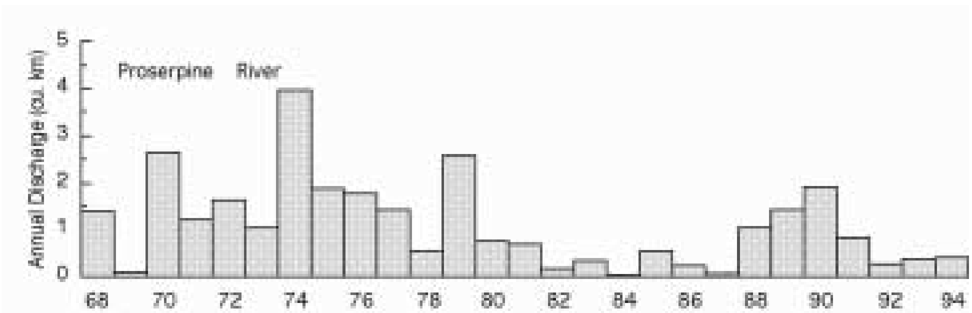


Figure 21. Water discharge patterns in the Proserpine River.

O'Connell River Catchment

Catchment Information

Description

Area (km^2)	2387
% Gauged	30
Mean Discharge Yr (km^3)	1.5
Rainfall (mm)	1469
Runoff (mm/m^2)	645
Runoff/Rainfall Ratio	44

Land Use

Population	5082
Clearing (km^2)	1214
% Cleared	51
Area under Grazing (km^2)	1904
Area under Sugar (km^2)	264
Area under Horticulture (km^2)	<1

Pesticide Application

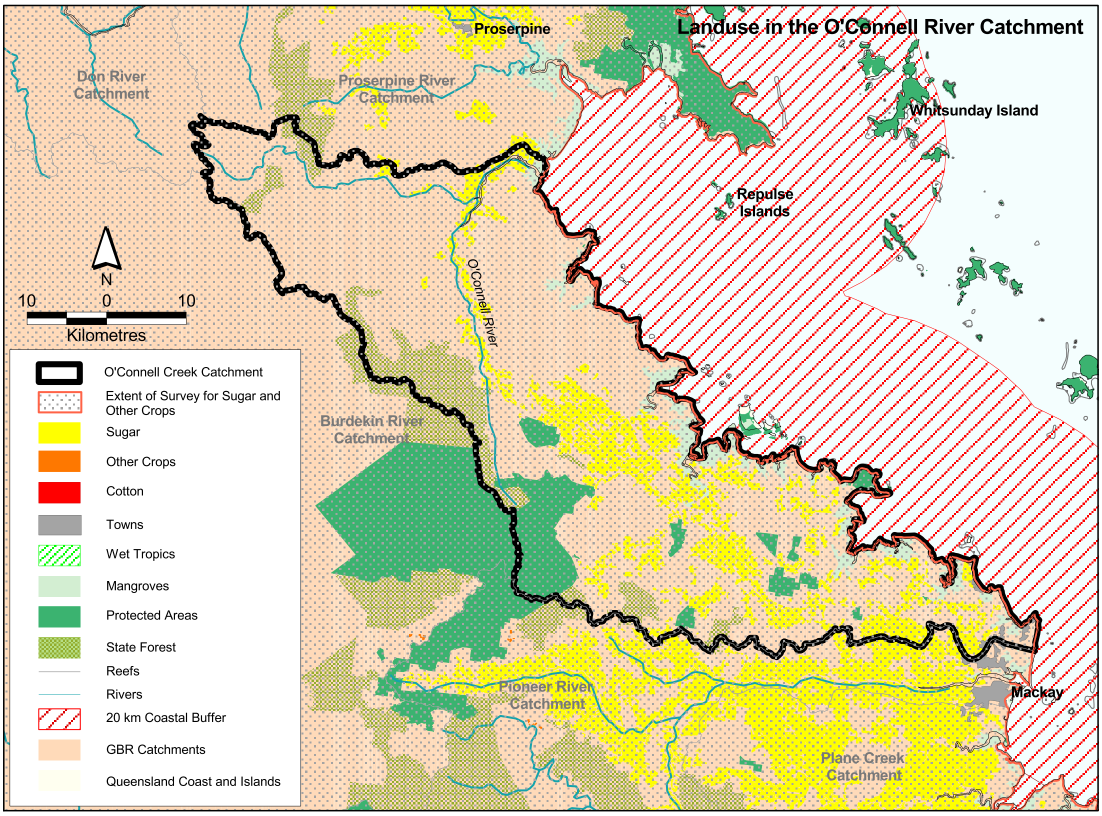
(Kg Active Ingredient/Yr)

Atrazine	25508
Diuron	23896
2-4D	8413
Chlorpyrifos	2024
MEMC	96

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km^3	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km^3 Target
Sediment Export	8000	366309	237662	45.8	50	183115	118831
Total N Export	375	1666	1082	4.4	50	833	541
Total P Export	19	365	237	19.2	50	183	119

Data Confidence Index = 1



O’Connell River Catchment

The O’Connell River Catchment covers an area of 2387 km^2. Grazing is the dominant land use occupying approximately 1904 km^2. Other land uses include 264 km^2 of sugarcane, predominantly on the river flats. State forest and timber reserves occupy 188 km^2 and protected areas cover 148 km^2. Sediment, total phosphorus and total nitrogen exports are classified as high risk in the O’Connell River catchment.

Issues in the catchment:

- Severe erosion has occurred on the river banks along the O’Connell River.
- Cultivated agriculture is dominated by the sugar industry.
- High contribution of nutrient (particularly nitrates) and pesticides.
- Approximately 50% of the catchment has been cleared mostly for grazing
- Approximately 6% of the catchment is within protected areas.
- Proximity to inshore reefal areas.
- Commercial and recreational fishery.
- Marine tourism.
- Proximity to seagrass beds and dugong protection area.

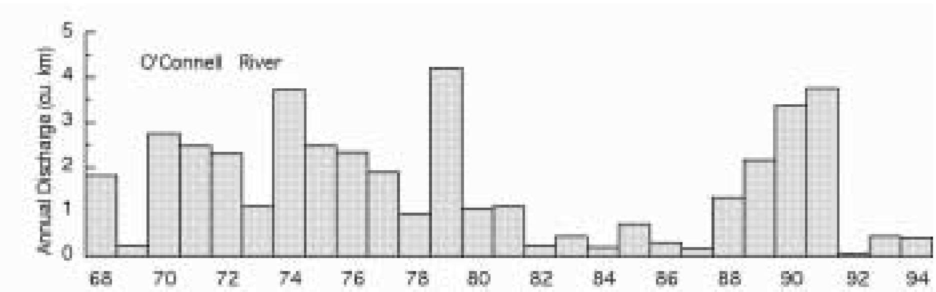


Figure 22. Water discharge patterns in the O’Connell River

Pioneer River Catchment

Catchment Information

Description

Area (km^2)	1570
% Gauged	92
Mean Discharge Yr (km^3)	1.2
Rainfall (mm)	1385
Runoff (mm/m^2)	758
Runoff/Rainfall Ratio	55

Land Use

Population	44159
Clearing (km^2)	466
% Cleared	30
Area under Grazing (km^2)	1166
Area under Sugar (km^2)	296
Area under Horticulture (km^2)	<1

