QUEENSLAND FLOODS COMMISSION OF INQUIRY

STATEMENT OF ROBERT ARTHUR SPEIRS

I, **ROBERT ARTHUR SPEIRS** of c/- 400 George Street, Brisbane, Queensland, General Manager, Natural Resource Management Programs & Policy, Department of Environment and Resource Management (DERM), solemnly and sincerely affirm and declare:-

Requirement from Queensland Floods Commission of Inquiry

1. I have seen a copy of a letter dated 21 November 2011, which is attachment **RAS-00**, from the Commissioner, Queensland Floods Commission of Inquiry (the Commission) to me requiring a written statement under oath or affirmation, and which details the topics my statement should cover.

Role

2. I am currently the General Manager, NRM Programs and Policy, Department of Environment and Resource Management and have held this position since 2009. In this role I have responsibility for the development and delivery of the Queensland Government's Reef Protection Package of regulation, research and extension to reduce pollution of Reef water quality from fertilizers, pesticides and sediment from sugarcane and cattle grazing in north Queensland.

Item 1: The State Government plan to fund 32 new research and support projects into how soil, fertiliser and pesticides are lost from cane farms and cattle properties, and their consequent impact on the Great Barrier Reef (refer to media release by The Honourable Vicky Darling dated 18 November 2011), with specific reference to:

- **a) a brief chronology of how the plan came about**
- **b) the reasons for establishing the plan**
- **c) whether flooding concerns formed part of the reasons for the plan, and if so how**
- **d) whether the reported deaths of large numbers of dugongs, turtles and dolphins in Queensland waters, and the diseases affecting fish and other marine life in the Gladstone harbour since the 2010/2011 floods contributed to the decision**
- **e) whether and how flooding considerations will be taken into account in the plan**
- **f) flood or flood impact related advice received from any State government agency about the plan or the reasons for the plan**

g) **a brief overview of how the research projects will be selected, whether flooding issues will be taken into account and if any have already been selected, an overview of those projects**
h) **a description of how the plan relates to the joint Federal and State Government Reef Water Quality Protection Plan.**

a. a brief chronology of how the plan came about

As part of the joint Federal and State Government Reef Water Quality Protection Plan (Reef Plan), the *Environmental Protection Act 1994* and the *Chemical Usage (Agricultural and Veterinary) Control Act 1988* were amended on 1 January 2010 by the *Great Barrier Reef Protection Amendment Act 2009*, enabling the Queensland Government to regulate certain activities on cattle grazing and sugarcane properties in the Burdekin Dry Tropics, Mackay-Whitsunday and Wet Tropics catchments. This resulted in the establishment of the Reef Protection Package (sometimes referred to as the Reef Regulation), which is administered by the Department of Environment and Resource Management (DERM) and which is funded for 5 years from June 2009 to June 2014, with a budget of $50 million. Within this budget, $10.1 million has been allocated to research and development (R&D) to assess and reduce the risks that sediment, nutrients and pesticides from agricultural practices pose to the Reef. $2.5 million was committed to R&D between 2009 and 2011, largely to inform regulatory requirements around nutrient management. However, it was recognised that a strategic approach was required to ensure that regulation of, and advice to, cane growers and graziers was defensible, through being supported by the best available scientific evidence, and that communication of this regulation and advice would be delivered in the most effective manner possible.

To these ends, the Reef Policy Unit of the Department of Environment and Resource Management undertook an R&D planning exercise between March and November 2011, resulting in the approval of investment of a further $7.6 million in the Reef Protection Package R&D Plan (**RAS-01**). A description of the process used to develop the Plan is attached (**RAS-02**), along with the portfolio of R&D projects that make up this plan (for funded projects, see **RAS-03**; for projects yet to be scoped, see **RAS-04**).

The process included:

- internal planning to identify the knowledge needs of Reef Protection Package (March to June 2011)
- external identification of knowledge gaps that would be an impediment to Reef Protection Package and Reef Plan (June 2011)
- call for R&D projects (June 2011 – August 2011)
- external assessment of projects (July – August 2011)
- internal review of the project portfolio (August 2011 – October 2011)
- negotiations with proponents to undertake projects (November 2011 – ongoing)

b. the reasons for establishing the plan

Significant evidence exists indicating that sediment, nutrients and pesticides derived from land use are damaging the Great Barrier Reef (**RAS-05**). A scientific consensus statement of the impacts of land use on the Reef was compiled by concerned scientists in 2008 (see **RAS-06** for the consensus statement and **RAS-07** for evidence supporting the statement). An assessment of the relative risk of pollutants to the Reef was undertaken in 2009 (see **RAS-08** for Stage 1 of this report and **RAS-09** for Stage 2). It identified that the pollutants most damaging to the Reef were nutrients and pesticides derived from sugar cane farming in the Wet Tropics catchment, followed by the Mackay-Whitsunday and Burdekin Dry tropics catchments, and sediments from the Burdekin Dry Tropics catchment. Sediment from the Fitzroy catchment was also identified as significant. However, this catchment was not included in the regulatory regime while the Burdekin Dry Tropics catchment was because the Burdekin Dry Tropics also has significant sugarcane production areas, and its discharge areas are closer to the Reef. It is still not fully understood which areas within the regulated catchments are producing the most pollutants, or in which areas improved management will lead to the greatest Reef water quality improvement. Therefore 51.5% of the R&D investment will be allocated to better define the risk to the Great Barrier Reef from cane and grazing management and help to identify where improvement efforts should be focused.

Land managers in both the cane and grazing industries have made significant efforts to improve their management practices to reduce pollutants leaving their properties. However, these efforts are impeded by significant knowledge gaps, such as the actual nitrogen needs of cane plants under different growing conditions, or the most economically viable means of improving water quality outcomes. Therefore 48.5% of the Reef Protection Package R&D investment will be allocated for identifying cane and grazing management solutions and support land managers to adopt management practices that improve both water quality and profitability.

c. whether flooding concerns formed part of the reasons for the plan, and if so how

Flooding concerns did not form part of the reasons for the plan.

The formulation of Reef Protection Package, including its provision for substantial funding for research and related activities, predates the 2010/2011 flood events. The focus of the Reef Protection Package is on reducing pollutants from agricultural sources (i.e. above natural levels) through improved agricultural management. Severe weather events, such as the 2010/2011 floods are effectively transparent to the thrust of the Reef Protection Package's investments and activities, because such phenomena are within normal climate variability over the long term. With respect to nutrients and pesticides, pollutant loads reaching the Great Barrier Reef lagoon are highly correlated to the amounts of nutrients and pesticides applied and the efficiency of their application. The Reef Protection Package therefore aims to reduce loads through reducing amounts applied and increasing application efficiency, regardless of rainfall or flood events.

d. whether the reported deaths of large numbers of dugongs, turtles and dolphins in Queensland waters, and the diseases affecting fish and other marine life in the Gladstone Harbour since the 2010/2011 floods contributed to the decision

The reported deaths of large numbers of dugongs, turtles and dolphins in Queensland waters, and the diseases affecting fish and other marine life in the Gladstone Harbour since the 2010/2011 floods did not contribute to the decision.

Although the work to develop the R & D Plan coincided with the turtle and dugong mortalities observed in 2011, the Plan responds to the mandate to address grazing and sugarcane farming practices to improve the quality of water reaching the Reef, based on the scientific consensus statement published in 2008 (see **RAS-06** and **RAS-07**) and the relative risk of individual pollutants to the variety of Reef species and ecosystems undertaken in 2009 (see **RAS-08** and **RAS-09**). These documents identified nutrients and pesticides from cane farming and sediment from grazing as the most significant pollutants affecting the Reef. These assessments remain valid notwithstanding the 2010/2011 floods and the recently observed mortalities and diseases affecting marine life.

The Reef Protection Package regulates land management only in the Wet Tropics, Burdekin Dry Tropics and Mackay Whitsunday catchments. Therefore Gladstone Harbour, which lies in the Fitzroy Basin catchment, is outside of the scope of the program.

e. whether and how flooding considerations will be taken into account in the plan

Flooding concerns have been considered in the formulation of the R&D Plan. Pesticides and fertilisers are most likely to contribute to Reef pollution if applied to waterlogged soils or prior to heavy rainfall or flooding. Two of the four projects examining the nitrogen needs of cane crops and nutrient application rates will be assessing the impact of water-logging and flooding on losses to waterways, and make recommendations to prevent such losses.

Sediment reaching the Reef increases with flooding. However, severe weather events (regardless of the contribution of climate change) are considered natural events, and therefore the sediment loads delivered through these events are also considered natural.

f. flood or flood impact related advice received from any State Government agency about the plan or the reasons for the plan

No advice on flooding or flood impacts was received or sought in the development of the R&D Plan.

g. a brief overview of how the research projects will be selected, whether flooding issues will be taken into account and if any have already been selected, an overview of those projects

As listed in **RAS-03**, 23 of the 32 proposed projects have been selected and negotiations with proponents are underway. A further 9 projects will be scoped early in 2012 (see **RAS-04**). A breakdown of investment in these projects is provided in Table 1.

Table 1. Budget allocation for new investments under Reef Protection Package portfolio 2011 – 2014

	Program-wide		Cane		Grazing		Total	
Funded projects	3	$750,000	12	$2,056,100	8	$2,770,000	23	$5,576,100
To-be-scoped projects			7	$1,765,000	2	$250,000	9	$2,015,000
Total	3	$750,000	19	$3,821,100	10	$3,020,000	32	$7,591,100

The projects were selected to address knowledge gaps in the Reef Protection Package program, using the process referred to in section 1a above. In this process, a program logic diagram was developed identifying the outcomes that the program was to achieve (**RAS-10**), 101 research questions needed to inform the program within 14 thematic areas, and 22 extension tools to be developed (see **RAS-02**). The external peer review panel then identified which research questions represented significant knowledge gaps relevant to the Reef Protection Package and Reef Plan. The Reef Policy Unit considered this information, along with stakeholder consultation regarding information support needs of growers and graziers, in allocating project funding. Funding was also balanced across the thematic areas of the program and across cane farming and grazing. A brief description of each of the projects is provided (**RAS-11**).

h. a description of how the plan relates to the joint Federal and State Government Reef Water Quality Protection Plan

The Reef Water Quality Protection Plan (Reef Plan) (**RAS-12**) is the overarching agreement between the Australian and Queensland Governments on actions that are required to halt and reverse the decline in Great Barrier Reef water quality as a result of broadscale agriculture. There are 11 key actions and 33 deliverables to be implemented by 12 different partners, both government and non-government. Reef Plan encompasses a range of initiatives, including the Reef Protection Package. The Reef Protection Package includes regulations under the *Great Barrier Reef Protection Amendment Act 2009* that requires landholders in two industries (cane and cattle grazing) in priority catchments (Mackay Whitsundays, Wet Tropics and Burdekin) to meet specified obligations and to take all reasonable and practical steps to improve the quality of run-off from their properties. The Reef Protection Package has an extension and research component to help effectively deliver those regulations and associated land management practices. The Reef Protection Package complements the Australian Government Reef Rescue program, which provides incentives to farmers to accelerate the adoption of best management practices.

As part of the Reef Water Quality Protection Plan, a Research, Development and Innovation Plan is prepared each year to identify the key information gaps and research priorities needed to deliver Reef Plan effectively. The R&D projects identified and funded through the Reef Protection Package R&D Plan are consistent with this plan and are critical to filling some of the fundamental knowledge gaps, particularly at the finer paddock scale. The Reef Protection Package R&D Plan complements other R&D programs relative to Reef water quality, including those delivered by the Australian Government through the Reef Rescue program and the National Environmental Research Program. A strongly collaborative approach between these programs is helping ensure coordination and integration across research projects that combined will deliver a significantly improved knowledge base.

Item 2: The involvement of the Department of Environment and Resource Management (DERM) in the development and implementation of the plan.

The Reef Protection Package R&D Plan was developed internally by the Reef Policy Unit of DERM, with the input of an external panel of research experts and in response to stakeholder consultation, as described in Item 1. The Reef Policy Unit will also implement the Plan. However, the Reef Policy Unit will not undertake the research. Of the 23 funded projects, 14 projects (total value $3.7 million) will be undertaken by DERM: 10 projects ($3.04 million) by Environment and Resource Sciences, two projects ($430,000) by Regional Service Delivery-Regional Science and two projects ($625,000) by the Queensland Climate Change Centre of Excellence. Two projects ($745,000) will be undertaken by the Department of Employment, Economic Development and Innovation. The remaining projects will be undertaken by non-government research providers (see **RAS-03**).

The Reef Policy Unit has established a Science Program, drawing on the services of 15 staff, to oversee the delivery of the Reef Protection Package R&D Plan. This program has established program and project governance procedures to ensure that the projects are delivered on time and within budget, that they produce the required outputs to a high standard, and that they are integrated into extension programs supported by DERM.

Item 3: Any preliminary research performed or commissioned by DERM or available to DERM which indicates that farm chemical, pesticide or fertiliser runoff or soil erosion from the 2010/2011 floods have had any adverse impacts on the Great Barrier Reef.

