

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 led 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)

- 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;

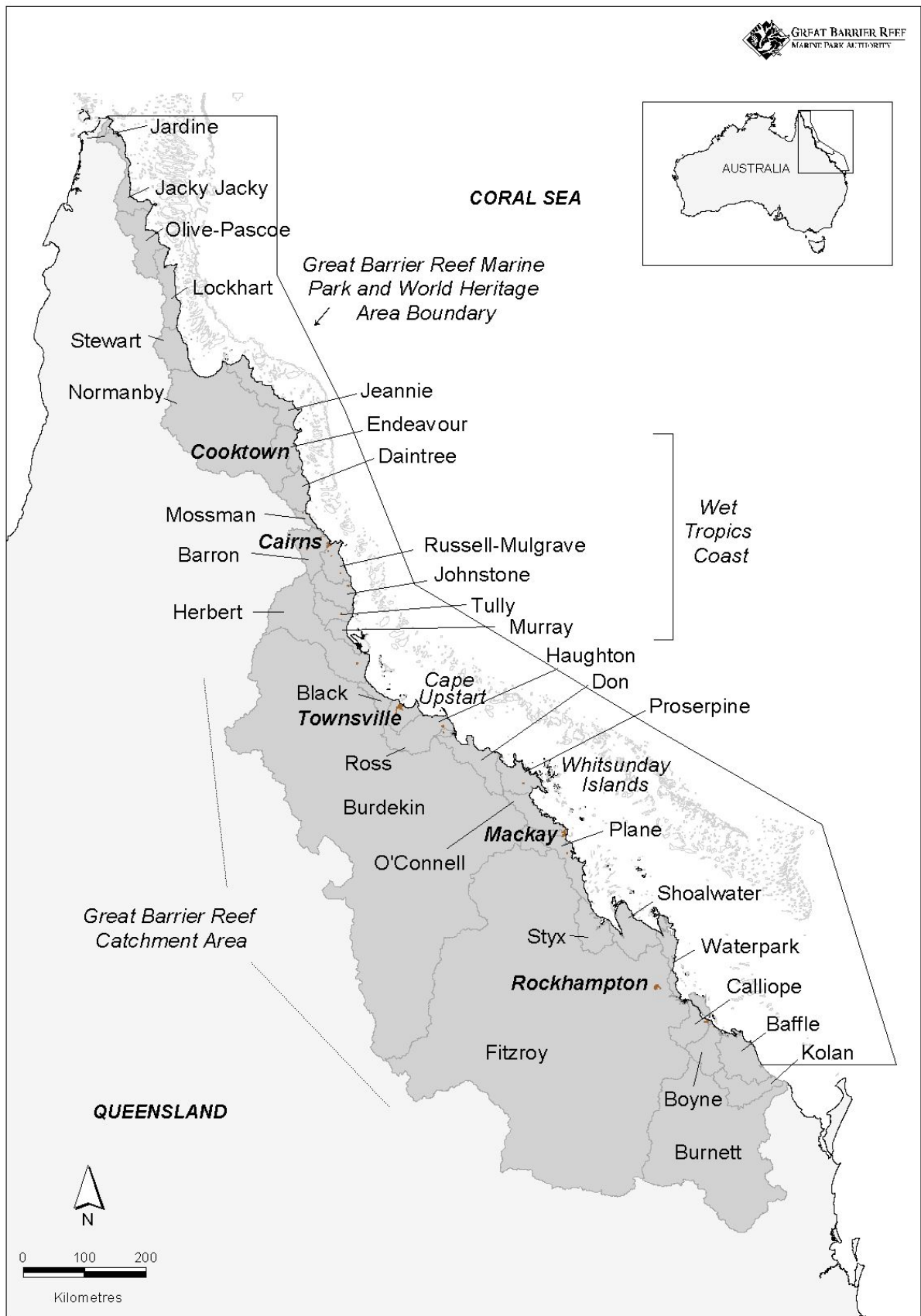


Figure 1. Catchments draining into the Great Barrier Reef World Heritage Area

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 reefs¹ 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.