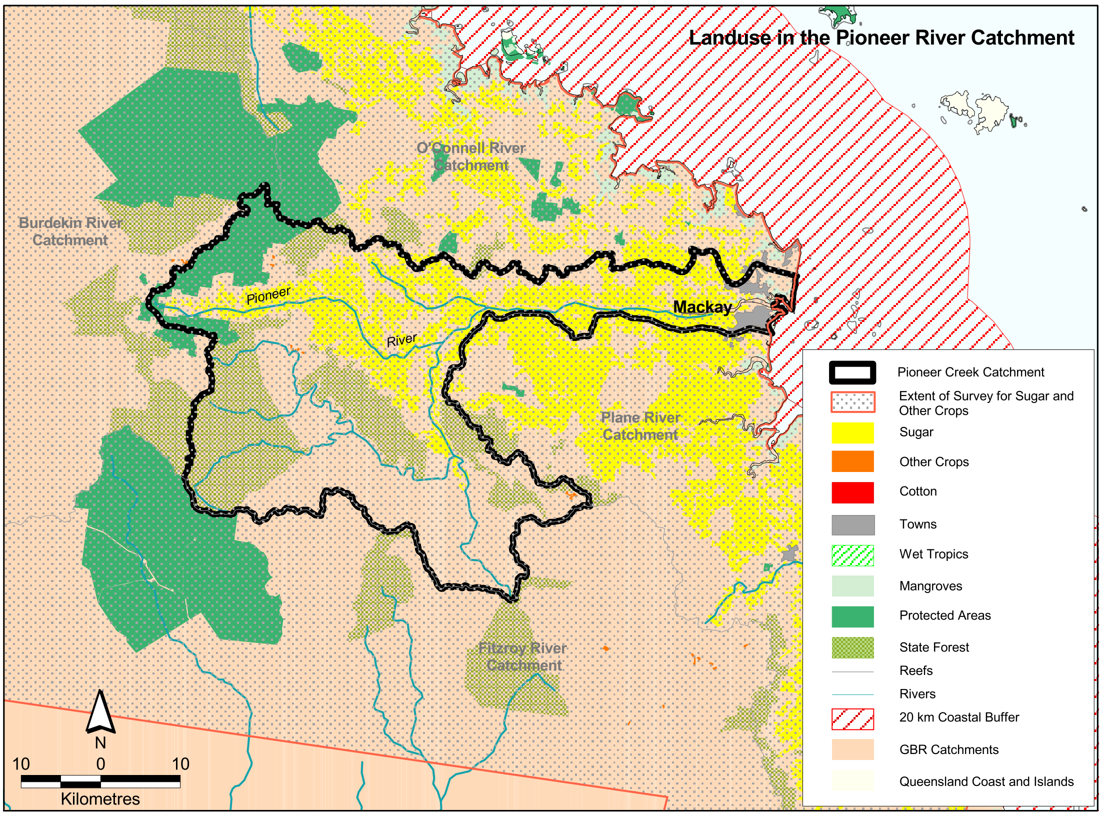
Pesticide Application
(Kg Active Ingredient/Yr)

Atrazine	25151
Diuron	23435
2-4D	7547
Chlorpyrifos	5519
MEMC	103

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km^3	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km^3 Target
Sediment Export	10000	288343	242017	28.8	50	144172	121008
Total N Export	160	471	396	2.9	50	236	198
Total P Export	8	50	42	6.3	50	25	21

Data Confidence Index = 1



Pioneer River Catchment

The Pioneer River catchment covers an area of 1570 km^2. Grazing is the dominant land use occupying approximately 1100 km^2. Other land uses include 296 km^2 of sugarcane, predominantly on the river flats. State forest and timber reserves occupy 354 km^2 and protected areas cover 109 km^2. Sediment, total nitrogen and total phosphorus exports are classified as high risk in the Pioneer River Catchment.

Issues in the catchment:

- Pioneer River catchment is used extensively for sugarcane production. Some sugar cane land has suffered serious erosion, especially in the upland areas on granitic soils.
- High contribution of nutrient (particularly nitrates) and pesticides.
- Several weirs and dams have been constructed on the river for irrigation and industrial purposes.
- Estuarine fauna are threatened by urban and tourism development.
- Approximately 30% of the catchment has been cleared mostly for sugar production.
- Approximately 7% of the catchment is within protected areas.
- Commercial and recreational fishery.
- Recreational marine use.

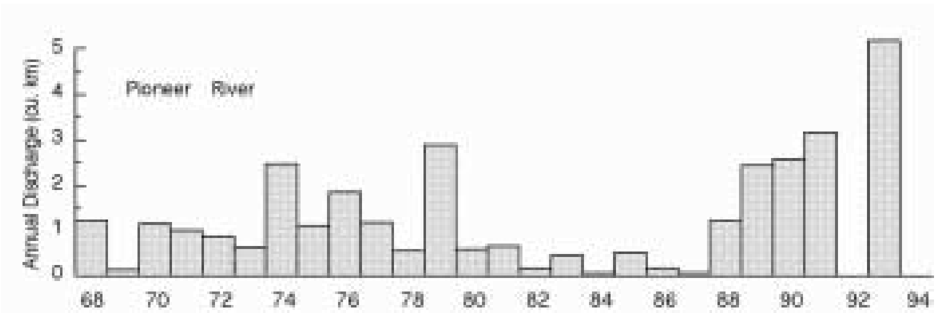


Figure 23. Water discharge patterns in the Pioneer River

Plane Creek Catchment

Catchment Information

Description

Area (km²)	2539
% Gauged	19
Mean Discharge Yr (km³)	1.5
Rainfall (mm)	1125
Runoff (mm/m²)	587
Runoff/Rainfall Ratio	52

Land Use

Population	6911
Clearing (km²)	822
% Cleared	32
Area under Grazing (km²)	1830
Area under Sugar (km²)	549
Area under Horticulture (km²)	<1

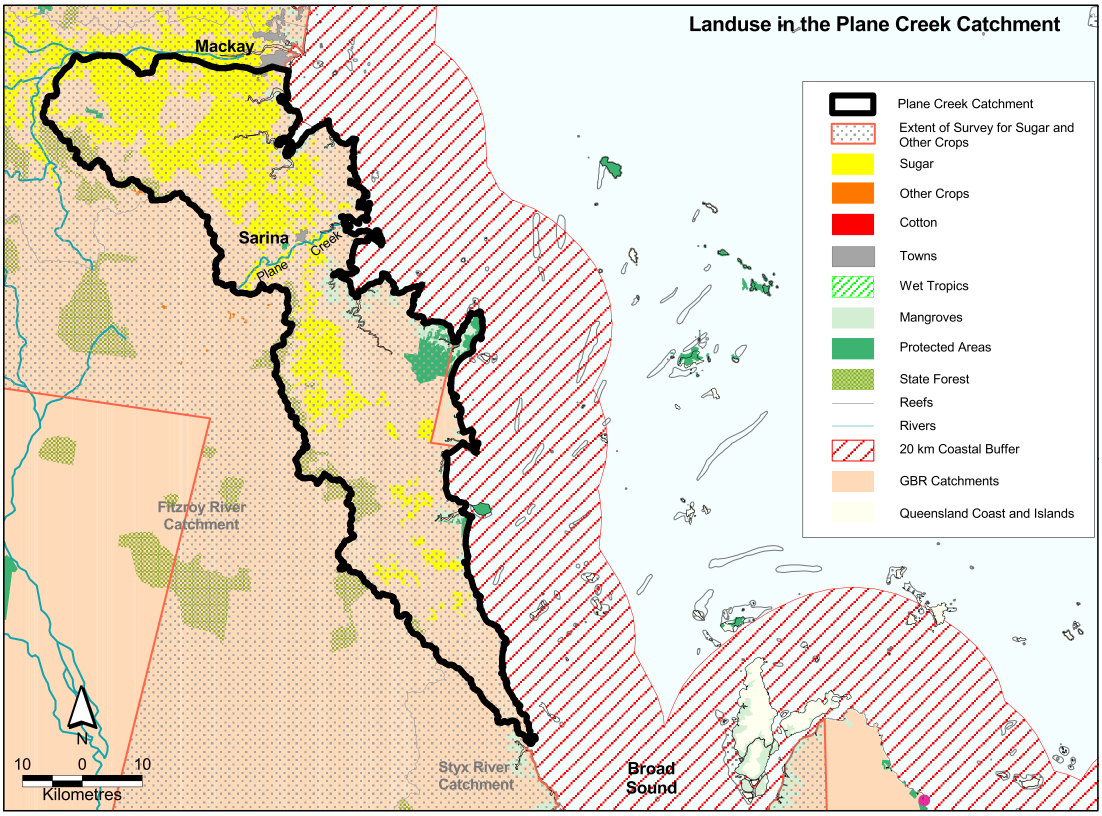
Pesticide Application
(Kg Active Ingredient/Yr)