As stated in Item 1, the evidence for farm chemical, pesticide or fertiliser runoff and soil erosion adversely affecting the Great Barrier Reef was well established in the scientific consensus statement published in 2008 (see **RAS-06** and **RAS-07**) and the relative risk of individual pollutants to the Reef undertaken in 2009 (see **RAS-08** and **RAS-09**). This work led to the implementation of Reef Plan to address agricultural pollution, encompassing both the Reef Protection Package and the Australian Government's Reef Rescue program as part of its Caring for Our Country program (**RAS-13**). In addition, the Paddock to Reef Water Quality Monitoring and Modelling Program (P2R) is using a combination of monitoring and modelling to assess reduction in end-of-catchment pollutant loads as a result of improved practices (**RAS-14**). Results of P2R monitoring and modelling have yet to be complied into information that can be used to assess the impacts of the 2010/2011 floods on the Reef, but are likely to be so within the next 6 months.

DERM regards marine monitoring in the Great Barrier Reef to be primarily the responsibility of the Great Barrier Reef Marine Park Authority. However, based on advice from my colleagues within DERM's Environmental and Resource Science (ERS) Business Group I am able to provide the following account. DERM currently monitors pollutants in a number of Queensland rivers that discharge to the Reef. This includes monitoring total suspended solids (TSS) and a variety of nutrients in 11 catchments and 13 sub-catchments, and pesticides in 9 catchments and 2 sub-catchments. Results from monitoring at eleven sites in 2009/2010 indicated that pesticide concentrations in creeks and rivers discharging into the Great Barrier Reef are likely to pose problems for freshwater aquatic ecosystems (**RAS-15**). Of the five pesticides (atrazine, hexazinone, diuron, ametryn and tebuthiuron) identified in the Reef Protection Package as having the most potential to cause damage to Reef ecosystems, all were found at two of these 11 pesticide monitoring sites and four out of the five were found in the remaining nine sites. Atrazine and hexazinone were found at every site, along with varying mixtures of diuron, ametryn and tebuthiuron. When considered in isolation, the highest concentrations of atrazine, diuron and metolachlor were found at up to 33 times greater than levels recommended to protect aquatic ecosystems by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Individual pesticides at Barratta and Sandy creeks, and the Tully, Suttor, Pioneer, Fitzroy, Comet and Burnet rivers regularly exceeded the environmental trigger levels. In combination, concentrations of these pesticides were up to 62 times greater than trigger levels at some sites.

While the ERS monitoring program includes measurements of water quality associated with the 2010/2011 floods, analysis of results has only been completed for the Fitzroy catchment (**RAS-16**). Estimates of the TSS load passing through the Fitzroy River end-of-catchment monitoring site (Rockhampton; DERM SITE 1300000) between 23 November 2010 and 1 February 2011 were approximately 6,302,000 tonnes; total nitrogen approximately 31,000 tonnes; and total phosphorus as approximately 14,000 tonnes. Results from the remaining catchments have not yet been analysed as this cannot be done until all samples have been validated. Raw data observations are available and can be provided on request. However, whether the floods of 2010/2011 resulted in greater pesticides loads reaching the Reef will only be clear once all relevant data have been validated and analysed. This is unlikely to be completed for at least six months.

The Australian Centre for Tropical Freshwater Research at James Cook University coordinated a monitoring response to the 2010/2011 floods in the Great Barrier Reef lagoon, funded by the Reef Rescue Marine Monitoring Program. DERM staff participated in this response, collecting water quality data from the discharge plume from the Burnet-Mary catchment. These data are yet to be analysed.

Regardless of the impact of pollutant loads associated with the 2010/2011 floods, improved practices as a result of the Reef Protection Package (including the regulation of nutrient and pesticide application on cane farms) and associated Reef Plan extension programs, are likely to have reduced the amounts of nutrient, pesticide and sediment in water reaching the Reef overall. This would have also resulted in the pollutant loads delivered to the Reef as a result of the 2010/2011 flood being less that what would have been expected without such management improvements.

In addressing the matters that are the subject of this requirement I have provided all of the information in my possession and additional relevant information I have been able to source, as reflected in my account and the attached documents. A substantial body of documents was generated by the process of developing the R&D Plan. To the best of my knowledge and understanding, the relevant information contained in such preparatory material is embodied within this account and the attached documents.

As commentary, I offer the view that the Reef Protection Package seeks to address a specific suite of chronic impacts on the health of the Great Barrier Reef, and as such does not account for acute impacts such as cyclones and floods. This is not to imply that such acute phenomena and their consequences are of no concern to Reef health. I seek only to clarify that the mandate for this R&D plan and the Reef Protection Package within which it is occurring is to reduce chronic stress on the Reef ecosystem from the historic and on-going consequences of sugarcane farming and cattle grazing land management practices in the three specified catchments.

I make these statements based upon my membership of and active participation in the Reef Plan Intergovernmental Operations Committee and in the DERM Reef Science Steering Committee, and as the senior executive with responsibility for the development and delivery of the Reef Protection Package.

I make this solemn declaration conscientiously believing the same to be true, and by virtue of the provisions of the *Oaths Act 1867*.

Signed .[redacted]...
Robert Arthur Speirs

Taken and declared before me, at Brisbane this 25th day of November 2011

...[redacted]............
Solicitor/~~Barrister/Justice of the Peace/Commissioner for Declarations~~

Our ref: Doc 1784154

23 November 2011

Mr [redacted]
Assistant Crown Solicitor
Crown Law
Department of Justice and Attorney-General
GPO Box 5221
BRISBANE QLD 4001

Dear [redacted]

I refer to an email received from Cosmo Cater of Crown Law earlier today, and enclose a Requirement to provide a statement addressed to Mr Robert Speirs of the Department of Environment and Resource Management.

Please note that item 1(h) of the Requirement has been edited to confine the amount of detail that Mr Speirs is required to provide about the Reef Water Quality Protection Plan.

Mr [redacted] and Mr [redacted] of the Department of Employment, Economic Development and Innovation may also assume that the edited terms of 1(h) apply to Requirements 1784144 and 1784126, issued on Monday 21 November 2011.

The material is returnable to the Commission no later than 12 pm, Friday, 25 November 2011.

If you require further information or assistance, please contact [redacted] on telephone [redacted] or [redacted] on telephone [redacted]

We thank you for your assistance.

Yours sincerely

[redacted]

Jane Moynihan
Executive Director

Encl.

Our ref: Doc 1784067

23 November 2011

Robert Speirs
General Manager
Natural Resource Management Programs & Policy
Department of Environment and Resource Management
GPO Box 2454
BRISBANE QLD 4001

REQUIREMENT TO PROVIDE STATEMENT TO COMMISSION OF INQUIRY

I, Justice Catherine E Holmes, Commissioner of Inquiry, pursuant to section 5(1)(d) of the *Commissions of Inquiry Act 1950* (Qld), require Mr Robert Speirs to provide a written statement, under oath or affirmation, to the Queensland Floods Commission of Inquiry, in which the said Mr Speirs gives an account of:

1. The State Government plan to fund 32 new research and support projects into how soil, fertiliser and pesticides are lost from cane farms and cattle properties, and their consequent impact on the Great Barrier Reef (refer to media release by The Honourable Vicky Darling dated 18 November 2011 ("the plan")), with specific reference to:
   a. a brief chronology of how the plan came about
   b. the reasons for establishing the plan
   c. whether flooding concerns formed part of the reasons for the plan, and if so how.
   d. whether the reported deaths of large numbers of dugongs, turtles and dolphins in Queensland waters, and the diseases affecting fish and other marine life in the Gladstone harbour since the 2010/2011 floods contributed to the decision
   e. whether and how flooding considerations will be taken into account in the plan
   f. flood or flood impact related advice received from any State government agency about the plan or the reasons for the plan
   g. a brief overview of how the research projects will be selected, whether flooding issues will be taken into account and if any have already been selected, an overview of those projects
   h. a brief description of how the plan relates to the joint Federal and State Government Reef Water Quality Protection Plan (only key documents to be attached).
2. The involvement of the Department of Environment and Resource Management (DERM) in the development and implementation of the plan.

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ABN 82 696 762 534

3. Any preliminary research performed or commissioned by DERM or available to DERM which indicates that farm chemical, pesticide or fertiliser runoff or soil erosion from the 2010/2011 floods have had any adverse impacts on the Great Barrier Reef.

In addressing these matters, Mr Speirs is to:

- provide all information in his possession and identify the source or sources of that information;
- make commentary and provide opinions he is qualified to give as to the appropriateness of particular actions or decisions and the basis of that commentary or opinion.

Mr Speirs may also address other topics relevant to the Terms of Reference of the Commission in the statement, if he wishes.

The statement is to be provided to the Queensland Floods Commission of Inquiry by 12 pm, Friday, 25 November 2011.

The statement can be provided by post, email or by arranging delivery to the Commission by emailing info@floodcommission.qld.gov.au.

C. Holmes

Commissioner
Justice C E Holmes

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ID	Title ... Australian Centre for Tropi... ...mes Cook University; AIMS: Australian Institute of Marine Sciences; CQU: Central Queensland University; GU: Griffith University; JCU: James Cook University; MLA: Meat and Livestock Australia; UQ: University of Queensland; D: Director; DG: Director General; GM: General Manager; M: Manager Business Services	Proponent/ Partners	Requested budget	Recommended budget	Maps	Loss pathway understanding	Management/ mitigation options	Regulatory tracking	Extension Support	Management information support	[illegible] for [illegible]	[illegible] group	Expected [illegible] date

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Title ...alian Institute of Marine Sciences; CQU: ...and University; GU: Griffith University; JCU: James ...ersity; MLA: Meat and Livestock Australia; UQ: University of Queensland; D: Director; DG: Director General; GM: General Manager; M: Manager Business Services	Partners	Funding	Research findings	Maps	Loss pathway	Management/mitigation options	Exp.

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ATTACHMENT [illegible]

ACTFR: Australian Centre for Tropical Freshwater Research, James Cook University; AIMS: Australian Institute of Marine Sciences; CQU: Central Queensland University; GU: Griffith University; JCU: James Cook University; MLA: Meat and Livestock Australia; UQ: University of Queensland;
D: Director; DG: Director General; GM: General Manager; M: Manager Business Services

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Current evidence	Additional evidence 2011/12	Additional evidence 2013/2014
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Current evidence	[illegible] evidence 2011/12	[illegible] evidence 2013/2014

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Current evidence	Additional evidence 2011/12	Additional evidence 2013/2014	[illegible]	[illegible]	[illegible]
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	Evidence 2011/12	Evidence 2013/2014	Evidence	Additional evidence 2011/12	2013/14
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Panel member	Organisation	R&D group Workshop 22/7/11	Assessment Session 1 27/7/11	Assessment Session 2 23/8/11
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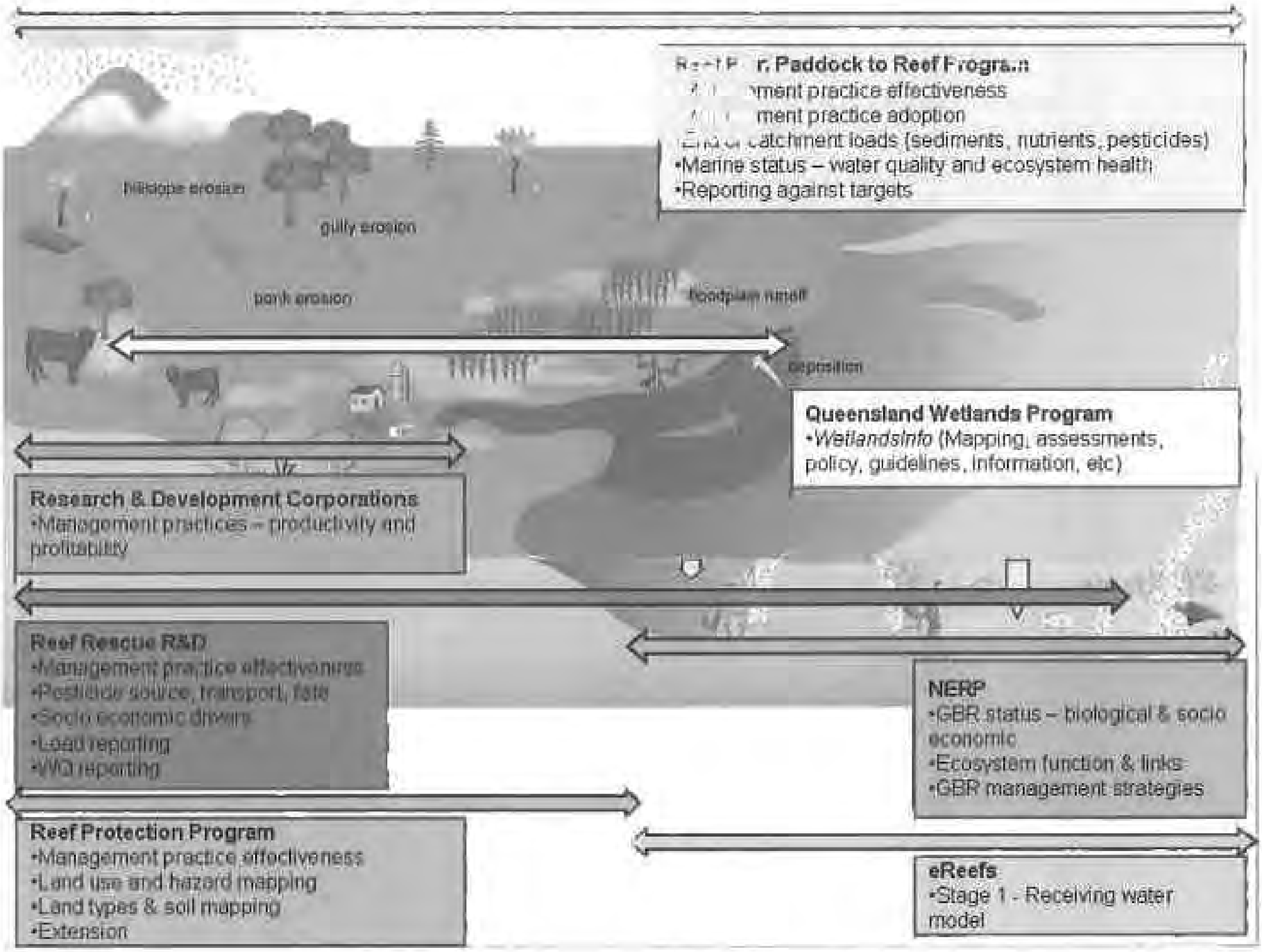