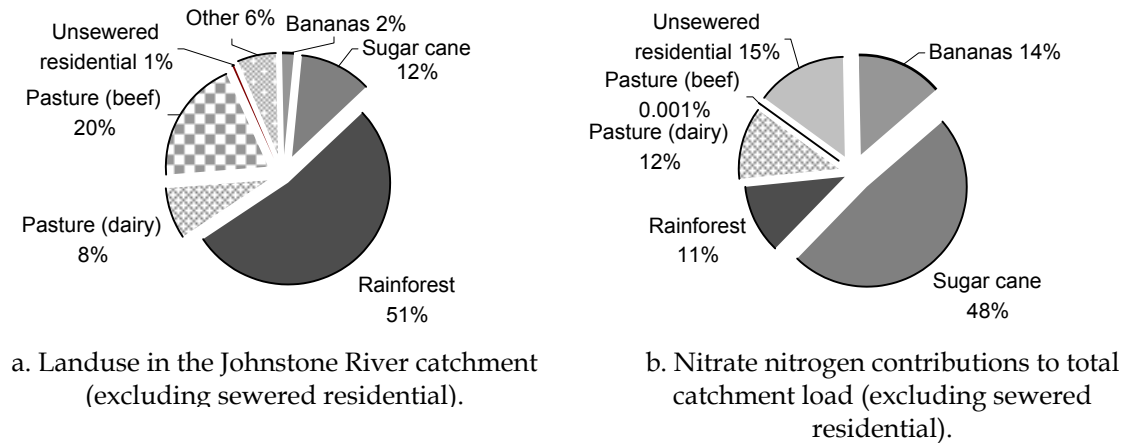
Agricultural activities that have resulted in increased erosion, the destruction of wetlands and stream bank vegetation, and run-off of sediment, fertiliser and chemical residues are the primary human impact on water quality in the Reef. The majority of the discharge of sediment and nutrient occurs during 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 bioavailable². Most of the increase in fertiliser nitrogen application has occurred in the last 40 years as a consequence of expansion of intensive

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).



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

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
<i>Organics</i>							
Atrazine	1	2.5	2.4	10	25	50	Ralph (2000)
Diuron	1	2.8	2.6	0.1	0.4	0.8	Haynes <i>et al.</i> (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 <i>et al.</i> (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)
<i>Metal</i>							
				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 overriding 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 km³ of discharge, a 38% reduction from the current 11,700,000 tonnes per year or 220,000 tonnes per km³.

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 km³ of discharge, a 39% reduction from the current 39,300 tonnes per year or 742 tonnes per km³.

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 km³ of discharge, a 47% reduction from the current 7,400 tonnes per year or 139 tonnes per km³.

Table 5. Sediment export risk analysis.

Catchment Name	¹ 1850 sediment export (t/y)	¹ 1850 sediment export (t/km ³)	¹ Current sediment export (t/y)	¹ Current sediment export (t/km ³)	Current divided by 1850	Sediment risk group	Overall Sediment target reduction factor	2011 Target Sediment export (t/y)	2011 Target Sediment export (t/km ³)
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/km ³)	¹ Current N export (t/y)	¹ Current N export (t/km ³)	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/km ³)
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	¹ 1850	¹ Current	¹ Current	¹ Current	P Risk group 1	² P	² P	P Risk group 2	Overall P risk group	Overall P Target Reduction factor	2011 Target P Export (t/y)	2011 Target P export (t/km ³)
	P export (t/y)	P export (t/km ³)	P export (t/y)	P export (t/km ³)	divided by 1850		fertiliser use 1990 (t)	fertiliser rate 1990 (kg/ha)					
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 km³ 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 (km³) by the nutrient run-off coefficient (tonnes per km³). 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 $3 - 7 \text{ mg m}^{-3}$ 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 Woessik, 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 ($< 20 \text{ km}$ 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.