Atrazine	55948
Diuron	52079
2-4D	19438
Chlorpyrifos	10816
MEMC	176

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	2000	114860	77181	57.4	50	57430	38591
Total N Export	363	1612	1082	4.4	50	806	541
Total P Export	18	353	237	19.6	50	177	119

Data Confidence Index = 1



Plane Creek Catchment

The Plane Creek catchment covers an area of 2539 km^2. Grazing occupies most of the catchment area with 1830 km^2. Sugarcane is the other dominant land use, occupying approximately 549km^2. State forests and timber reserves occupy 136 km^2 and protected areas cover 79 km^2. Sediment, total nitrogen and total phosphorus exports are classified as high risk in the Plane Creek Catchment.

Issues in the catchment:

- Grazing in drier lands show signs of overgrazing and inappropriate land-clearing practices which has led to weed problems and sheet and gully erosion in some areas.
- Approximately 32% of the catchment has been cleared mostly for sugarcane.
- Only 3% of the catchment is within protected areas.
- Ponded pasture development may impact riverine and wetland habitats.
- Very high contribution of nutrient (particularly nitrogen) and pesticides.
- Highly modified flood plain.
- Fauna in the catchment has been affected by changes in land use.
- Close proximity to inshore reefal areas.
- Proximity to seagrass beds and dugong protection areas.
- Commercial port.
- Commercial and recreational fishery.
- Recreational marine use.

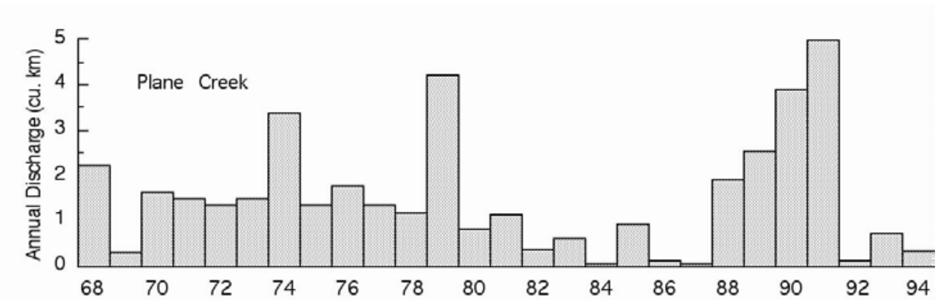


Figure 24. Water discharge patterns in the Plane Creek

Styx River Catchment

Catchment Information

Description

Area (km²)	3012
% Gauged	0
Mean Discharge Yr (km³)	N/A
Rainfall (mm)	1010
Runoff (mm/m²)	N/A
Runoff/Rainfall Ratio	N/A

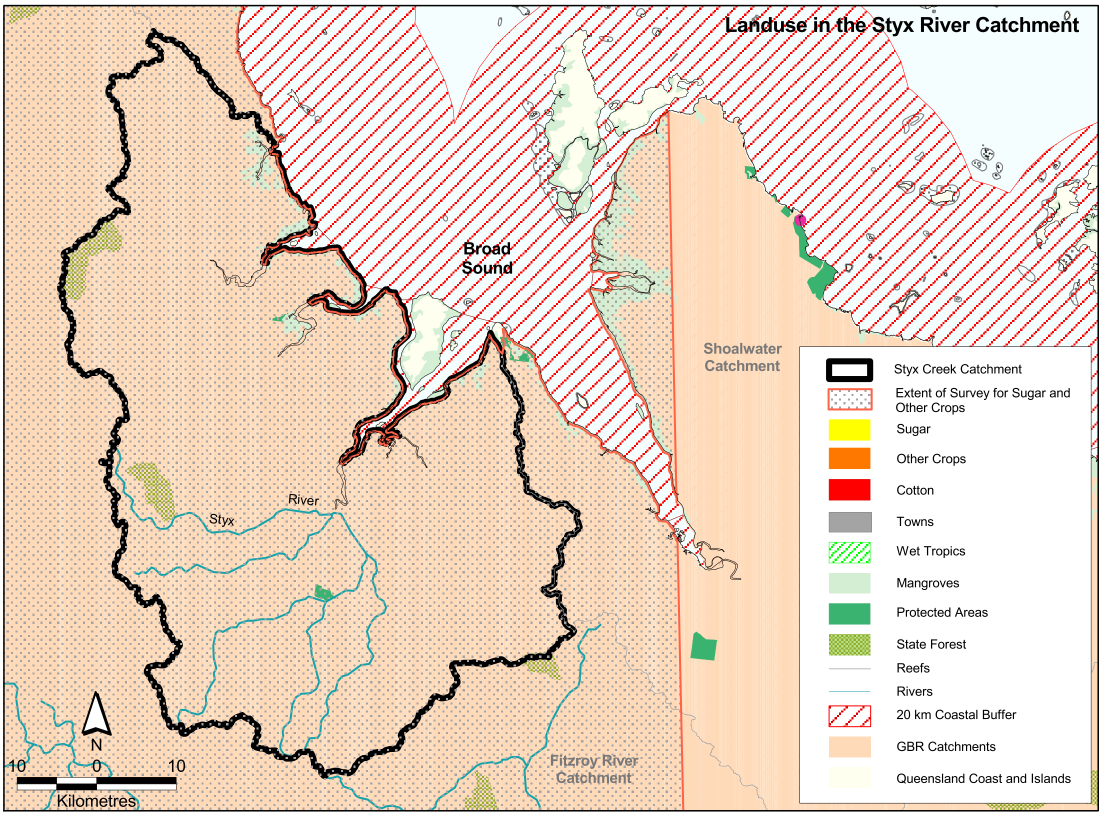
Land Use

Population	N/A
Clearing (km²)	1223
% Cleared	41
Area under Grazing (km²)	2961
Area under Sugar (km²)	N/A
Area under Horticulture (km²)	N/A

Catchment Targets

	1850 T/Yr	Current T/Yr	Current/1850	Current T/km3	2011 % Reduction	2011 T/Yr Target
Sediment Export	4000	136000	34	**	50	68000
Total N Export	145	642	4	**	33	**
Total P Export	7.2	140	19	**	33	**

**Data for the above table is shown in Tonnes per Year (T/Yr) as there is insufficient data to calculate estimates based on river discharge for this catchment.
Data Confidence Index = 1



Styx River Catchment

The Styx River catchment covers an area of 3012 km^2. Grazing is the dominant land use occupying approximately 2961 km^2. State forest and timber reserves occupy 51 km^2 and protected areas cover <5 km^2. Data is not available for other land uses in the catchment. Sediment export is classified as high risk, whilst total nitrogen and total phosphorus exports are classified as medium risk in the Styx River catchment.