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ATTACHMENT [illegible] List [illegible] applications [illegible] for funding [illegible]

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ATTACHMENT [illegible] gaps [illegible] addressed [illegible] program

Table [illegible] [illegible] in the [illegible] projects in the RPP R&D portfolio

	Funded project / scoping addressing gap	Comment	Significant unaddressed gap (RPP/ Reef Plan)
Program prioritisation			
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible] Reef Plan
[illegible]			
[illegible]	[illegible]	[illegible]	[illegible] Reef Plan

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[illegible]	Funds [illegible] spent scoping addressing gap	Comment	[illegible]
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[illegible] gaps [illegible] addressed by [illegible] program

	Funded program addressing gap	Comment	Significant unmet need (EPP/Best Plan)
[illegible]		[illegible]	
[illegible]		[illegible]	
[illegible]		[illegible]	
[illegible]		[illegible]	Yes – EPP Best Plan
[illegible] nutrient			
[illegible]			
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	

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[illegible]	[illegible] addressing gap	[illegible]	[illegible]

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[illegible] gaps [illegible] addressed [illegible] program

	Funded project supporting addressing gap	Comment	Significant unaddressed gap [illegible]
[illegible]	[illegible]	[illegible]	
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[illegible]	Funded project ... ping addressing gap	Comment	Significant ... EPF ... Plan
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[illegible]	Funded project(s) [illegible] addressing gap	Comment	Significant unaddressed gap (RPF Rest Plan)
[illegible]	[illegible]		
[illegible]	[illegible]		
[illegible] [illegible] assessment [illegible] establishment			
[illegible]	[illegible]	[illegible]	Yes: RPF Rest Plan
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	Yes: Rest Plan
[illegible]		[illegible]	Yes: RPF Rest Plan; RPF Rest Plan

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[illegible]	[illegible] addressing gap	Comment	[illegible] unaddressed gap ([illegible] Best Plan)
[illegible]	[illegible]	[illegible]	Yes – [illegible] Best Plan
[illegible]		[illegible]	Y[illegible]
[illegible] management			
[illegible]	[illegible]	[illegible]	Yes – RBP Best Plan
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[illegible]	[illegible] scoping addressing gap	Comment	[illegible] Best Plan
[illegible]		[illegible]	
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ROBERT SPEIRS STATEMENT ATTACHMENT 2.

Process for RPP R&D portfolio development

At its establishment, Reef Protection Program (RPP) intended to develop a scientifically rigorous evidence base to inform its decisions and the advice provided to growers and graziers about land management. A number of investments were made that responded to immediate program needs (Attachment 3), notably to identify which properties were to be regulated; provide resources needed to assist land managers develop and submit Environmental Risk Management Plans (ERMPs); inform strict requirements for nutrient and pesticide application; to assess management practice effectiveness; and understand the motivation and barriers to land managers adopting improved management and complying to strict requirements. A substantial contribution was also made to the marine-focused eReefs program. Once these commitments were fulfilled, there was the opportunity to develop a more strategic Research and Development (R&D) Portfolio to address whole-of-program knowledge needs.

To identify the evidence base needed for effectively delivery of RPP, it was necessary to enunciate RPP's objectives. This was done through an internal Program Logic exercise, in which 12 high level questions (Table 1), 14 topics areas (Table 2), 43 knowledge outcomes (Table 3) and 101 detailed research questions (Table 4) were identified, along with 22 extension and operator tools (Table 5) required to support management decisions by growers and graziers, and the assessment of ERMPs and formulating advice to land managers by Reef Protection Officers (RPOs). All aspects of the program were thus addressed in this planning exercise, ranging from identification and prioritisation of the pollutant sources to be targeted; understanding of current management and managers; the development of cost-effective management solutions; and the effective delivery of the program to ensure Reef Plan targets will be met.

Table 1. RPP high level questions
A. In which catchments/ subcatchments should RPP focus its efforts?
B. What pollutants should RPP be targeting?
C. What land uses should RPP be targeting?
D. Where in the regulated catchments/ subcatchments is the greatest mobilisation of Reef-related pollutants?
E. What pollutant generating processes should RPP be targeting?
F. What management practices/systems most improve land condition/ water quality?
G. Where on the property should landholders focus their efforts?
H. What management practices/ systems to improve land condition/ water quality are the most economically viable?
I. What is the best way to get land managers to adopt profitable water quality improvement?
J. How can land managers best incorporate water quality considerations in their management decisions?
K. What do land managers need to know to make water quality improvements?
L. Where and what is least cost abatement?

ROBERT SPEIRS STATEMENT ATTACHMENT 2.

Table 2. RPP topics area
1. Program prioritisation
2. Pollutant fate
3. Cane systems & loads
4. Cane landscapes & sediment sources
5. Cane sediment management
6. Cane nutrients
7. Cane weeds & pesticides
8. Cane socio-economics
9. Grazing systems & loads
10. Grazing landscapes & sediment sources
11. Grazing sediment management (including land condition)
12. Grazing nutrients
13. Grazing weeds & pesticides
14. Grazing socio-economics

Table 3. RPP knowledge outcomes
1. Know the extent to which Reef Plan targets to improve management and reduce PSII pesticide, fertiliser and sediment loads entering the reef through cultural change have been successful
2. Ability to deliver long term improvement in management in places where this will lead to significant improvement in reef pollutant loads with a reasonable level of certainty
3. Know how & why cane management is changing & the impact on reef water quality
4. Know how & why grazing management is changing & the impact on reef water quality
5. Know where efforts to reduce PSII pesticides, fertilisers & sediments will produce the most cost effective improvement in reef water quality & have the capacity to deliver change using an effective mix of hotspot management and general improvement
6. Know which cane farming systems are most cost effective at reducing PSII pesticide, nutrients & sediment loads & how to achieve the necessary cultural change to ensure their widespread adoption
7. Know which grazing systems are most cost effective at reducing PSII pesticide, nutrients & sediment loads & how to achieve the necessary cultural change to ensure their widespread adoption
8. Know & have the tools to communicate cane farm management options to minimise PSII pesticide loss at least cost
9. Know & have the tools to communicate cane farm management options to minimise fertiliser loss at least cost
10. Know & have the tools to communicate cane farm management options to minimise sediment loss at least cost
11. Know & have tools to communicate grazing management options to minimise PSII pesticide & nutrient loss at least cost
12. Know & have tools to communicate grazing management options to minimise sediment loss at least cost
13. Know & have tools to communicate which cane farms/districts/catchments are contributing the most significant pollution to the reef
14. Know & have tools to communicate which grazing properties/districts/catchments are contributing the most significant pollution to the reef
15. Know the best methods & mixes of technological innovation, extension, regulation & economics to ensure reduced pollutant loads from cane farming

16. Know the best methods & mixes of technological innovation, extension, regulation & economics to ensure reduced pollutant loads from grazing
17. Understand the costs & benefits of cane farming systems that reduce pollutant loads
18. Understand the costs & benefits of grazing systems that reduce pollutant loads
19/20. Understand decision-making by land managers and motivations for them to change their management
21. Know the contribution of current & likely future cane farming management to significant pollutant loads
22. Know the contribution of current & likely future grazing management to significant pollutant loads
23. Know which parts of the property/ Wet Topics are most likely to contribute significant pollutants to the reef
24. Know which parts of the property/ Burdekin catchment are most likely to contribute significant pollutants to the reef
25. Know options for reducing pollutant loads from cane farms
26. Know options for reducing PSII pesticide loads from cane farms
27. Know options for reducing nutrient loads from cane farms
28. Know options for reducing sediment loss from cane farms
29. Know options for reducing pollutant loads from pastoral properties
30. Know options for reducing PSII pesticide & nutrient loads from pastoral properties
31. Know options for reducing sediment loss from pastoral properties
32. Understand the transport & fate of reef pollutants & the risk they pose to the reef
33. Understand pollutant sources & generation from cane farms
34. Understand PSII pesticides sources & generation from cane farms
35. Understand nutrient sources & generation from cane farms
36. Understand sediment sources & generation from cane farms
37. Understand pollutant sources & generation from grazing land
38. Understand PSII pesticides sources & generation from grazing land
39. Understand nutrient sources & generation from grazing land
40. Understand sediment sources & generation from grazing land
41. Understand current & future cane farm management systems
42. Understand current & future grazing management systems
43. Understand pollutant impacts on reef well enough to prioritise & communicate land-based responses

Table 4. RPP research questions
3a. What are the best indicators for success for the RPP intervention in cane management? 4a. What are the best indicators for success for the RPP intervention in grazing management? 5a. Is the most cost effective investment hot spot management or general improvement? 6a. Why do some cane growers manage impacts significantly more profitably than comparable cane growers? 7a. Why do some pastoralists manage impacts significantly more profitably than comparable pastoralists? 8a. What changes in systems and practices will be most cost effective at reducing loss of PSII to waterways from cane farms? 9a. What changes in systems and practices will be most cost effective at reducing loss of N&P to waterways from cane farms? 10a. What changes in systems and practices will be most cost effective at reducing loss of sediment to waterways from cane farms? 11a. What changes in systems and practices will be most cost effective at reducing loss of PSII to waterways from pastoral properties? 12a. What changes in systems and practices will be most cost effective at reducing sediment loss to waterways from pastoral properties? 13a. Which regulated landscapes, sub-catchments and catchments under cane are the most susceptible to investment in system/practice change to achieve the most cost efficient reduction in

PSII pesticides reaching the reef in the least time?
13b. Which regulated landscapes, sub-catchments and catchments under cane, are the most susceptible to investment in system/practice change to achieve the most cost efficient reduction in N & P loads reaching the reef in the least time?
13c. Which regulated landscapes, sub-catchments and catchments under cane, are the most susceptible to investment in system/practice change to achieve the most cost efficient reduction in sediment loads reaching the reef in the least time?
14a. Which landscapes & sub-catchments under grazing in the Burdekin catchment are the most susceptible to investment in system/practice change to achieve the most cost efficient reduction in PSII pesticides reaching the reef in the least time?
14b. Which landscapes & sub-catchments under grazing in the Burdekin catchment are most susceptible to cost effective reduction in sediment loss to the reef in the least time?
15/16a. What are the best methods & mixes of technological innovation, extension, regulation & economics to ensure adoption of reef friendly management?
15/16a. What are the best methods & mixes of technological innovation, extension, regulation & economics to ensure adoption of reef friendly management?
17a. What are the costs & benefits of preventive weed control?
17b. What are the costs & benefits of cane farm management systems that minimise the use and loss of PSII pesticides?
17c. What are the costs & benefits of cane farm management options that optimise the use and minimise the loss of N & P?
17d. What are the costs & benefits of cane farm management options that cause the least erosion of damaging sediment fractions?
17e. What are the costs & benefit of efficient mill mud application on the farm at the mill?
18a. Given the net loss of sediment from various Burdekin districts, what is the current life expectancy for grazing production?
18b. What are the costs & benefits of preventive woody weed management?
18c. What is the return on use of PSII pesticides per unit of beef produced?
18d. What are the costs & benefits of grazing management options that cause the least erosion & loss of damaging sediment fractions?
18e. How do utilisation rates, effective ground cover and grazing land condition affect enterprise profitability?
18g. What investment strategies have the best potential least cost abatement for reducing sediment loads from grazing lands in the Burdekin catchment - a general improvement in effective ground cover or restoration of eroding gullies?
18h. What is the most time / cost-effective approach to improving grazing land condition for reef water quality and at what scale - focusing on stabilising/reversing down-trending A, B, or C condition land or improving D, C or B condition land, & what features should be targeted (general cover, land types, steep slopes, gullies or stream banks)?
19/20a. What are the characteristics of land managers that influence their management decisions (e.g. demography, property ownership, training & educational experience, level of economic independence)?
19/20b. What are the critical factors influencing managers in adopting reef-friendly practices 1. that they know will improve short term profitability, 2. that they are told will improve short term profitability?
19/20c. What is the spatial extent and number / proportion of enterprises that are genuinely profitable by normal fiduciary standards independent of internal and external cross-subsidies?
21a. How much PSII pesticide, N, P and additional sediment is generated by different cane management systems?
22a. How much PSII pesticides and above natural N, P and sediment is generated from different grazing management systems?
23a. What topographic areas under cane in the regulated catchments generate the most significant above-natural reef pollution?
24a. What parts of the Burdekin grazing lands generate the most significant above-natural reef pollution?
25a. What cane management systems generate the least reef pollutants?