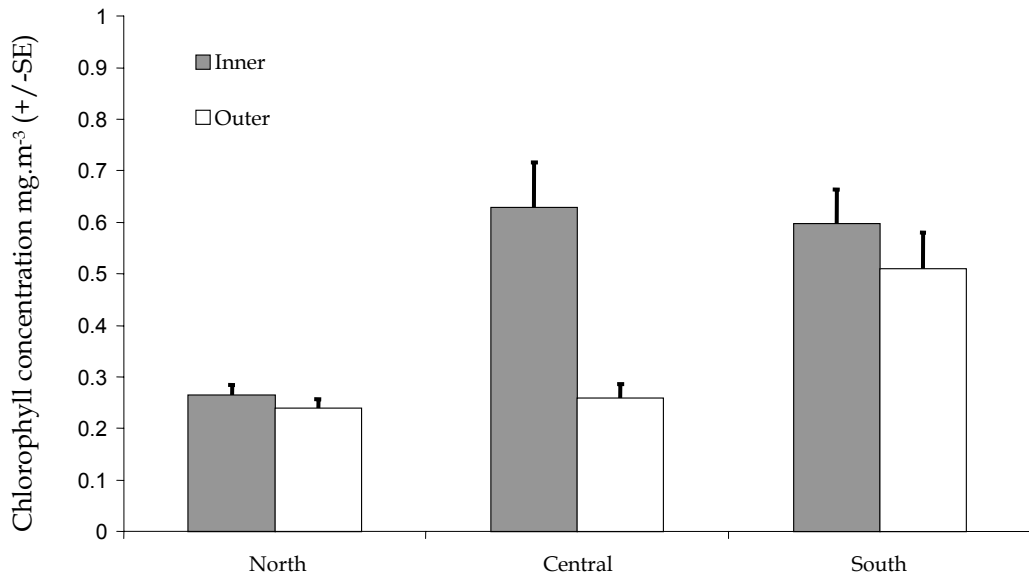
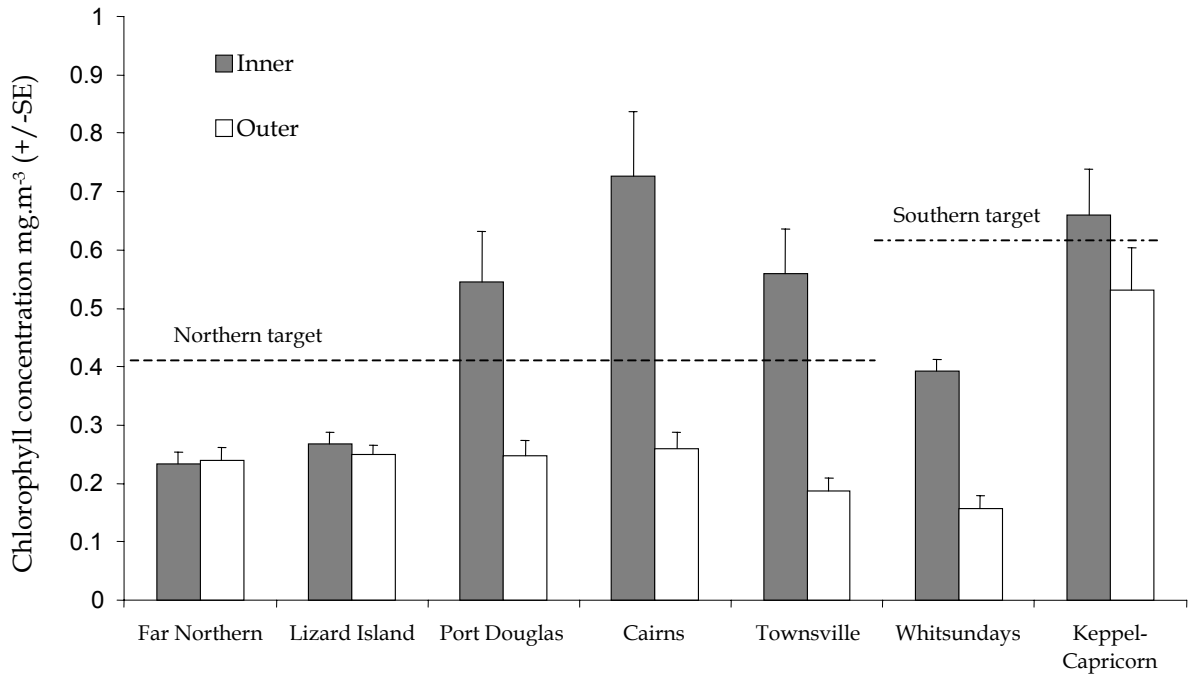


Figure 4. Average latitudinal chlorophyll results, 1993 to 2000.



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:

$$\text{Sediment threshold} = K_{ow} * C_w * (\% \text{ organic fraction of the sediment}).$$

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.