Issues in the catchment:

- Grazing in drier lands show signs of overgrazing and inappropriate land-clearing practices which has led to weed problems and sheet and gully erosion in some areas.
- Approximately 41% of the Catchment is cleared mostly for grazing.
- Less than 0.2% of the catchment is within protected areas.
- Ponded pasture development may impact riverine and wetland habitats.
- Floodplains have been modified.
- Fauna in the catchment has been affected by changes in land use.
- Commercial and recreational fishery.
- Recreational marine use.

* limited data available on cropping area and nutrient and pesticide use.

No flow data is available for the Styx River catchment.

Fitzroy River Catchment

Catchment Information

Description

Area (km²)	142537
% Gauged	95
Mean Discharge Yr (km³)	6
Rainfall (mm)	735
Runoff (mm/m²)	43
Runoff/Rainfall Ratio	6

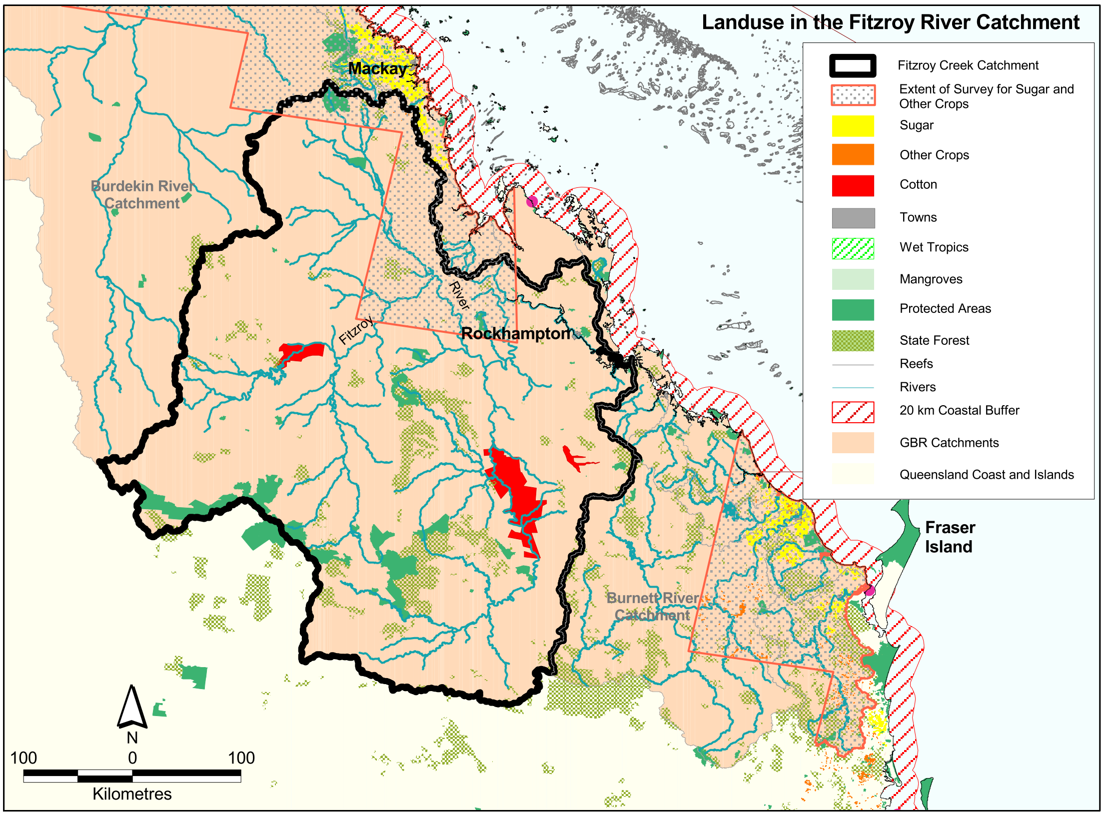
Land Use

Population	114536
Clearing (km²)	85942
% Cleared	60
Area under Grazing (km²)	124732
Area under Sugar (km²)	<1
Area under Horticulture (km²)	2790

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	126000	2635482	433388	20.9	50	1317741	216694
Total N Export	1482	6579	1082	4.4	33	4408	725
Total P Export	74	1440	237	19.5	50	720	119

Data Confidence Index = 3



Fitzroy River Catchment

The Fitzroy River catchment covers an area of 142537 km^2. Grazing is the dominant land use occupying approximately 124732 km^2, whilst cotton occupies approximately 2790 km^2 of the catchment (derived from data provided by Cotton Australia, 2000). State forest and timber reserves occupy 9820 km^2 and protected areas cover 5195 km^2. Sediment and total phosphorus exports are classified as high risk, whilst total nitrogen export is classified as medium risk.

Issues in the catchment:

- Grazing land is under reasonable stocking rates. Drought conditions can cause pressure on grazing land. Severe gully erosion has occurred in some areas.
- Coal and mining industries are developed and prevention of acid runoff from mined areas will ensure the water quality of the region is maintained.
- Water storage structures and dams have been constructed within this catchment area. These structures impact on instream activities of aquatic fauna limiting their upstream movements.
- Flood plain contains intensive fertilised cropping, predominantly cotton.
- Increasing areas of cotton cultivation in the catchment can contribute towards the amount of sediment, fertiliser and pesticides entering the Fitzroy River.
- Fauna species are threatened due to changes in the catchment.
- Approximately 4% of the catchment is within protected areas.
- Approximately 60% of the catchments have been cleared mostly for grazing.
- Large commercial and recreational fishery.
- Marine tourism.
- Military reserves.
- Close proximity to critical dugong protection areas in the southern Great Barrier Reef.

AIMS conducted water sampling for nutrient analysis in the Fitzroy River between 1992 and 1997 in collaboration with the Central Queensland University and Rockhampton City Council. An automated AIMS river logger has been deployed in this river for a number of years to obtain five-scale turbidity profiles through each wet season. DNR have carried out water quality studies identifying the sources of suspended sediments, nutrients and pesticide residues in the river.

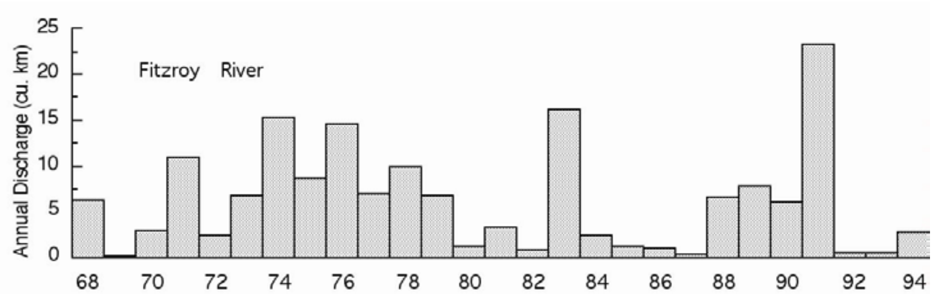


Figure 25. Water discharge patterns in the Fitzroy River.