25b. What are the most effective methods for trapping loss of reef pollutants from cane farms (e.g. EVTAs)?
26a. What is the potential to reduce weed pressure and use of PSII pesticides using (1) non-PSII pesticides or non pesticide treatments, (2) integrated weed management at the property scale, (3) collaborative catchment-wide/mill district management and (4) technological innovation?
27a. What is the potential for cane crop needs for N & P to be met by non-synthetic sources (e.g. soil, legumes, irrigation water, mill mud etc)?
27b. What are the supplied needs of N & P of cane crops (1) directly to the plant by location & variety, and (2) total to maximum productivity by variety, soil type and location?
27c. Evaluate the management options for reducing the need to apply fertiliser on cane farms (e.g. legumes, cane varieties)?
27d. Which cane management systems lead to the most efficient use of N & P fertilisers (minimum loss/unit of production)?
27e. What is the capacity to improve efficiency of fertiliser use through technological innovation?
27f. What are the lowest rates of mill mud that can be safely & practically applied to cane crops by mill district?
27g. What are the factors affecting N&P residence in the soil, uptake by the plant and loss from the system?
28a. What are the options for managing cane & associated crops to minimise erosion of damaging sediment fractions?
28b. What are the options for managing headlands, stream banks and drainage lines to minimise erosion of damaging sediment fractions?
29a. What grazing management systems generate the least reef pollutants?
30a. What are the options for preventing/managing woody thickening that do not require PSII pesticides?
30b. Where PSII pesticide is the only option for weed/woody weed control on pastoral properties, how can this be used to minimise loss to waterways?
31a. What are the grazing managing options to minimise sediment loss from grazing lands (stocking rate, spelling, etc) and how is this translated to the property scale taking into account herd composition etc?
31b. What constitutes poor, medium & good land condition for each land type, and how does this relate to sediment loss?
31c. What rehabilitation work is required to achieve the stabilisation of most severely eroding land (e.g. gullies, stream banks, D-condition lands)?
32a. How is movement & transformation of reef pollutants on the farm affected by biophysical factors & interactions between them?
32b. How is the movement & transformation of reef pollutants beyond the farm affected by biophysical factors & interactions between them?
32c. How do interactions between reef pollutants affect their transport and transformation?
32d. What is the relative importance of surface (stream & overland) and groundwater flow for transporting pollutants to the reef, and how can this be assessed for individual catchments, sub-catchments & properties?
32e. How do reductions of reef pollutants at the catchment, sub-catchment & property level translate to reductions at the reef?
32f. How much and where do reef pollutants enter the groundwater?
32g. How do interactions between reef pollutants affect their transport and transformation?
33a. Which areas under cane in the regulated catchments require more detailed mapping of biophysical characteristics to identify vulnerable areas (based on course-scale information and management susceptibility to change)?
33c. What are the interactions between weed control, fertiliser use and other aspects of cane farming that are most important in determining pollutant impacts on the reef?
34a. Which PSII pesticides are being used on cane farms, at what rate and for what purpose by location, sub-catchment & catchment?
34b. What are the on- and off-farm weed pressures, processes & issues affecting PSII pesticide use on cane farms?
34c. Which cane management systems lose the greatest amounts of PSII pesticides to waterways

(including groundwater)?
34d. What are the loss rates of PSII pesticide from cane lands by district, and what are the reasons for this loss?
34e. What is the input/output efficiency of PSII pesticides per unit of cane/sugar produced, is this changing and, if so, why, and how and why is this likely to change in the future?
35a. Which N & P fertilisers are being used on cane farms, at what rate and for what purpose by location, sub-catchment & catchment?
35b. What are the loss rates of N & P from cane lands by district, and what are the reasons for this loss?
35c. What is the input/output efficiency of N & P (non-utilisation rate) per unit of cane/sugar produced, is this changing and, if so, why, and how and why is this likely to change in the future?
36a. What are the above-natural rates of erosion & sediment loss from cane lands, and how are these affected by landscape characteristics, such as geology, soil, slope, rainfall etc?
36b. Which cane farming systems & practices, in which locations, cause the greatest increase in volume of overland flow and most elevated erosion of damaging sediment fractions at the property, sub-catchment & catchment scale, and why?
36c. What parts of cane farms are contributing the most damaging sediments to the reef?
36d. Which landscapes in cane lands are contributing the most damaging sediment to the reef (paddock, stream bank, channels)?
36e. What is the soil loss per unit of cane/sugar produced, is this changing and, if so, why, and how and why is this likely to change in the future?
37a. Which areas of grazing land in the Burdekin catchment require more detailed mapping of biophysical characteristics to identify vulnerable areas (based on coarse-scale information and management susceptibility to change)?
37b. What interactions between grazing management practices are most important in determining pollutant impacts on the reef?
38a. Which PSII pesticides are being used on pastoral properties, at what rate and for what purpose by location, sub-catchment & catchment?
38b. What are the weed pressures and vegetation dynamic, processes & issues affecting PSII pesticide use on pastoral properties?
38c. Which grazing-related activities lose the greatest amounts of PSII pesticides to waterways (including groundwater)?
38d. What are the loss rates of PSII pesticide from grazing lands by district, and what are the reasons for this loss?
39a. Which N & P fertilisers are being used on pastoral properties in the Burdekin catchment, at what rate and for what purpose by location & sub-catchment?
39b. What are the loss rates of N & P from pastoral properties in the Burdekin catchment by sub-catchment, and what are the reasons for this loss?
40a. What are the above-natural rates of erosion & sediment loss from grazing lands in the Burdekin catchment, and how are these affected by landscape characteristics, such as geology, soil, slope, rainfall etc?
40b. Which grazing systems & practices, in which locations, cause the greatest increase in volume of overland flow and most elevated erosion of damaging sediment fractions at the property, sub-catchment & catchment scale, and why?
40c. What parts of pastoral properties are contributing the most damaging sediments to the reef?
40d. Which landscapes in grazing lands are contributing the most damaging sediment to the reef (hillslopes, gullies, stream banks, rock types, soil types, land types, topography)?
40e. How do utilisation rates and ground cover affect infiltration rates, overland flow and sediment erosion?
40f. What is the soil loss per unit of beef produced, is this changing and, if so, why, and how and why is this likely to change in the future?
41a. What is the current nature and distribution of cane management and pollutant mitigation practices in the regulated catchments?
41b. What are the trends in use of PSII and other pesticides in cane farming (residuals vs knockdowns), what is driving them and what future issues will affect this?
41c. What are the trends in use of fertilisers in cane farming, what is driving them and what future

issues will affect this?
41d. What are the trends in cane farming affecting sediment loss, what is driving them and what future issues will affect this?
42a. What is the current nature and distribution of grazing management and pollutant mitigation practices in the Burdekin catchment?
42b. What are the trends in use of PSII and other pesticides in grazing management (residuals vs knockdowns), and what future issues will affect this?
42c. What are the trends in use of fertilisers in grazing management in the Burdekin catchment and what future issues will affect this?
42d. What are the trends in grazing management practices and how are they influencing sediment loss?
43a. What is the relative risk of each element of nutrient, pesticide and sediment to reef health (reef pollutants), and which are the most susceptible to investment to reduce them?
43b. What are the natural baseline loads of reef pollutants, and how have these changed historically in response to land use change?
43c. How much of the reef pollutants is coming from cane farms or pastoral properties in each catchment & sub-catchment?
43d. In which catchments, sub-catchments and landscapes, on which mix of fertilisers, pesticides and sediments, and on which industries, should efforts be focused to achieve the greatest reduction in loads of PSII pesticide reaching the reef at the least cost
18h. What is the most time / cost-effective approach to improving grazing land condition for reef water quality and at what scale - focusing on stabilising/reversing down-trending A, B, or 43d. In which catchments, sub-catchments and landscapes, on which mix of fertilisers, pesticides and sediments, and on which industries, should efforts be focused to achieve the greatest reduction in loads of PSII pesticide reaching the reef at the least cost

Table 5. RPP extension tools
T3/4.1. Tools to capture information and report on management (ERMPs) T8.1. Catchment/district planning arrangements to reduce spread of weeds through the catchment T8.2. Arrangements for ensuring weed hygiene of harvesting & other machinery entering cane farms T8.3. Property planning tools to maximise weed prevention and targeted pesticide use T8.4. Weed identification tools that include information of weed ecology and control T8.5. Pesticide use guidelines to maximise efficiency & minimise loss T8.6. Risk assessment tools for pesticide application T9.1. Tools for calculating phosphorus application from phosphorus availability and crop needs T9.2. Tools for calculating nitrogen application from nitrogen availability and crop needs T9.3. Guidelines for efficient N & P application (timing, applicators etc) T9.4. Tools for assessing economic & environmental implications of N & P application methods, rates, form & timing T9.5. Tools, appliances & arrangements for efficient application of mill mud T10.1. Mapping tools to show the areas at high risk of erosion and soil/sediment loss T10.2. Education programs about soil properties and principles of soil management T10.3. Guidelines for managing cane to minimise erosion and soil/sediment loss T33.1. Natural characteristic mappings of the areas under cane to identify potential hazards T11.1. Guidelines for managing woody weeds to minimise PSII pesticides T12.1. Mapping tools to show the areas at high risk of erosion and soil/sediment loss T12.2. Stocking rate calculator with inbuilt spelling regimes and climate forecasting, which also indicate risk of management to reef water quality T12.3. Property planning tool to allow management of whole of property grazing pressure T12.4. Guidelines for managing grazing lands to minimise sediment loads T37.1. Land-type mapping with profiles, including vulnerability for sediment loss

ROBERT SPEIRS STATEMENT ATTACHMENT 2.

To prioritise areas for R&D investment, the 101 research questions were assessed to identify the adequacy of the current evidence base, and the extent to which effective delivery of RPP would be improved by addressing gaps in this evidence base.

Prioritisation process

A peer review panel was formed to assist development of the RPP's R&D portfolio. The panel was convened three times through the course of the process: initially, in the identification of priority areas for R&D investment (Attachment 8) and, subsequently, to assess research submissions addressing these priorities. Panel composition was balanced across technical expertise of the cane and grazing industries, and production and water quality issues, and varied over the three sessions, depending on the nature of expertise required (Table 6).

Table 6. RPP Science Framework peer review panel

Panel member	Organisation	Prioritisation of R&D gaps Workshop 22/6/11	Proposal Assessment Session 1 27/7/11	Proposal Assessment Session 2 23/8/11
[redacted]	ACTFR-JCU	✓		✓
[redacted]	AgForce		✓	
[redacted]	BSES	✓		
[redacted]	CSIRO	✓		✓
[redacted]	DEEDI	✓		
[redacted]	DEEDI	✓		
[redacted]	DEEDI			✓
[redacted]	DEEDI	✓	✓	
[redacted]	DEEDI		✓	
[redacted]	DEEDI			✓
[redacted]	DEEDI	✓		✓
[redacted]	DERM	✓	✓	✓
[redacted]	DERM	✓		✓
[redacted]	DERM	✓	✓	
[redacted]	DERM	✓	✓	✓
[redacted]	DERM	✓		✓
[redacted]	DERM	✓	✓	
[redacted]	DERM		✓	
[redacted]	DPC/Reef Plan	✓		
[redacted]	DPC/Reef Plan/P2R	✓		
[redacted]	Fitzroy Basin Association		✓	
[redacted]	GBRPMA	✓		✓
[redacted]	Independent	✓	✓	
[redacted]	North Queensland Dry Tropics		✓	

Industry groups, NRM groups and WWF were consulted to determine their expectation or R&D outcomes and partnerships (Table 7). Stakeholder consultation began during the planning phase and continued through to the end of the project selection process. End-users will also be engaged in project development and delivery to maximise applicability and uptake of project outputs. Value-adding to existing research effort, while avoiding duplication, was ensured through good communications with representatives Reef-related R&D programs throughout the program planning and project selection process (Table 8).

ROBERT SPEIRS STATEMENT ATTACHMENT 2.

Table 7. RPP Science Framework consultation process		
Person	**Organisation**	**Dates of consultation sessions**
Industry		
[redacted]	AgForce	RPP Technical Task Group: 28/9/11 See also Table 6
[redacted]	AgForce	31/8/11
[redacted]	Australian Cane Growers Association	Weed Management Core Working Group: 8/4/11, 21/6/11 Cane Industry Working Group: 8/8/11 RPP Technical Task Group: 29/6/11, 28/9/11
[redacted]	Australian Sugar Milling Council	Cane Industry Working Group: 8/8/11 RPP Technical Task Group: 29/6/11, 28/9/11
[redacted]	BSES	Weed Management Core Working Group: 8/4/11, 14/9/11 Cane Industry Working Group: 8/8/11 15/7/11
[redacted]	BSES	Weed Management Core Working Group: 8/4/11, 21/6/11,
[redacted]	BSES	Weed Management Core Working Group: 8/4/11,
[redacted]	BSES	Weed Management Core Working Group: 14/9/11
[redacted]	BSES	RPP Technical Task Group: 29/6/11 15/7/11, See also Table 6
[redacted]	Canegrowers	RPP Technical Task Group: 29/6/11, 28/9/11 Weed Management Core Working Group: 8/4/11, 14/9/11
[redacted]	Elders	RPP Technical Task Group: 29/6/11
[redacted]	Incitec	RPP Technical Task Group: 28/9/11
[redacted]	Farmacist	Cane Industry Working Group: 8/8/11
[redacted]	Sucrogren	Cane Industry Working Group: 8/8/11
[redacted]	Kalamia Cane Growers Organisation	RPP Technical Task Group: 29/6/11
NRM Groups		
[redacted]	Terrain NRM	NRM Group Briefing: 4/8/11, 30/8/11
[redacted]	Terrain NRM	Cane Industry Working Group: 8/8/11
[redacted]	Terrain NRM/DEEDI	Cane Industry Working Group: 8/8/11
[redacted]	Reef Catchments	Cane Industry Working Group: 8/8/11 NRM Group Briefing: 4/8/11, 30/8/11
[redacted]	North Queensland Dry Tropics	NRM Group Briefings: 4/8/11, 30/8/11 RPP Grazing Extension meeting 22/09/11 31/8/11
[redacted]	North Queensland Dry Tropics	NRM Group Briefing: 30/8/11 RPP Grazing Extension meeting 22/09/11 31/8/11
[redacted]	North Queensland Dry Tropics	See Table 6
[redacted]	Fitzroy Basin Association	See Table 6
Conservation		
[redacted]	WWF	29/7/11
[redacted]	WWF	29/7/11; 30/9/11
[redacted]	WWF	29/7/11

ROBERT SPEIRS STATEMENT ATTACHMENT 2.