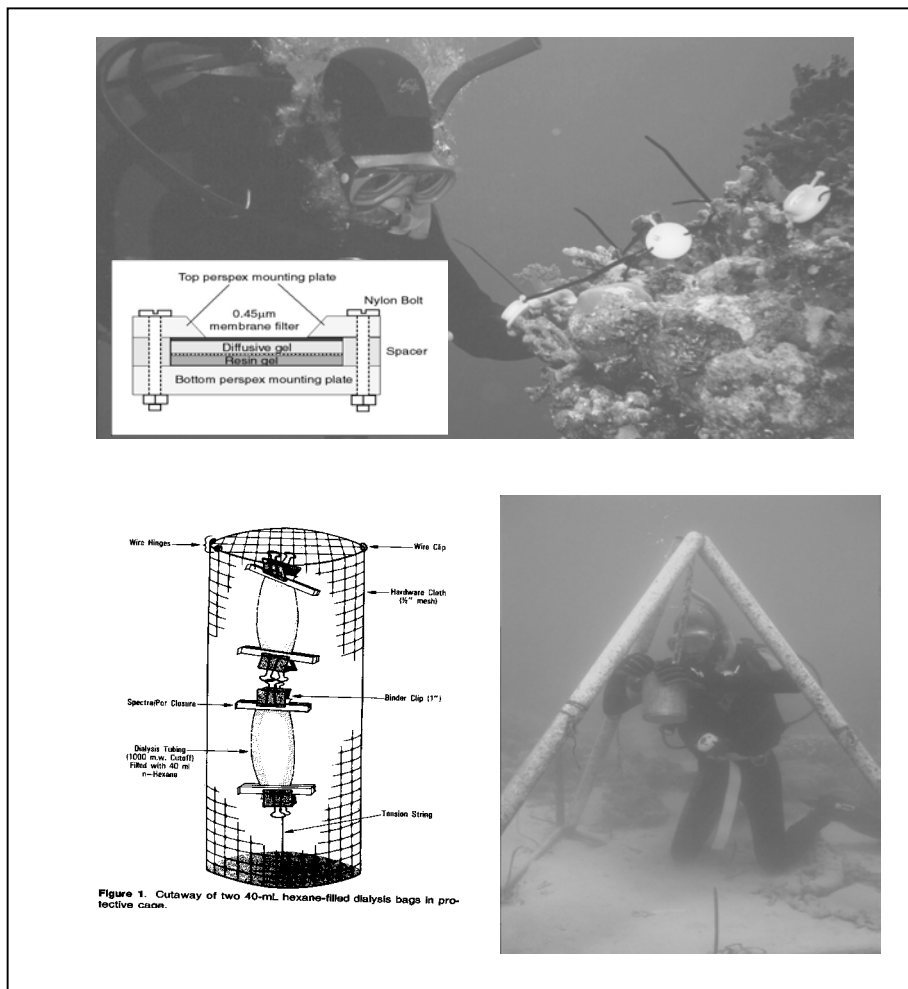


Figure 5. Deployment of innovative water quality samplers, GBR.

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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), Soilloss (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):

$$Y = RKLSCP$$

(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 can 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

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

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 km² 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 km² 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; Rutherford, 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.

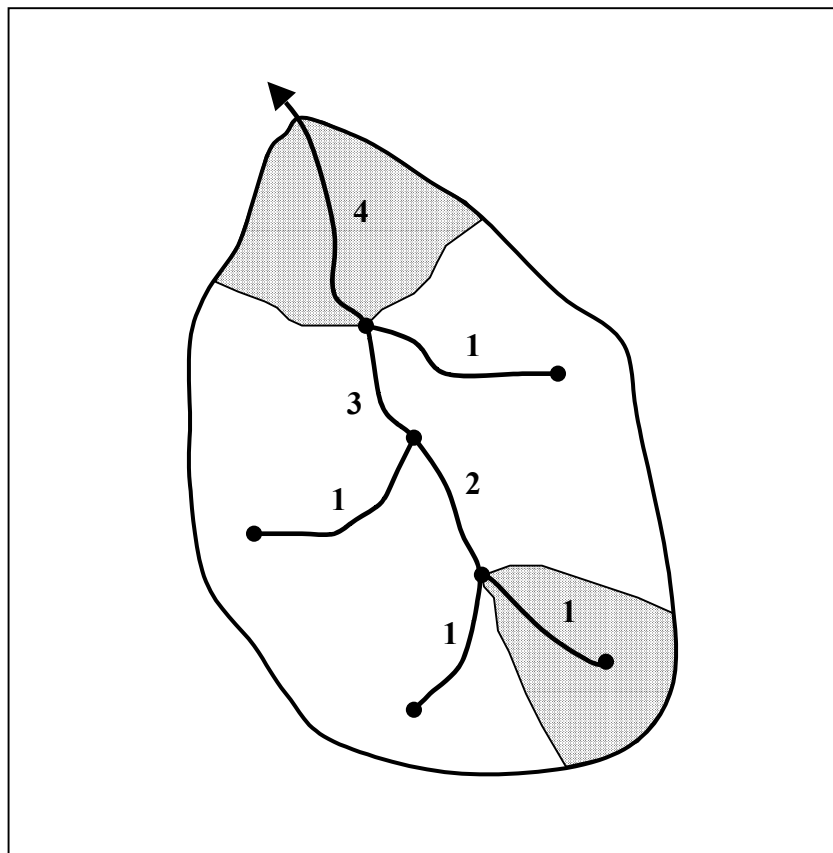


Figure 1: A river network showing links, nodes, Shreve magnitude of each link (Shreve, 1966) and internal catchment area of a magnitude one and a magnitude four link.