Calliope River Catchment

Catchment Information

Description

Area (km²)	2236
% Gauged	58
Mean Discharge Yr (km³)	0.3
Rainfall (mm)	790
Runoff (mm/m²)	134
Runoff/Rainfall Ratio	17

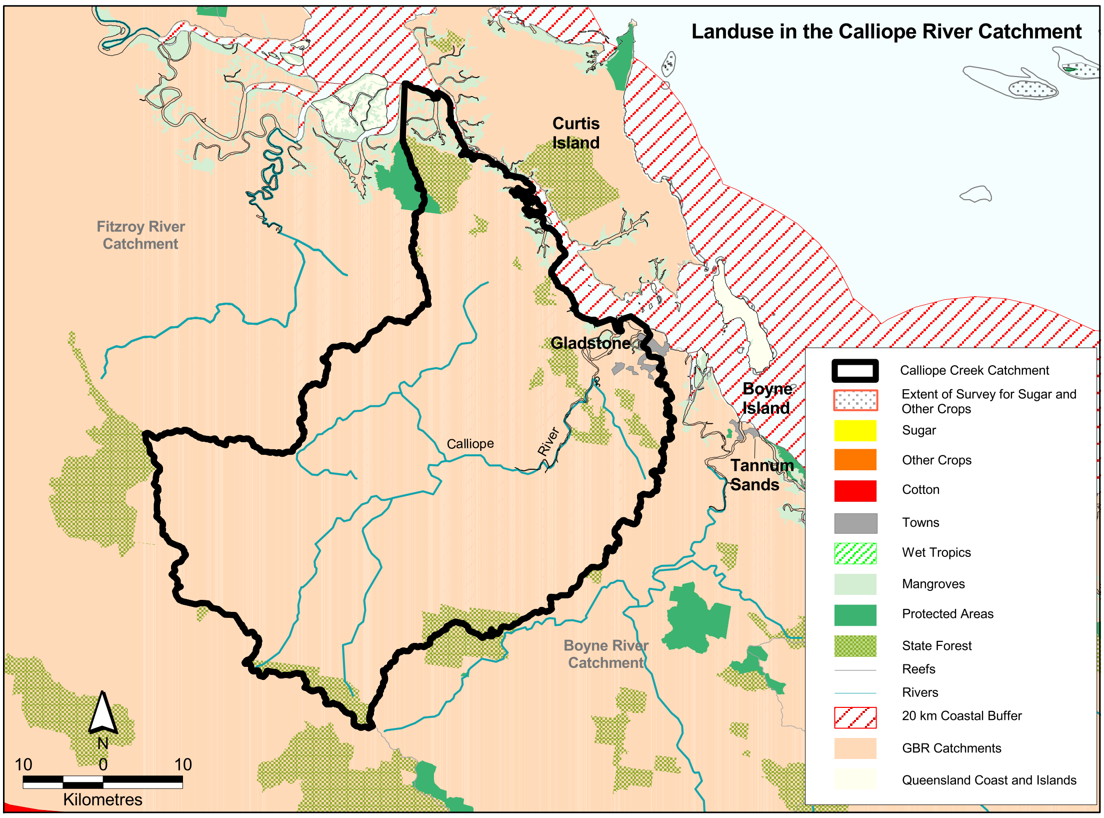
Land Use

Population	24387
Clearing (km²)	1865
% Cleared	83
Area under Grazing (km²)	2032
Area under Sugar (km²)	N/A
Area under Horticulture (km²)	N/A

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	2000	60772	203333	30.4	50	30386	101667
Total N Export	73	235	1082	4.5	33	218	725
Total P Export	4	71	237	17.8	33	47	159

Data Confidence Index = 1



Calliope River Catchment

The Calliope River catchment covers an area of 2236 km^2. Grazing is the dominant land use occupying approximately 2032 km^2. State forest and timber reserves occupy 162 km^2 and protected areas cover <10 km^2. Data is not available for other land uses in the catchment. Sediment export is classified as high risk, whilst total nitrogen and total phosphorus export are classified as medium risk in the Calliope River Catchment.

Issues in the catchment:

- Grazing land has been cleared on slopes and marginal areas which has resulted in erosion and salinity problems.
- Approximately 83% of the catchment has been cleared, mostly for grazing.
- Heavy industrial development in the catchment.
- Significant mining interests in the catchment.
- Species are endangered due to land use and changes in vegetation cover.
- Less than 0.3% of the catchment is within protected areas.
- Proximity to seagrass beds and dugong protection areas.
- Commercial and recreational fishery.
- Marine tourism.
- Commercial port.

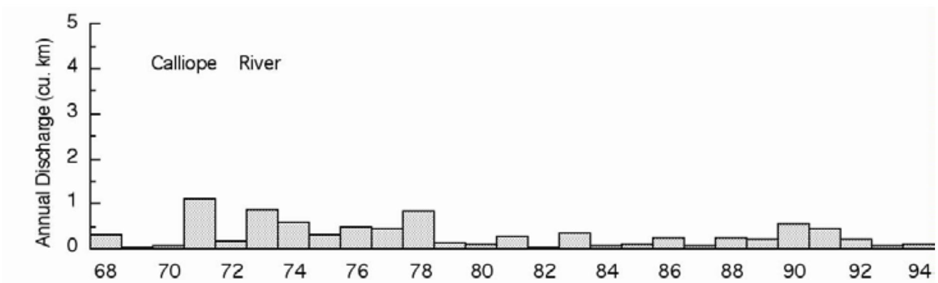


Figure 26. Water discharge patterns in the Calliope River.

Boyne River Catchment

Catchment Information

Description

Area (km^2)	2590
% Gauged	88
Mean Discharge Yr (km^3)	0.3
Rainfall (mm)	968
Runoff (mm/m^2)	112
Runoff/Rainfall Ratio	12