Table 8. RPP Science Framework consultation with other reef-related research programs		
Person	**Organisation**	**Dates of consultation sessions**
[redacted]	DPC/Reef Plan	14/7/11, See Table 6
[redacted]	DPC/Reef Plan/P2R	14/7/11
[redacted]	Reef Rescue R&D	31/8/11
[redacted]	Reef Rescue R&D	31/8/11
[redacted]	SRDC	2/9/11
[redacted]	SRDC	2/9/11
[redacted]	P2R	See Table 6
[redacted]	North Australia Beef Research Council	22/08/11
[redacted]	Meat and Livestock Australia	30/06/11, See Table 6

R&D applications

In late June 2011, RPP invited submissions from established Reef researchers to address its R&D priorities, and provided an application form delineating the elements that were to be addressed in the applications. This included how the proposal would contribute to RPP objective, with the applicant being required to identify of up to three RPP questions that would be addressed by the proposal, as well as how the proposal would contribute to Reef Plan. Linkages to other research project, recent or current, had to be identified. The applicant was asked to identify stakeholders and partners essential to the proposal's success, not only in the generation of research findings, but in their acceptance and application. The applicant was then asked to briefly describe the aims of the project, the methods to be used and the outcomes and outputs, along with a milestone schedule and budget table.

Forty seven research proposals were received with a total value of $13.9M (Table 9). The majority of these submissions were from within DERM, with these proposals accounting for almost half of the funds requested. Similar levels of funding were requested for grazing-related and cane-related proposals. Proposals were received that addressed most topic areas and R&D questions.

Table 9. Summary of applications submitted to the RPP Science Framework								
Organisation	**Program-wide**		**Cane**		**Grazing**		**Total**	
CSIRO	1	$460,000	2	$739,000	2	$690,000	5	$1,889,000
DEEDI			2	$584,096	1	$313,831	3	$897,927
DERM	4	$713,950	9	$1,361,622	8	$4,573,000	21	$6,648,572
NRM			6	$1,665,806			6	$1,665,806
Unis	3	$696,800	3	$847,500	1	$220,000	7	$1,764,300
Other			4	$946,700	1	$50,000	5	$996,700
Total	**8**	**$1,870,750**	**26**	**$6,144,724**	**13**	**$5,846,831**	**47**	**$13,862,305**

Project selection

All proposals were presented to the peer review panel over two assessment sessions: Session 1 dealt with grazing-related proposals; Session 2 dealt with program-wide and cane-related proposals. Proponents were invited to answer questions at these sessions and to provide supplementary material to explain their proposals. Some proposals were also submitted to external review, where adequate technical expertise was not present in the panel.

ROBERT SPEIRS STATEMENT ATTACHMENT 2.

Responses from the peer review panel were collated and combined with an internal assessment of RPP program needs. Decisions to fund proposals were based on:

- contribution to RPP (extent of addressing RPP priority questions and outcomes)
- contribution to broader Reef Plan objectives
- value to industry and the development of extension tools
- budgetary considerations (e.g. value for money; value adding/duplication of existing work; overall expense)

Budgetary consideration

The original budget for RPP was $50M over five years (2009-2014). Of this amount, half was to support regulatory activities, and the remaining half to support both extension and research. After other requirements of the program (e.g. staffing and extension contracts) are been accounted for, the R&D budget is approximately $10M over the 5 years. RPP had previously invested approximately $2.5M in R&D projects (Attachment3). This leaves approximately $7.5M in funds for R&D. Hence, in the case that all projects were identified as a priority, and all priority areas were met, a project funding success rate would be around 54% at best.

Peer review assessment indicated that most applications had scientific merit. Given the funding constraints, RPP gave priority to projects with on-ground outputs that would assist ERMP assessment and efforts by land manager in the regulated community to improve water quality management. RPP also gave priority to projects addressing key gaps in P2R and Reef Plan science, primarily those influencing RPP delivery. However, budgetary constraints limited RPP's capacity to fund these broader projects.

The R&D portfolio

The R&D portfolio of projects recommended for funding provides a strategic evidence base to underpin RPP, ensuring the program's decisions and advice provided to land managers are based on strong, defensible evidence. Short-term (prior April 2012) outputs will deliver synthesis of new knowledge arising out of work completed since 2008, when Reef Plan 2 commenced, to inform RPP extension and regulatory activities in 2012/13. Longer term (up to Feb 2014) results focus on improving extension tools and products for landholders, and value-add to other R&D programs.

Of the 23 applications recommended for funding (Table 10):

- 14 projects (total value $3.7M) will be delivered or led by DERM (partnering with five external organisations)
- two projects ($745K) will be delivered by DEEDI (two external organisations)
- seven projects ($1.1M) will be delivered by four non-government proponents (two external partner organisations)

Table 10. Projects recommended for funding by the RPP Science Framework

Organisation	Program-wide		Cane		Grazing		Total	
CSIRO								
DEEDI			1	$435,000	1	$310,000	2	$745,000
DERM	1	$400,000	7	$886,100	6	$2,410,000	14	$3,696,100
NRM								
Unis	2	$350,000	2	$400,000			4	$750,000
Other			2	$335,000	1	$50,000	3	$385,000
Total	**3**	**$750,000**	**12**	**$2,056,100**	**8**	**$2,770,000**	**23**	**$5,576,100**

ROBERT SPEIRS STATEMENT ATTACHMENT 2.

To fill remaining priority R&D gaps, RPP, in consultation with key stakeholders, will scope a further nine projects ($2.0M), before engaging appropriate proponents (Attachment 2).

The R&D portfolio's highlights include:

- 51.5% of the projects will enhance monitoring of progress towards targets by extending, or providing outputs to, **P2R** and delivery of **Reef Plan** science program.
- 48.5% of investment will identify management solutions and support land managers to adopt management to improve both water quality and profitability
- six projects will contribute to mapping products to better target mitigation activities
- 18 projects will help to improve Reef-related extension services to land managers
- 14 projects will improve information and tools that can be used by land managers to support their decisions about production and water quality management

ROBERT SPEIRS STATEMENT ATTACHMENT 3. List of RPP R&D projects approved for funding

					Outputs					
ID	**ACTFR**: Australian Centre for Tropical Freshwater Research, James Cook University; **AIMS**: Australian Institute of Marine Sciences; **CQU**: Central Queensland University; **GU**: Griffith University; **JCU**: James Cook University; **MLA**: Meat and Livestock Australia; **UQ**: University of Queensland; **D**: Director; **DG**: Director General; **GM**: General Manager; **M**: Manager Business Services **Title**	**Proponent/ Partners**	**Requested budget**	**Recommended budget**	**Maps**	**Loss pathway understanding**	**Management/ mitigation options**	**Regulatory targeting**	**Extension Support**	**Management information support**
Program prioritisation & target setting										
RP71P	Historical land use change and pollutant load – Burdekin Dry Tropics	ACTFR/ AIMS	$70,000	$50,000				✓		
RP72P	Relative risk assessment update – reef catchments	ACTFR/ AIMS, CSIRO, DERM	$540,000	$300,000		✓✓		✓✓		
RP73P	Reef Protection Program modelling, analysis and integration – regulated catchments	DERM	$400,000	$400,000		✓✓		✓✓		
PROGRAM PRIORITISATION & TARGET SETTING TOTAL				$750,000						
Cane pollutant fate										
RP52C	Pollutant trapping in vegetated systems – regulated catchments	ACTFR/ CSIRO, DERM	$380,000	$250,000		✓✓	✓✓	✓		
RP51C	Groundwater scoping – regulated catchments	H. Hunter	$85,000	$85,000		✓✓				
RP53C	Groundwater pollutant transport – Burdekin Dry Tropics	DERM/ ACTFR	$150,000	$100,000		✓✓		✓✓		
RP54C	Baseline groundwater pesticide data – Burdekin Dry Tropics and Wet Tropics	DERM/ EnTOX-UQ	$82,225	$30,000		✓✓		✓✓		
Cane landscapes and sediment sources										
RP55C	Environmental characteristics mapping of cane lands – Burdekin Dry Tropics and Mackay-Whitsunday	DERM	$171,000	$171,100	✓✓	✓		✓✓	✓✓	✓
Cane weeds & pesticides										
RP56C	Trends in pesticide use by cane farmers – regulated catchments	ACTFR/ BSES, DEEDI, DERM	$380,000	$150,000		✓	✓✓	✓✓		

ROBERT SPEIRS STATEMENT ATTACHMENT 3. List of RPP R&D projects approved for funding

ID	**ACTFR**: Australian Centre for Tropical Freshwater Research, James Cook University; **AIMS**: Australian Institute of Marine Sciences; **CQU**: Central Queensland University; **GU**: Griffith University; **JCU**: James Cook University; **MLA**: Meat and Livestock Australia; **UQ**: University of Queensland; **D**: Director; **DG**: Director General; **GM**: General Manager; **M**: Manager Business Services **Title**	**Proponent/ Partners**	**Requested budget**	**Recommended budget**	**Outputs**					
					Maps	**Loss pathway understanding**	**Management/ mitigation options**	**Regulatory targeting**	**Extension Support**	**Management information support**
RP57C	Monitoring alternative pesticide use – regulated catchments	DERM	$295,397	$120,000				✓✓		
Cane nutrients										
RP58C	Legumes and the cane nitrogen cycle – regulated catchments	DERM/ BSES	$150,000	$150,000		✓	✓✓	✓✓	✓	✓
RP59C	Managing the cane nitrogen cycle – regulated catchments	DERM	$245,000	$215,000		✓	✓✓	✓✓	✓	✓
RP60C	Extension of Burdekin trial – loss pathways	DERM	$100,000	$100,000			✓✓			
RP61C	Wet Tropics cane farming nutrient trials	BSES	$371,500	$250,000		✓	✓	✓	✓✓	✓
Cane economics										
RP62C	Economics of pesticide management on cane farms – regulated catchments	DEEDI/ CQU, CSIRO	$439,096	$435,000		✓	✓	✓	✓✓	✓✓
CANE TOTAL				$2,056,100						
Grazing landscapes & sediment sources										
RP63G	Mapping erodible soils – Burdekin Dry Tropics	DERM/ GU	$538,000	$535,000	✓✓	✓✓	✓	✓		✓
RP64G	Ground cover and fire mapping in grazing lands – reef catchments	DERM	$1.05M	$350,000	✓✓	✓	✓	✓✓	✓	✓
RP65G	Identifying erosion sources and drivers in grazing lands – Burdekin Dry Tropics	DERM/ CSIRO, JCU, GU	$550,000	$550,000	✓	✓✓	✓	✓✓		
RP66G	Gully mapping and drivers in grazing lands – Burdekin Dry Tropics	DERM	$350,000	$350,000	✓✓	✓	✓	✓✓		
Grazing decision-support tools										
RP67G	Paddock GRASP redevelopment	DERM	$250,000	$250,000		✓		✓	✓✓	
RP68G	Enhancing FORAGE – Burdekin Dry Tropics	DERM	$375,000	$375,000	✓	✓			✓✓	✓✓
RP69G	Grazing management systems report - Burdekin Dry Tropics	M. Quirk/ DEEDI, MLA	$50,000	$50,000			✓		✓✓	✓✓

ROBERT SPEIRS STATEMENT ATTACHMENT 3. List of RPP R&D projects approved for funding

ID	**ACTFR**: Australian Centre for Tropical Freshwater Research, James Cook University; **AIMS**: Australian Institute of Marine Sciences; **CQU**: Central Queensland University; **GU**: Griffith University; **JCU**: James Cook University; **MLA**: Meat and Livestock Australia; **UQ**: University of Queensland; **D**: Director; **DG**: Director General; **GM**: General Manager; **M**: Manager Business Services **Title**	**Proponent/ Partners**	**Requested budget**	**Recommended budget**	**Outputs**					
					Maps	**Loss pathway understanding**	**Management/ mitigation options**	**Regulatory targeting**	**Extension Support**	**Management information support**
Grazing economics										
RP70G	Costs and benefits of improving grazing management - Burdekin Dry Tropics	DEEDI/ CQU	$313,831	$310,000		✓	✓✓	✓	✓✓	✓✓
GRAZING TOTAL				$2,770,000						
TOTAL PROJECT EXPENDITURE				$5,576,100						

ROBERT SPEIRS STATEMENT ATTACHMENT 4. List of RPP R&D proposed projects to be scoped internally before appointing proponents