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 km². 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 km² 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.

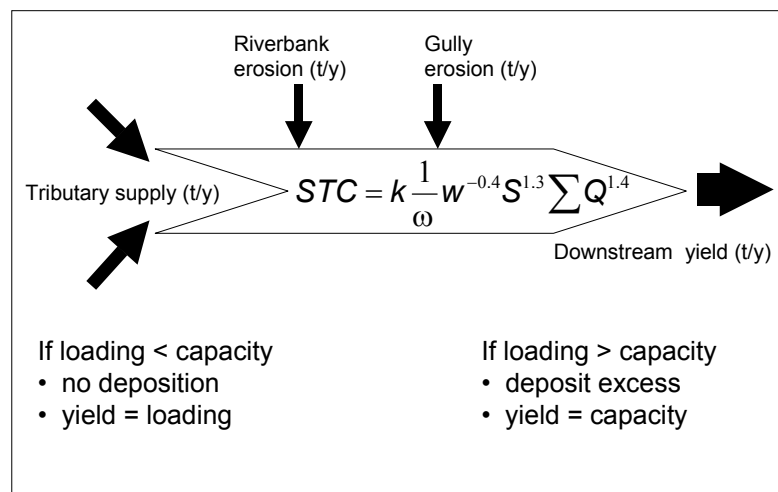


Figure 2: Conceptual diagram of the bedload sediment budget for a river link. The equation is used to calculate sediment transport capacity (STC), where k is a constant, ω is sediment settling velocity, w is river width, S is river slope and $\sum Q^{1.4}$ is the mean annual sum of daily discharge

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 m².

The supply of sediment from riverbank erosion was calculated from the results of a global review of river bank migration data (Rutherford, 2000). The best predictor of bank erosion rate (BE ; m/y) was found by Rutherford 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:

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

where ω is the settling velocity of the bedload particles (m/s). $\sum Q_x^{1.4}$ 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).

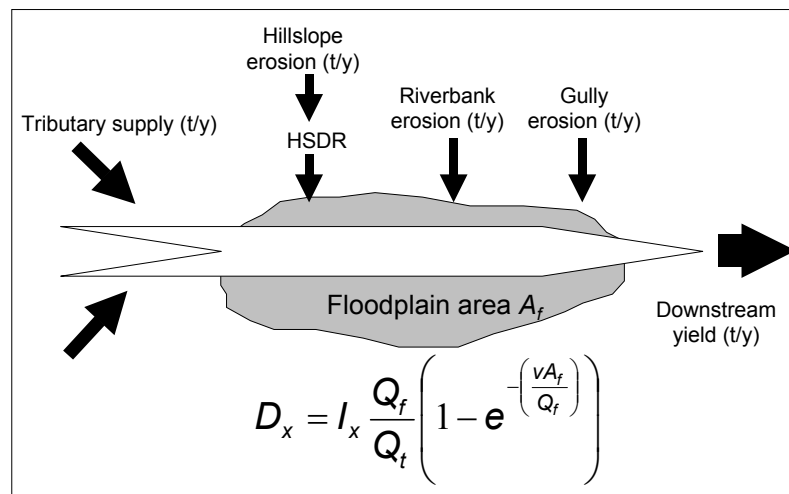


Figure 3: Conceptual diagram for the suspended sediment budget of a river link. HSDR is hillslope sediment delivery ratio. The equation is for the amount of sediment deposited on the floodplain (t/y), where I_x is the sediment load input to the link, Q_f/Q_t is the proportion of flow that goes overbank, A_f/Q_f is the ratio of floodplain area to floodplain discharge and v 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 km² 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:

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

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 from 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@gbmpa.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 ARC/INFO 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 ARC/INFO 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 <i>et al.</i> (1995). Estimates of the area of each catchment that is cleared were calculated using spatial analysis in ARC/INFO 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 ARC/INFO 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 ARC/INFO by combining horticultural data with DNR basin boundaries.

Pesticide Application (kg active ingredient/year)	Hamilton and Haydon (1996). <i>Pesticides and fertilisers in the Queensland sugar industry - estimates of usage and likely environmental fate</i> . 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.