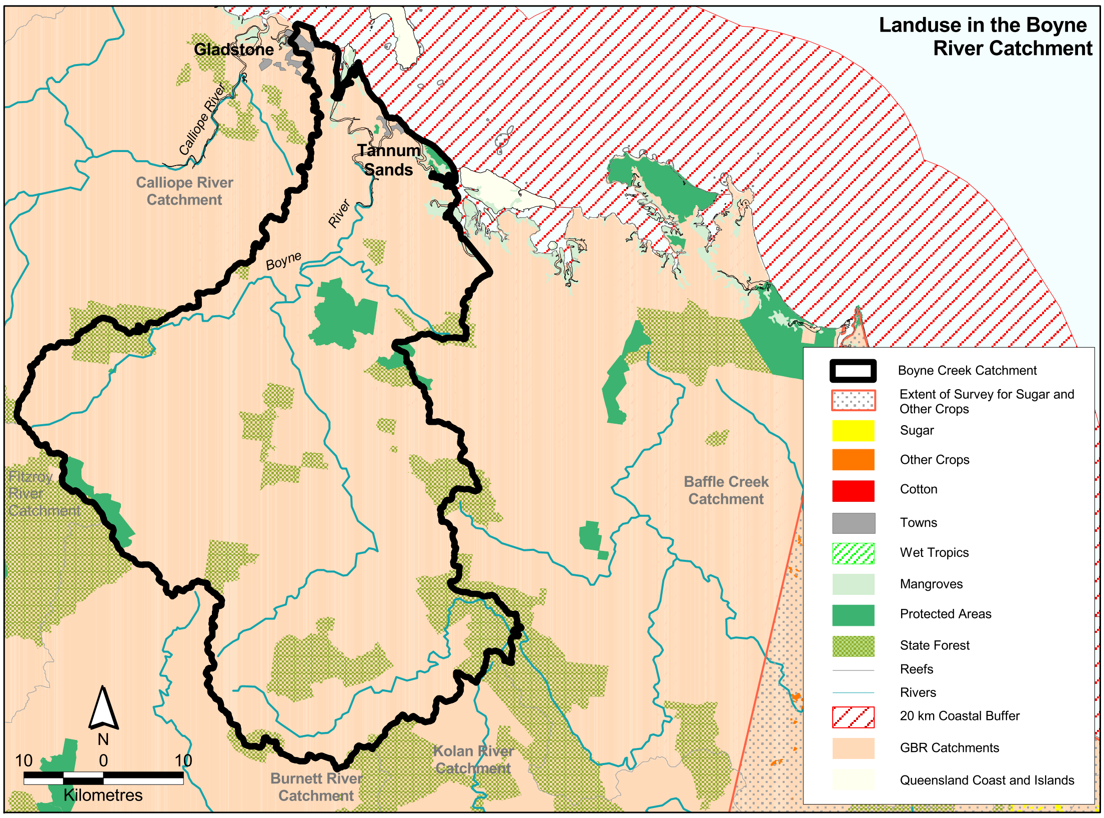
Land Use

Population	5009
Clearing (km^2)	1959
% Cleared	76
Area under Grazing (km^2)	2226
Area under Sugar (km^2)	N/A
Area under Horticulture (km^2)	N/A

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km^3	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km^3 Target
Sediment Export	2000	16974	58621	8.5	33	11372	39276
Total N Export	71	314	1082	4.4	33	210	725
Total P Export	4	69	237	17.3	33	46	159

Data Confidence Index = 1



Boyne River Catchment

The Boyne River catchment covers an area of 2590 km^2. Grazing is the dominant land use occupying approximately 2226 km^2. State forest and timber reserves occupy 332 km^2 and protected areas cover 74 km^2. Data is not available for other land uses in the catchment. Sediment, total nitrogen and total phosphorus exports are classified as medium risk in the Boyne River Catchment.

Issues in the catchment:

- Grazing land has been cleared on slopes and marginal areas which has resulted in erosion and salinity problems.
- Approximately 76% of the catchment has been cleared mostly for grazing.
- Only 3% of the catchment is within protected areas.
- Weirs and dams have modified river flows.
- Heavy industrial development in the catchment.
- Species are endangered due to land use and changes in vegetation cover.
- Commercial and recreational fisheries.
- Proximity to seagrass beds and dugong protection area.

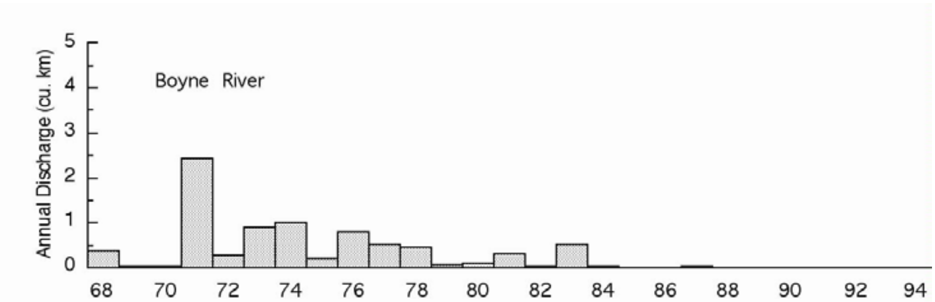


Figure 27. Water discharge patterns in the Boyne River.

Baffle Creek Catchment

Catchment Information

Description

Area (km²)	3996
% Gauged	37
Mean Discharge Yr (km³)	0.8
Rainfall (mm)	893
Runoff (mm/m²)	195
Runoff/Rainfall Ratio	22

Land Use

Population	447
Clearing (km²)	3184
% Cleared	80
Area under Grazing (km²)	3495
Area under Sugar (km²)	14
Area under Horticulture (km²)	7.9

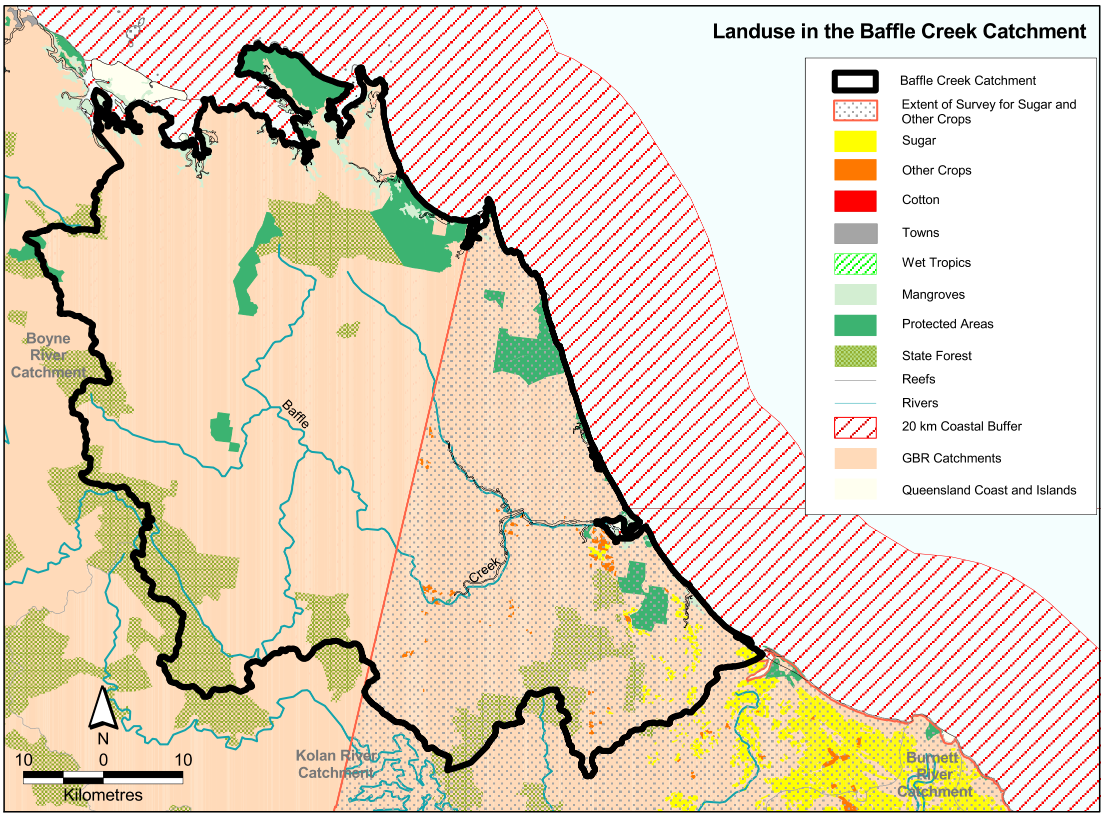
Pesticide Application
(Kg Active Ingredient/Yr)

Atrazine	523
Diuron	234
2-4D	66
Chlorpyrifos	356
MEMC	24

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	3000	103376	132051	34.5	50	51688	66026
Total N Export	190	874	1082	4.4	33	565	725
Total P Export	10	185	237	18.5	33	123	159

Data confidence Index = 1



Baffle Creek Catchment

The Baffle Creek catchment covers an area of 3996 km^2. Grazing is the dominant land use occupying approximately 3495 km^2. Other land uses include 14 km^2 of sugarcane and approximately 8 km^2 of horticulture. State forest and timber reserves occupy 477 km^2 and protected areas cover 214 km^2. Sediment export is classified as high risk, and total nitrogen and total phosphorus export are classified as medium risk in the Baffle Creek Catchment.