ID	Title	Recommended budget	Maps	Loss pathway understanding	Management/ Mitigation Options	Regulatory targeting	Extension Support	Management information support
Program prioritisation & target setting								
RP74C	Benchmarking use of nutrients and pesticides in cane farming	$600,000		✓✓	✓	✓✓		
PROGRAM PRIORITISATION & TARGET SETTING TOTALS		$600,000						
Pollutant Fate								
RP75C	Management advice to address groundwater	$50,000					✓	✓
Cane weeds & pesticides								
RP76C	Achieving regional Integrated Weed Management in cane lands	$200,000			✓		✓✓	
Cane socioeconomics								
RP77C	Cane socio-analysis to inform extension and regulation	$200,000				✓	✓✓	
Cane decision-support tools								
RP78C	SafeGauge for pesticides- web enable decision tool	$165,000					✓	✓✓
RP79C	Cane management effectiveness review	$150,000					✓✓	✓✓
Cane adaptive management								
RP80C	Support adaptive management trials (e.g. weeds, BBIFMAC, Reghenzani - Test strips etc)	$400,000			✓✓		✓	✓
CANE TOTALS		$1,165,000						
Grazing decision-support tools								
RP81G	Rehab D and gullies	$50,000			✓		✓✓	✓✓
Grazing socio-economics								
RP82G	Grazing socio-economics to inform extension and regulation	$200,000				✓	✓✓	
GRAZING TOTALS		$250,000						
TOTAL SCOPING ESTIMATE		$2,015,000						

RPP Evidence base	**Program-wide**		
	Current evidence	**2011/12**	**2013/2014**
A. In which catchments/ subcatchments should RPP focus its efforts?	Brodie J & Waterhouse J (2009) Assessment of the impact of broad-scale agriculture on the Great barrier Reef and priorities for investment under the Reef Protection Package. Stage 1 REPORT, April 2009). Australian Centre for Tropical Freshwater Research, James Cook University. *Identified the catchments & subcatchments producing the most Reef-*	NERP project *Scoping for Relative Risk Assessment Report to refine information on the catchments and sub-catchments producing the most Reef-related pollutants and the nature of those pollutants (Sub04) and preliminary findings report*	**Sub04** *Relative Risk Assessment Report refining information on the sub-catchments producing the most Reef-related pollutants and the nature of those pollutants*
	Brodie J *et al.* (2008a) Scientific consensus statement on water quality in the Great Barrier Reef. The State of Queensland (Department of the Premier and Cabinet). *Summarised the evidence base for land-use having an adverse impact on Reef health.*		
	Brodie J *et al.* (2008b) Synthesis of evidence to support the Scientific Consensus Statement on Water Quality in the Great Barrier Reef. *Compiled the evidence base for land-use having an adverse impact on Reef health.*		
	Kroon F *et al.* (2009) Baseline pollutant loads to the Great Barrier Reef. CSIRO & Australian Centre for Tropical Freshwater Research, James Cook University. *Identified the natural pollutant loads and the 2008/9levels of pollutants*		
	Great Barrier Reef - First Report Card 2009 Baseline	Great Barrier Reef - Second Report Card 2010	Great Barrier Reef - Third Report Card 2011 Great Barrier Reef - Fourth Report Card 2012
B. What pollutants should RPP be targetting?	Brodie J & Waterhouse J (2009) (refer to Question A)		**Sub04** **(refer to Question A)**
	Brodie J et al. (2008a) (refer to Question A)		
	Brodie J et al. (2008b) (refer to Question A)		
	Great Barrier Reef - First Report Card 2009 Baseline	Great Barrier Reef - Second Report Card 2010	Great Barrier Reef - Third Report Card 2011 Great Barrier Reef - Fourth Report Card 2012

C. What land uses should RPP be targetting?	Brodie J & Waterhouse J (2009) (refer to Question A)		**Sub04** **(refer to Question A)**
	Brodie J et al. (2008a) (refer to Question A)		**Sub03** *Report on how Reef pollution has changed with changing land use history*
	Brodie J et al. (2008b) (refer to Question A)		
	Dight I (2009) Burdekin Water Quality Improvement Plan. NQ Dry Tropics, Townsville. (refer to above) Provides information on the types and sources of priority pollutants and land management for improved water quality in the BDT region.		
	Barron F & Haynes D (2009) Water Quality Improvement Plan for the catchments of the Barron River and Trinity Inlet. Terrain NRM. *Provides information on the types and sources of priority pollutants and land management for improved water quality in parts of the WT region.*		**RP27** *Report on the relative contribution of different land uses Herbert River catchment to Reef pollution*
	Davis R (2006) Douglas Shire Water Quality Improvement Plan. Douglas Shire Council (Draft). *Provides information on the types and sources of priority pollutants and land management for improved water quality in parts of the WT region.*		
	Kroon FJ (2008) Draft Tully Water Quality Improvement Plan. Report to Terrain NRM. CSIRO. (refer to above) Provides information on the types and sources of priority pollutants and land management for improved water quality in parts of the WT region.		
	Drewry J, Higham W & Mitchell C (2008) Mackay-Whitsunday region water quality improvement plan (WQIP). Mackay Whitsunday NRM Group. *Provides information on the types and sources of priority pollutants and land management for improved water quality in the MW region.*		
	Great Barrier Reef - First Report Card 2009 Baseline	Great Barrier Reef - Second Report Card 2010	Great Barrier Reef - Third Report Card 2011 Great Barrier Reef - Fourth Report Card 2012

D. Where in the regulated catchments/ subcatchments is the greatest mobilisation of	Brodie J & Waterhouse J (2009) (refer to Question A)	NERP project (refer to Question A)	**Sub04** Relative Risk Assessment Report refining information on the sub-catchments producing the most Reef-related pollutants and the nature of those pollutants
	Brodie J, Mitchell A & Waterhouse J (2009) Regional assessment of the relative risk of the impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under the Reef Protection Package. Stage 2 Report *Identified the catchments & subcatchments producing the most Reef-related pollutants and the nature of those pollutants*		
	Dight I (2009) (refer to Question C)		
	Barron F & Haynes D (2009) (refer to Question C)		
	Davis R (2006) (refer to Question C)		
	Kroon FJ (2008) (refer to Question C)		
	Drewry J, Higham W & Mitchell C (2008) (refer to Question C)		
	Great Barrier Reef - First Report Card 2009 Baseline	Great Barrier Reef - Second Report Card 2010	Great Barrier Reef - Third Report Card 2011 Great Barrier Reef - Fourth Report Card 2012
	RP01 *Mapped cane and grazing properties in regulated catchments (2009*		
			Sub25 *RPP-P2R modelling & targets* *Update and refine relative contribution to reef pollution of individual sub-catchments and industries for sediment fractions and species of N, P and PSII pesticides*

	Cane			Grazing		
	Current evidence	**2011/12**	**2013/2014**	**Current evidence**	**2011/12**	**2013/2014**
	RP02 *Mapped and Monitored Sugar Cane Cropping Practices*			**RP26** *Report on the sources of sediment as a Reef pollutant for BDT*		
		Sub19 *Preliminary report on current and likely changes in pesticide use*	**Sub19** *Report on likely changes in pesticide use and appropriate RPP response*	DERM Ground cover mapping	**Sub11** *Preliminary map areas with low or deteriorating ground cover in BDT, so in need of improved grazing management*	**Sub11** *Identify areas with low or deteriorating ground cover over last 12 years in BDT, so in need of improved grazing management*
			Sub33 *Report and tracking of inputs, yields and management practices to identify the areas most susceptible to WQ improvement*	Rogers *et al.* (2009) Land Resources Survey of the Dalrymple Shire. Queensland Department of Natural Resources. *Describes patterns of land degradation in the Dalrymple Shire.*	**Sub1d** *Preliminary report and map of areas of BDT likely to have erodible* soils	**Sub1d** *Report and map of soil erosion risk for BDT*
		Sub24 *Report on what is known about groundwater systems in the regulated catchments and the implications for nutrient and pesticide management*	**Sub30** *Track movement of pesticides and nutrients through the groundwater in the lower Burdekin*		**Sub1c** *Preliminary report and map of areas of BDT with a high risk of gullying*	**Sub1c** *Report and map of areas of BDT with a high risk of gullying*
			Sub05 ***Report on ecological filtering of pollutants derived from cane farms***			
			Sub44 *Report on baseline pesticide loads in groundwater for incorporating into P2R modelling*			

RPP Evidence base	**Program-wide**		
	Current evidence	**2011/12**	**2013/2014**
E. What pollutant generating processes should RPP be targeting?	Dight I (2009) (refer to Question C)		
	Barron F & Haynes D (2009) (refer to Question C)		
	Davis R (2006) (refer to Question C)		
	Kroon FJ (2008) (refer to Question C)		
	Drewry J, Higham W & Mitchell C (2008) (refer to Question C)		

RPP Evidence base	**Cane**			**Grazing**		
	Current evidence	**2011/12**	**2013/2014**	**Current evidence**	**2011/12**	**2013/2014**
E. What pollutant generating processes should RPP be targeting?		**Sub19** **(refer to Question D)**	**Sub19** **(refer to Question D)**			**Sub1b** *Report and map of areas of relative importance of hillslope and gully erosion in BDT for Reef pollution*
			Sub27 *Report on the changing uses of PSII and other pesticides based on water quality monitoring*			
			Sub33 *Report and tracking of inputs, yields and management practices to identify the areas most susceptible to WQ improvement*			

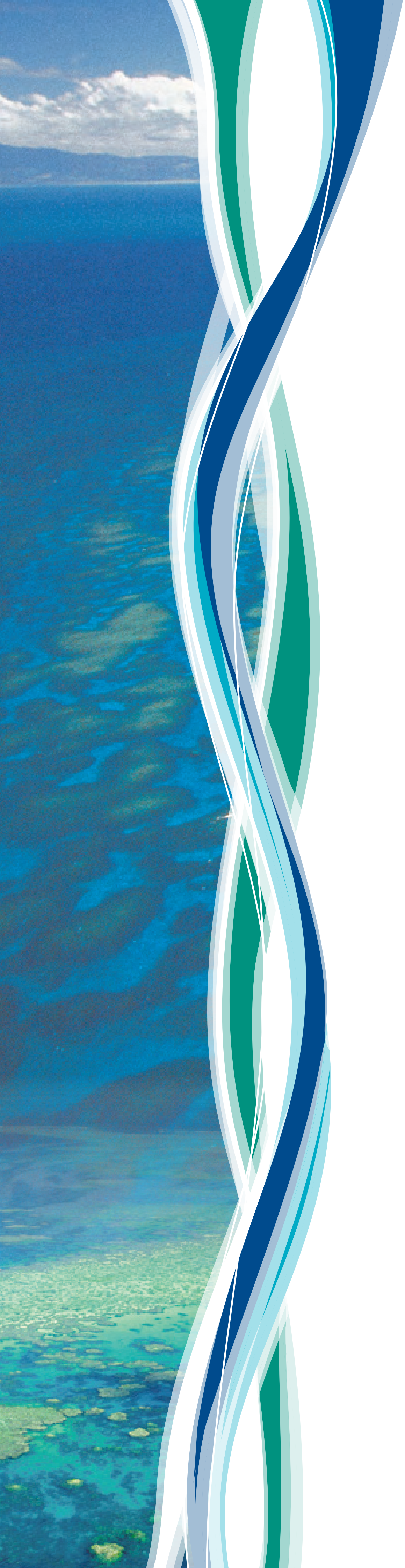
RPP Evidence base	Program-wide					
	Current evidence		2011/12		2013/2014	
F. What management practices/ systems most improve land condition/ water quality?	Dight I (2009) (refer to Question C)					
	Barron F & Haynes D (2009) (refer to Question C)					
	Davis R (2006) (refer to Question C)					
	Kroon FJ (2008) (refer to Question C)					
	Drewry J, Higham W & Mitchell C (2008) (refer to Question C)					
	Cane			**Grazing**		
	Current evidence	**2011/12**	**2013/2014**	**Current evidence**	**2011/12**	**2013/2014**
	Six Easy Steps	**Sub54** *Report summarising best-bet cane management for production and water quality benefits*		GLM courses *Extension program promoting sustainable grazing management consistent with water quality outcomes*		
				Stocktake *Extension/operator tool to assist graziers calculate safe stocking rates*		
	Poggio et al. (2010a) Paddock to Reef monitoring & evaluation: Economic analysis of ABCD cane management practices for the Burdekin River Irrigation area. Queensland Government.	**Sub31** *Preliminary report on Least Cost Abatement options for improving water quality on cane farms*	**Sub31** *Report on Least Cost Abatement options for improving water quality on cane farms*	Donaghy P et al. (2010) Strategies to improve the profitability of extensive grazing systems in central Queensland. Queensland Government.	**Sub10** *Preliminary report on Least Cost Abatement options for improving water quality on grazing properties*	**Sub10** *Report on Least Cost Abatement options for improving water quality on grazing properties*
	Poggio et al. (2010b) Paddock to Reef monitoring & evaluation: Economic analysis of ABCD cane management practices for the Tully region. Queensland Government.			Star M and Donaghy P (2010) Economic modelling of grazing systems in the Fitzroy and Burdekin catchments. Queensland		
	Poggio et al. (2010c) Paddock to Reef monitoring & evaluation: Economic analysis of ABCD cane management practices for the Burdekin Delta region. Queensland Government.			O'Reagain P *et al.* (2008) Wambiana Grazing Trial: Water Quality Update to Burdekin Dry Tropics NRM. *Assessment of the erosion and water quality impacts of different grazing regimes.*		
	East M & Star M (2010) Paddock to Reef monitoring & evaluation: Economic analysis of ABCD cane management practices for the Mackay Whitsunday region. Queensland Government.			Ash A *et al.* (2002) The Ecograze Project: developing guidelines to better manage grazing country. CSIRO, Meat & Livestock Australia, and Queensland Government. *Demonstrated the environmental and economic benefits of wet season spelling*		
					Sub47 *Report on the effectiveness of efforts to rehabilitate poor condition land and erosion gullies*	

			Sub33 **(refer to Question D)**		**Sub22** *Report summarising best-bet grazing management for production and water quality benefits*	

G. Where on the property should landholders focus their efforts?	**RP07** *Environmental characteristics mapping - WT*		**Sub28** *Environmental characteristics mapping BDT & MW*	VegMachine *Extension tool highlighting areas with low or declining ground cover.*	**Sub12** **(refer to Question F)**	**Sub11** *Improved ground cover mapping for use in VegMachine and Forage*
	RP18 *Web Based Soil Information*			Forage Reports *Extension tool highlighting areas with low or declining ground cover.*	**Sub12** *Improved Forage reports to include land types*	**Sub12** *Improved Forage reports to incorporate landholder data*
				Stocktake *Extension/operator tool to assist graziers calculate safe stocking rates*		**Sub13** *Improved GRASP modelling to underpin Stocktake and water quality modelling*
				Rogers et al. (2009) (refer to Question D)		
H. What management practices/ systems to improve land condition/ water quality are the most economically viable?	Poggio et al. (2010a) (refer to Question F)	**Sub31** **(refer to Question F)**	**Sub31** **(refer to Question F)**	Donaghy P et al. (2010) (refer to Question F)	**Sub10** **(refer to Question F)**	**Sub10** **(refer to Question F)**
	Poggio et al. (2010b) (refer to Question F)			Star M and Donaghy P (2010) (refer to Question F)		
	Poggio et al. (2010c) (refer to Question F)			O'Reagain P et al. (2008) (refer to Question F)		
	East M & Star M (2010) (refer to Question F)			Ash A et al. (2002) (refer to above)		
RPP Evidence base	**Program-wide**					
	Current evidence		**2011/12**		**2013/2014**	
I. What is the best way to get land managers to adopt profitable water quality improvement?	**RP14 & RP19** *Assessing motivations and barriers to adoption of improved practices and*					
	Cane			**Grazing**		
	Current evidence	**2011/12**	**2013/2014**	**Current evidence**	**2011/12**	**2013/2014**
		Sub57 *Preliminary report on how cane growers make decisions and how best to encourage uptake of improved practices*	**Sub57** *Report on effective methods of improving compliance and improved management by cane growers in the regulated catchments based on experience of extension programs*	Greiner R, Patterson L & Miller O (2009) Motivations, risk perceptions and adoption of conservation practices by farmers. *Agricultural Systems* 99:86-104.	**Sub55** *Preliminary report on how graziers make decisions and how best to encourage uptake of improved practices*	**Sub55** *Report on effective methods of improving compliance and improved management by BDT graziers catchments based on experience of extension programs*
		Sub34 *Preliminary assessment of regional weed management issues in the Wet Tropics*	**Sub34** *Assess and address regional weed management issues in the Wet Tropics*	Jarrad *et al.* (2011) Integration and synthesis of state of the environment indicators. Case study: Downstream Effects from Grazing in the Burdekin on Water Quality of the Reef. Queensland University of Technology. *Report on the factors affecting decision-making by BDT graziers with respect to land condition management.*	**Sub48** *Report on a revised assessment of the motivations of BDT graziers and factors affecting their adoption of management with environmental benefits*	

J. How can land managers best incorporate water quality considerations in their management decisions?	**RP09** SafeGauge for Pesticides *Extension tool to inform landholder decisions about pesticide applications (CD)*		**Sub29** SafeGauge for Pesticides *Improved extension tool to inform landholder decisions about pesticide applications (Web)*	GLM courses (refer to Question F)	**Sub11** (refer to Question G)	**Sub11** (refer to Question G)
	RP10 SafeGauge for Nutrients *Extension tool to inform landholder decisions about nutrient applications (Web)*			Stocktake (refer to Question F)	**Sub12** (refer to Question G)	**Sub12** (refer to Question F)
				O'Reagain P et al. (2008) (refer to Question F)		
				Ash A et al. (2002) (refer to Question F)		
				Roth C et al. (2004) (refer to Question F)		
K. What do land managers need to know to make water quality improvements?	**RP11** *Developed cane soil testing method*			GLM courses (refer to Question F)	**Sub47** (refer to Question F)	
	RP12 *Assessed mill mud and mill mud product efficacy*			Stocktake (refer to Question F)	**Sub22** (refer to Question F)	
	RP15 *Assessed phosphorus status of Burdekin alkaline soils under cane*			O'Reagain P et al. (2008) (refer to Question F)		
	RP16 *Developed cane soil testing and nutrient calculation*			Ash A et al. (2002) (refer to Question F)		
	RP20 *Assessing nitrogen application rates in the BRIA and Burdekin Delta*	**RP22** *Assisting land managers in the Lower Burdekin to assess nitrates in Irrigation Water and adjust nitrogen application rates accordingly*	**Sub58** *Report on the water quality benefits of slow release N and improved management systems in the lower Burdekin*	Roth C et al. (2004) (refer to Question F)		
	RP21 *Reviewed Yield and Crop Classes*					
	RP23 *Report on the effectiveness of Community Drainage Schemes and EVTAs*					
			Sub08 *Report on accounting for legume contribution to nitrogen budgets in nitrogen application rates and calibration of SafeGauge for Nutrients*			
			Sub38 *Report identifying factors affecting nitrogen use efficiency in the cane cropping system and calibration of SafeGauge for Nutrients*			
			Sub59 *Assessment of nitrogen application rates in the Herbert river catchment*			
L. Where and what is least cost abatement?	All of the above lines of evidence combined	All of the above lines of evidence combined	All of the above lines of evidence combined	All of the above lines of evidence combined	All of the above lines of evidence combined	All of the above lines of evidence combined

Scientific consensus statement on water quality in the Great Barrier Reef



Scientific consensus statement on water quality in the Great Barrier Reef

The establishment of the Reef Water Quality Protection Plan (Reef Plan) in 2003 by the Australian and Queensland Governments was supported by a body of evidence showing a decline in water quality on the Great Barrier Reef (GBR). A comprehensive review of the evidence available at the time, "*Summary Statement of the Reef Science Panel regarding water quality in and adjacent to the Great Barrier Reef*" was prepared by a taskforce of experts led by [redacted]

Since that time, there have been significant advances in knowledge to support implementation of the Reef Plan. As the Reef Plan approaches the halfway mark of the 10-year plan, it is considered timely to review and synthesise this knowledge and reach consensus on the current understanding of the system.

A taskforce of scientists has prepared a discussion paper that reviews the 2003 summary statement of evidence and, where appropriate, updates the statement based on the results of more recently published and peer-reviewed articles. This scientific consensus statement is based upon the outcomes of that discussion paper.

Analysis of the latest available evidence leads us to conclude:

1. **Water discharged from rivers to the GBR continues to be of poor quality in many locations.**
2. **Land derived contaminants, including suspended sediments, nutrients and pesticides are present in the GBR at concentrations likely to cause environmental harm.**
3. **There is strengthened evidence of the causal relationship between water quality and coastal and marine ecosystem health.**
4. **The health of freshwater ecosystems is impaired by agricultural land use, hydrological change, riparian degradation and weed infestation**
5. **Current management interventions are not effectively solving the problem.**
6. **Climate change and major land use change will have confounding influences on GBR health.**
7. **Effective science coordination to collate, synthesise and integrate disparate knowledge across disciplines is urgently needed.**

The scientific consensus

1. Water discharged from rivers to the GBR continues to be of poor quality in many locations.

1.1 Pesticide residues, particularly herbicides, are present in surface and groundwater in many locations in the catchments – these substances do not occur naturally in the environment.

1.2 Concentrations of nitrate and nitrite are elevated in groundwater in areas under intensive agriculture – a portion of this groundwater is believed to enter coastal waters.

1.3 River loads of nutrients, sediments and pesticides are higher than in pre-European times – this is inferred from changes in land use and estimated through monitoring and modelling, although with significant model uncertainty.

1.4 Concentrations of contaminants in waterways are related to specific forms of land use – monitoring and modelling data identify the main sources of nutrients, sediments and pesticides, and show strong regional differences. Evidence includes:

1.4.1 Nitrogen – A strong relationship exists between the areas of nitrogen-fertilised land use in a catchment and the mean nitrate concentration during high flow conditions, implicating fertiliser residues as the source of nitrate. Elevated stream concentrations of nitrate indicate fertiliser application above plant requirements in sugar cane and bananas.

1.4.2 Phosphorus – Elevated concentrations of dissolved inorganic phosphorus are related to fertiliser application above plant requirements in intensive cropping and to locally specific soil characteristics.

1.4.3 Sediment – Most sediment originates from the extensive grazing lands of the Dry and Sub Tropics.

1.4.4 Pesticides – Concentrations in waterways are highest in areas of intensive agricultural activity including sugarcane and cotton.

1.5 The priority source areas of contaminants are now relatively well known for GBR catchments.

1.5.1 Analysis of data on fertiliser use, loss potential and transport has ranked fertilised agricultural areas of the coastal Wet Tropics and Mackay Whitsunday as the hot-spot areas for nutrients (mainly nitrogen) that pose the greatest risk to GBR reefs.

1.5.2 In the Dry Tropics, high suspended sediment concentrations in streams are associated with rangeland grazing and locally specific catchment characteristics, whereas sediment fluxes are relatively low from cropping land uses due to improvements in management practices over the last 20 years.

1.5.3 In the Wet Tropics sediment fluxes are comparatively lower due to high vegetation cover maintained throughout the year from high and year round rainfall and different land management practices from Dry Tropics regions within industries such as beef grazing.

1.5.4 Urban development sites can be local high impact sources of suspended sediment.

1.5.5 Of the herbicide residues most commonly found in surface waters in the GBR region, diuron, atrazine, ametryn, hexazinone derive largely from areas of sugarcane cultivation, while tebuthiuron is derived from rangeland beef grazing areas.

2. Land derived contaminants, including suspended sediments, nutrients and pesticides are present in the GBR at concentrations likely to cause environmental harm.

Considerable advances have been made in recent years to understand the presence, nature and extent of land-derived contaminants in GBR waters. The lines of evidence to support this include:

2.1 Contaminants are dispersed widely within the GBR – satellite remote sensing demonstrates the transport of river-plume-derived dissolved matter across and along the GBR lagoon and out to the Coral Sea. Particulate matter is dispersed less widely and tends to be trapped and deposited inshore.

2.2 Pesticides are present in the GBR – pesticide residues, especially herbicides, are detected in many GBR waters. Pesticides at biologically active concentrations have been found up to 60km offshore in the wet season and in low but detectable concentrations in the dry season.

2.3 Contaminants may have long residence times in the GBR lagoon – most sediment is trapped near the coast and hence has decadal residence times in the GBR lagoon. Dissolved nutrients are dispersed more rapidly and may be trapped in the lagoon by biological uptake and persist in this particulate form for years; most pesticide residues have short residence times (at most a few years) due to their chemical breakdown.

2.4 Large river discharge events ('floods') in the wet season are the major delivery mechanism of land-derived contaminants to the GBR – in GBR waters, concentrations of dissolved inorganic nitrogen (nitrate, ammonium), suspended sediment and dissolved inorganic phosphorus are many times higher in flood plumes than in non-flood waters.

2.5 Correlations exist between river-discharged material and water quality in the GBR lagoon – phytoplankton biomass and pesticide concentrations in the GBR lagoon are directly correlated with river nutrient and pesticide loads, respectively.

3. There is strengthened evidence of the causal relationship between water quality and coastal and marine ecosystem health.

Qualitative and quantitative understanding of the effects of land-sourced contaminants on GBR species and ecosystems has been greatly improved since 2002. Pesticides are now recognised as a greater potential threat to GBR ecosystems than was realised before 2003.

The following are lines of evidence exist of causal and dose-response relationships between water quality change and coastal and marine ecosystem health:

3.1 Seagrass – There is evidence of decline in seagrass health with increasing concentrations of herbicides.

3.2 Coral reefs – The impacts of water quality on corals has been demonstrated through both field studies and laboratory experiments. Field studies have shown that:

- 3.2.1 Macroalgae increase and coral species richness decline with increasing turbidity and chlorophyll in the GBR (Lat 12 - 24º S).
- 3.2.2 Links between nutrient enrichment and crown-of-thorns starfish population outbreaks are now well supported.
- 3.2.3 Coral reef development diminishes along a water quality gradient in the Whitsunday Islands.
- 3.2.4 Coral cores from reefs off Mackay show that increasing exposure to nitrogen from the Pioneer River is correlated with poor reef condition and high macroalgal cover.
- 3.2.5 Inshore reefs off the Wet Tropics have lower coral and octocoral diversity and higher macroalgal cover than expected based on latitudinal changes.
- 3.2.6 Stress and mortality in corals exposed to sedimentation increases with increasing organic content of the sediment.
- 3.2.7 The presence of muddy marine snow increases sedimentation stress and mortality in coral recruits.
- 3.2.8 Various pesticides exert detrimental effects on zooxanthellae. photosynthesis and coral reproduction at trace concentrations.
- 3.2.9 There are synergistic effects between herbicides and sediments on crustose coralline algae.

4. The health of freshwater ecosystems is impaired by agricultural land use, hydrological change, riparian degradation and weed infestation.