Issues in the catchment:

- Grazing land has been cleared on slopes and marginal areas which has resulted in erosion and salinity problems.
- Approximately 80% of the catchment has been cleared mostly for grazing.
- Approximately 5% of the catchment is within protected areas.
- Medium nutrient and pesticide contribution.
- Species are endangered due to land use and changes in vegetation cover.

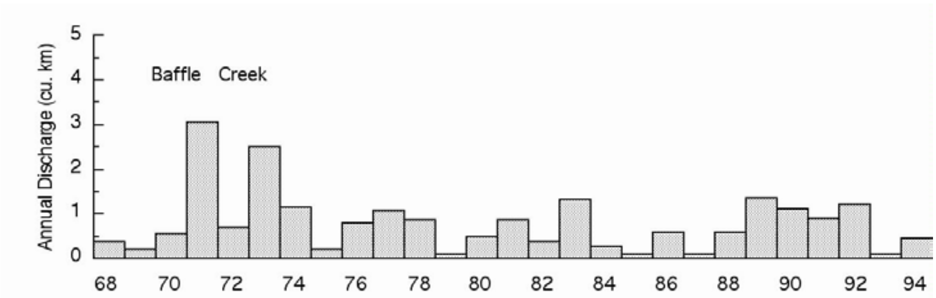


Figure 28. Water discharge patterns in the Baffle Creek.

Kolan River Catchment

Catchment Information

Description

Area (km²)	2901
% Gauged	80
Mean Discharge Yr (km³)	0.4
Rainfall (mm)	1065
Runoff (mm/m²)	141
Runoff/Rainfall Ratio	13

Land Use

Population	1471
Clearing (km²)	2487
% Cleared	86
Area under Grazing (km²)	2349
Area under Sugar (km²)	161
Area under Horticulture (km²)	5.1

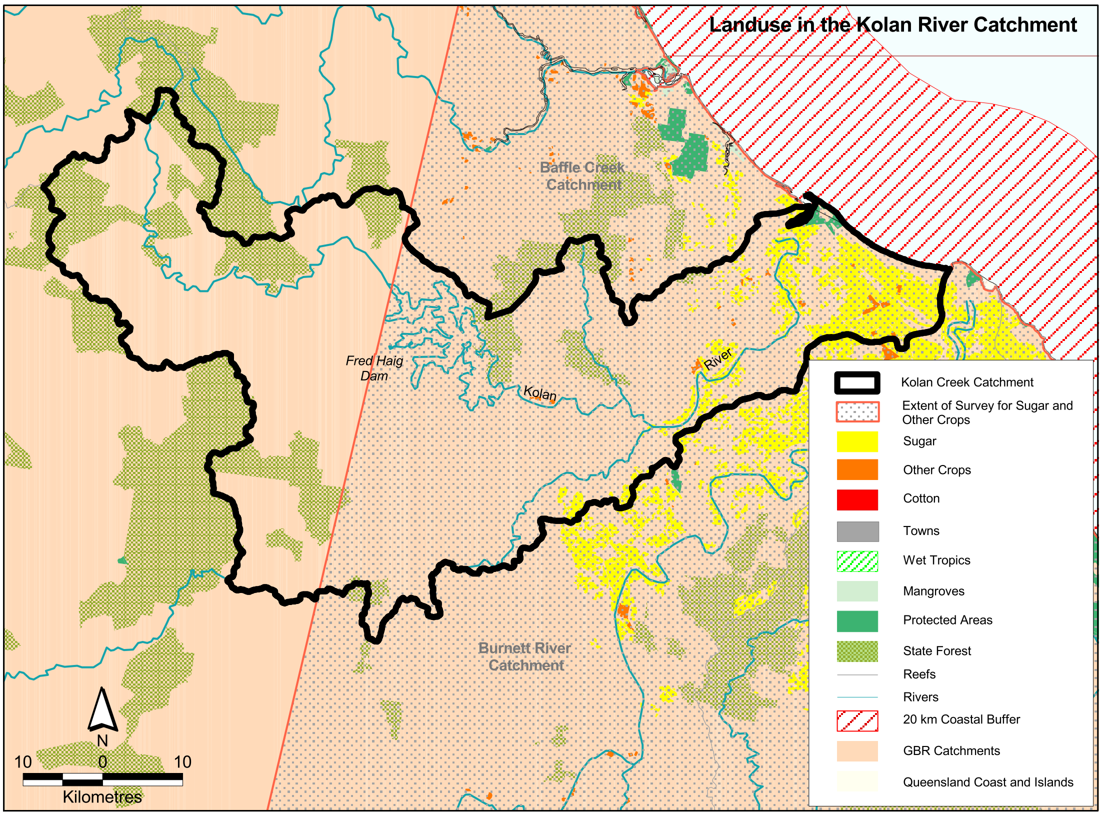
Pesticide Application
(Kg Active Ingredient/Yr)

Atrazine	4070
Diuron	1761
2-4D	499
Chlorpyrifos	2696
MEMC	39

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	2000	61589	151220	30.8	50	30794	75610
Total N Export	100	444	1082	4.4	33	297	725
Total P Export	5	97	237	19.4	50	49	119

Data Confidence Index = 1



Kolan River Catchment

The Kolan River catchment covers an area of 2901 km^2. Grazing is the dominant land use occupying approximately 2349 km^2. Other land uses include 161 km^2 of sugarcane and approximately 5 km^2 of horticulture. State forest and timber reserves occupy 381 km^2 and protected areas cover <5 km^2. Sediment and total phosphorus exports are classified as high risk, whilst total nitrogen export is classified as medium risk in the Kolan River Catchment.

Issues in the catchment:

- Grazing lands have been extensively cleared and sown with improved pasture.
- Approximately 86% of the catchment has been cleared mostly for grazing.
- Less than 0.2% of the catchment is within protected areas.
- Soil areas are susceptible to erosion and flooding which has caused severe sheet and rill erosion in some areas.
- Cultivation mainly occurs on better drained, sloping and fertile soils.
- Native pasture decline has occurred.
- Woody weed invasion in coastal areas is a problem.
- Salinity is a problem which is associated with high watertables on cultivated lands. Salt water intrusion to coastal aquifers has occurred from overuse of ground water.
- Urbanisation and use of agricultural chemicals has caused contamination in some local ground waters.
- Proximity to extensive seagrass beds.
- Changes to habitat and land usage in the catchment have brought about changes to fauna species.

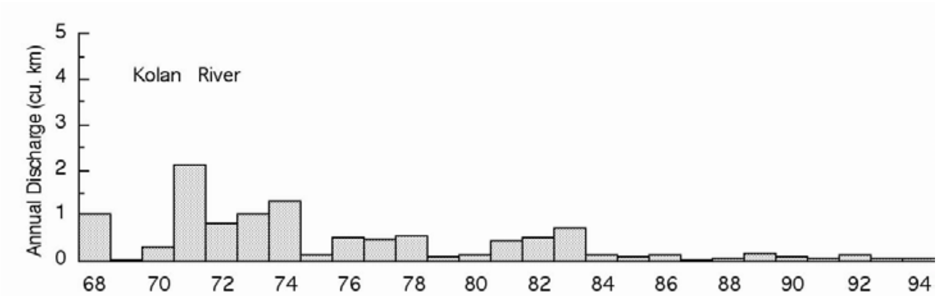


Figure 29. Water discharge patterns in the Kolan River

Burnett River Catchment

Catchment Information

Description

Area (km²)	33248
% Gauged	98
Mean Discharge Yr (km³)	1.15
Rainfall (mm)	763
Runoff (mm/m²)	35
Runoff/Rainfall Ratio	5

Land Use

Population	59284
Clearing (km²)	23750
% Cleared	71
Area under Grazing (km²)	27944
Area under Sugar (km²)	231
Area under Horticulture (km²)	75

Pesticide Application

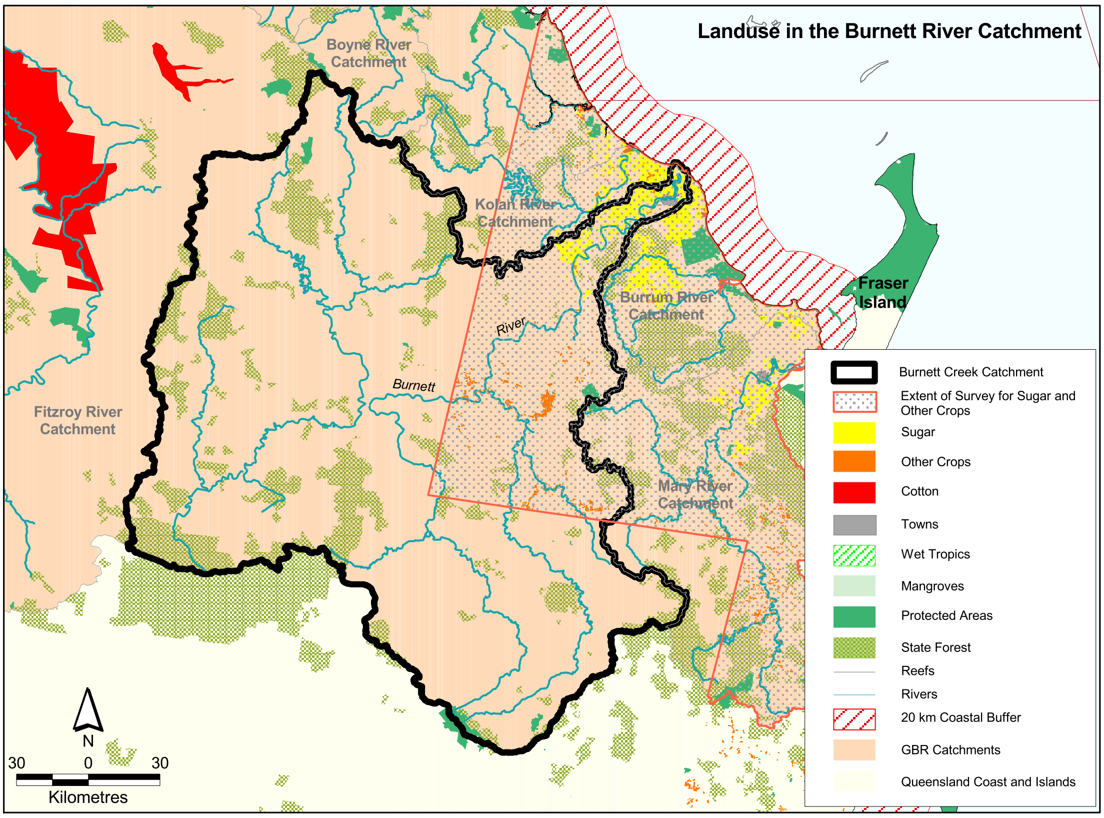
(Kg Active Ingredient/Yr)

Atrazine	8169
Diuron	3445
2-4D	1028
Chlorpyrifos	5220
MEMC	109

Catchment Targets

	1850 T/yr	Current T/yr	Current T/ km³	ratio	2011 % Red'n	2011 T/yr Target	2011 T/ km³ Target
Sediment Export	8000	728607	633913	91.1	50	364304	316957
Total N Export	281	1244	1082	4.4	33	833	725
Total P Export	14	272	237	19.4	50	136	119

Data Confidence Index = 1



Burnett River Catchment

The Burnett River catchment covers an area of 33248 km^2. Grazing is the dominant land use occupying approximately 27944 km^2. Other land uses include 231 km^2 of sugarcane and 75 km^2 of horticulture. State forest and timber reserves occupy 4874 km^2 and protected areas cover 148 km^2. Sediment and total phosphorus export are classified as high risk, and total nitrogen as medium risk in the Burnett River Catchment.

Issues in the catchment:

- Grazing lands have been extensively cleared and sown with improved pasture.
- Flood plains contain intensively fertilised cropping, predominantly sugar cane.
- Approximately 71% of the catchment has been cleared mostly for grazing.
- Soil areas are susceptible to erosion and flooding which has caused severe sheet and rill erosion in some areas.
- Less than 0.5% of the catchment is within protected areas.
- Cultivation mainly occurs on better drained, sloping and fertile soils.
- Native pasture decline has occurred.
- Salinity is a problem which is associated with high watertables on cultivated lands.
- Salt water intrusion to coastal aquifers has occurred from overuse of ground water. ground waters.
- Medium contribution of nutrient and pesticides.
- Irrigation infrastructure (such as dams, weirs, channels) threatens existing fisheries through siltation of the Burnett River below the barrage and restriction of fish movement.
- Proximity to significant seagrass beds and dugong habitat.
- Changes to habitat and land usage in the catchment have brought about changes to fauna species.

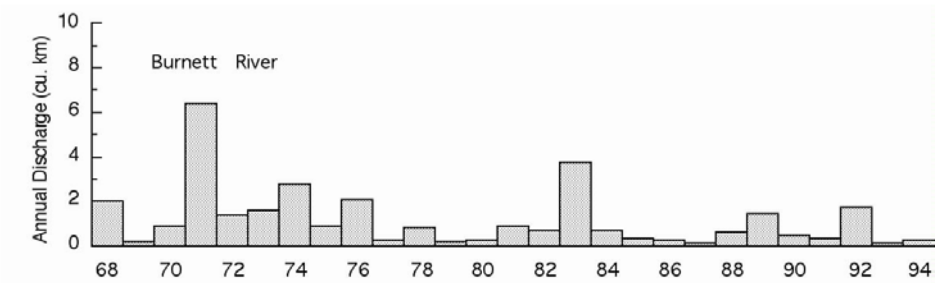


Figure 30. Water discharge patterns in the Burnett River.