Understanding of the ecosystem health of catchment waterways has been greatly enhanced by recent research in Wet Tropics streams and floodplain waterways, and on the riverine waterholes and floodplains of the Dry Tropics. Clear relationships between land use, hydrological change, riparian management, weed infestation and waterway ecosystem health have been established. The lines of evidence to support this include:

4.1 Primary factors affecting instream ecosystem health are riparian vegetation condition, aquatic and riparian weed prevalence, vegetation removal and habitat loss – these factors have been shown to be more important in reducing instream ecosystem health than water quality per se.

4.2 Concentrations of nutrients in fresh waters in many catchments are proportional to the area of land under agriculture – elevated nutrient inputs from agricultural sources are known to contribute to enhanced weed growth, vegetation change and associated changes in instream community structure.

4.3 Agricultural development has led to substantial damage to riparian and wetland health in many catchments – these influences have negative consequential effects on water quality and hence detrimental effects on instream biota.

4.4 Concentrations of pesticides in waterways are highest in areas of intensive agricultural activity – the implications of this for community structure in freshwater ecosystems are potentially severe but our knowledge is limited.

4.5 The condition of riverine waterholes in the Dry Tropics is largely determined by cattle access – cattle contaminate and disturb the waterholes causing deoxygenation from excreta, increased turbidity, and consequent loss of biodiversity.

4.6 The condition and biodiversity of floodplain waterways are adversely affected by irrigation inputs and drainage – sediments, nutrients from fertilisers and organic material have been shown to lead to oxygen depletion, enhanced weed growth, turbidity, reduced connectivity, and hence biodiversity loss.

5. Current management interventions are not effectively solving the problem.

Understanding of the effectiveness of management interventions has improved in the last five years, but there are still significant knowledge gaps that undermine our present ability to identify investment priorities and provide confidence in likely water quality outcomes. Current evidence relating to management intervention is:

5.1 Priority contaminants for intervention are known for Water Quality Improvement Plan areas – there is improved regional understanding of management practices associated with the presence of contaminants in waterways, including knowledge of variability in risks across and within catchments and industries. However, prioritisation between the regions and between industries at a GBR-wide scale is lacking.

5.2 A range of measures for managing sediment, nutrient and pesticide loss are available for implementation across industries and across regions in the GBR catchments – agricultural industry land management systems such as Grazing Land Management and fertiliser efficiency techniques are established.

5.3 Quantification of water quality outcomes of management practices is inadequate – management systems believed to be effective (based on limited information) are known for the sugar cane and grazing industries; less information is available for many of the regions' diverse horticultural industries.

5.4 There are many social and economic impediments to the implementation of management interventions – there are multiple economic and social impediments to the implementation of changes of management practices aimed at reducing contaminant loads to the GBR. While win-win scenarios exist for some management interventions such as the 'Six Easy Steps' nutrient management system in sugarcane, many practices involve net costs to producers, particularly in the shorter term. Economic and social impediments to practice change vary between regions, complicating the design of policies to achieve agricultural practice change.

5.4 Knowledge of the effectiveness of restoration techniques is insufficient to guide investment – the effectiveness of riparian vegetation and wetlands as potential filters of sediments, nutrients and pesticides is known for some cropping locations, but is limited for grazing areas.

5.5 Targets have been set at regional scales based on best available science but GBR-wide targets are lacking – the setting of targets for management actions, end-of-catchment loads and resource condition has been integral to the development of GBR Water Quality Improvement Plans. The targets are thus far more robust than previously set but still require modification in the light of new information. However, no targets have been set at the GBR scale which would allow trade-offs in management actions across the GBR region to be considered.

6. Climate change and major land use change will have confounding influences on GBR health.

The primary confounding influences related to GBR water quality are climate change and major land use change. The complex interactions between the impacts of water quality stressors and other stressors such as climate change (bleaching, ocean acidification) and fishing/harvesting and their interaction are yet to be resolved. Predicted changes in the climate both globally and for the GBR are an increase in the frequency of extreme weather events including heat periods and cold snaps, more intense cyclones, and more frequent droughts alternating with severe floods. Overall, the changing climate as observed and/or predicted within the GBR region will increase the frequency with which coral reefs are being disturbed and thus the ability of the GBR to recover from perturbations.

Current evidence for interactions between potential climate change, major land use change and water quality include:

6.1 Increasing concentrations of CO2 in the atmosphere lead to a reduction in the pH of seawater ('ocean acidification') which reduces the ability of corals and other calcifying organisms to grow, and diminishes the capacity of coral reefs to withstand erosion and storms.

6.2 Warmer waters lead to changes in the growth rates in most species and altered food availability and ecological functions within GBR ecosystems.

6.3 Increased rainfall variability and intensity of weather events (droughts, floods etc) will make land management more difficult and increase the risks of soil erosion and loss, thus increasing loads of sediment and nutrients discharged into the GBR lagoon. Droughts reduce vegetation cover and expose soils to higher erosional losses to freshwater and marine environments during floods. Changing hydrology may have severe effects on catchment water quality.

6.4 Storm energy increases with the cube of wind speed and some forms of storm damage (e.g., the dislodgement of large massive corals) are only observed at cyclone categories three or higher.

6.5 Successful coral reproduction and recruitment is needed to compensate for the predicted increase in coral mortality resulting from bleaching, cyclones, floods and crown-of-thorns outbreaks. Good water quality is essential for successful coral reproduction and the survival of coral recruits on inshore reefs, and for keeping macroalgal cover low. Managing inputs of nutrients, sediments and pesticides is therefore considered essential to facilitate resilience during climate change.

6.6 Any reduction in the abundance and diversity of grazing fishes strongly influences the balance between macroalgal and coral cover. This has been shown to influence the rate at which coral reefs recover after bleaching events.

6.7 Increasing pressure for agricultural industries to seek alternative and viable ventures will lead to major land use change in the GBR catchments, which is likely to have implications for the amount of nutrients, sediments and pesticides discharged to the GBR.

7. Effective science coordination to collate, synthesise and integrate disparate knowledge across disciplines is urgently needed.

Effective science coordination to collate, synthesise and integrate disparate knowledge across disciplines is currently limited and inadequate, and is needed as a matter of urgency to manage GBR water quality. Science integration is the key to informing management decisions for the Reef Plan, and is required to understand and quantify the following links between the system components that determine GBR water quality and ecosystem health:

- within and across catchments of the GBR, so that the linkages between catchment actions and the health of catchments and the GBR can be quantified
- between biophysical, social and economic variables so that realistic targets and implementation strategies can be developed and assessed
- across local to regional to GBR scales, to determine whether existing and proposed activities are sufficient to achieve the Reef Plan goal of reversing water quality declines within a 10-year timeframe.

Panel of scientific contributors:

[redacted]

This document was prepared by an independent panel of scientists with expertise in Great Barrier Reef Water Quality.
This document does not represent government policy.

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Synthesis of evidence to support the Scientific Consensus Statement on Water Quality in the Great Barrier Reef

Prepared by: [redacted]

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Contents

Background

A consensus statement of the current understanding of Great Barrier Reef (GBR) water quality science was prepared to underpin the future direction of the Reef Water Quality Protection Plan (Reef Plan) actions and to guide future investment in Reef Plan activities.

Terms of Reference

The Terms of Reference for the statement, prepared by the Reef Water Quality Partnership (RWQP) Support Team and Reef Plan Secretariat, and reviewed by the RWQP Scientific Advisory Panel, are provided below.

Purpose

To review the *Summary Statement of the Reef Science Panel regarding water quality in and adjacent to the Great Barrier Reef*, in a contemporary context. This statement, which was produced by technical experts in 2002, supported the development of the Reef Plan. Given that it was nearing the halfway mark of the 10-year plan, it was considered timely to review and, where appropriate, update the statement to support the reinvigoration of Reef Plan and guide future investment in Reef Plan priority activities.

Tasks

Review the 2002 statement and update it by:

1. Reviewing scientific evidence for:

- a decline in the quality of water that discharges from the catchments into the Great Barrier Reef
- a decline in the quality of water in GBR catchment waterways leading to reduced instream ecosystem health
- the presence, nature and extent of land-derived contaminants in Reef waters
- causal relationships between water quality change and ecosystem health
- the effectiveness of current or proposed management intervention in solving the problem and the social and economic impediments to uptake.

2. Evaluating current research, and advising on capabilities, gaps and priority research needs, to:

- assess water quality impacts
- quantify acceptable levels of pollution
- locate and quantify the sources of pollution
- reduce pollution from key sources
- assess the effectiveness of actions to reduce pollution.

3. Discussing the implications of confounding influences, including climate change.

The wording of the above Terms of Reference has been slightly modified by the Taskforce, in consultation with the Reef Plan Secretariat.

The taskforce

A taskforce has been convened to prepare the consensus statement and includes the contributors listed in the table below.

Contributor	Title	Organisation	Expertise
[redacted]	Principal Research Officer, Water Quality	Australian Centre for Tropical Freshwater Research	Water quality and agricultural science – catchment to reef
[redacted]	Senior Consultant	Marsden Jacob Associates	Resource economics
[redacted]	Principal Research Scientist, Coral Reef Ecology	Australian Institute of Marine Science	Coral reef ecology
[redacted]	Theme Leader, Healthy Terrestrial Ecosystems	CSIRO Sustainable Ecosystems	Terrestrial ecology and social interactions
[redacted]	Director, Centre for Marine Studies	University of Queensland	Coral reef ecology and climate change
[redacted]	Principal Scientist, Natural Resource Sciences	Department of Natural Resource and Water	Biogeochemistry of land and water systems
[redacted]	Principal Scientist	Department of Primary Industries and Fisheries	Agricultural science – grazing
[redacted]	Director, School of Tropical Biology	James Cook University	Tropical ecology
[redacted]	Senior Consultant	Contracted to Meat and Livestock Australia	Agricultural science – grazing
[redacted]	Principal Research Scientist, Tropical Production Systems	CSIRO Sustainable Ecosystems	Agricultural and environmental science – cropping
[redacted]	Science Coordinator, GBR Projects	CSIRO	Water quality science – catchment to reef
[redacted]	Research Scientist, Catchment and Aquatic Systems	CSIRO Land and Water	Catchment and marine hydrodynamics and biogeochemistry
Additional contributors			
[redacted]	Research Scientist, Catchment and Aquatic Systems	CSIRO Land and Water	Catchment hydrology and material fluxes

Apologies have been received from the following individuals that were approached to participate:

[redacted] (Canegrowers – cane management practices)

[redacted] (DPI&F – grazing management practices)

[redacted] (AIMS – marine water quality and oceanography)

[redacted] (ANU – marine water quality and climate change).

Definitions

The following terms are defined for the purposes of this discussion paper:

Contaminant – any material that can be detected in water at above 'natural' concentrations.

Pollutant – when a contaminant is at concentrations known to cause environmental harm.

Introduction

The establishment of the Reef Water Quality Protection Plan (Reef Plan – Anon, 2003) by the Australian and Queensland governments was supported by a body of evidence showing a decline in water quality on the GBR. Efforts to review this evidence included Williams (2002), Williams et al. (2002) and the Great Barrier Reef Protection Interdepartmental Committee Science Panel (2003). The latter document was a comprehensive review of the evidence available at the time, prepared by a taskforce of experts led by Dr [redacted]

As the Reef Plan approached its five-year (half-way) mark there was recognition of the need to improve the effectiveness of its delivery, particularly through improved partnership arrangements and a clear focus on land management actions. In November 2007, the Labor party released an election policy document proposing funding of $200 million over five years for a Reef Rescue program 'to tackle climate change and improve water quality in the Great Barrier Reef'. This package includes substantial funding ($146 million) for a Water Quality Grants Scheme, and supporting monitoring, reporting and research programs, with additional funding to build partnerships.

This package will constitute Commonwealth Government investment over the next five years for addressing GBR water quality improvement targets. There is a need to focus investment in GBR water quality in a way that demonstrates a tangible return on investment for government agencies, regional National Resource Management (NRM) bodies and industry groups over the life of the Reef Rescue policy.

Since 2003, there have been significant advances in the knowledge to support implementation of the Reef Plan. It is timely to synthesise this knowledge and reach consensus on current understanding of the system to support the reinvigoration of Reef Plan and guide future investment in Reef Plan priority activities. This discussion paper provides a synthesis of current knowledge against a set of Terms of Reference defined by the Reef Water Quality Partnership Scientific Advisory Panel and the Reef Plan Secretariat. It reviews the *Summary Statement of the Reef Science Panel regarding water quality in and adjacent to the Great Barrier Reef* in a contemporary context and, where appropriate, updates the statement.

Part A

Review the 2003 statement and update it by reviewing available scientific evidence

1. Review scientific evidence for a decline in the quality of water that discharges from the catchments into the GBR

Conclusion: Water discharged from rivers to the GBR continues to be of poor water quality in many locations.

The quality of waters entering the GBR from its river systems and groundwater is highly variable both spatially and temporally across the region. Natural catchment characteristics (e.g. geology, climate) and anthropogenic activities (e.g. land use, land and water management) both strongly influence water quality, including the concentrations and loads of land-derived materials transported from the catchment to the GBR lagoon. Excessive levels of suspended sediment and nutrients (nitrogen and phosphorus) are of concern, as well as the presence of pesticide residues or other substances that do not occur naturally in the environment. These pose a risk to the health of aquatic ecosystems both within the catchment and in the GBR.

Evidence suggests that concentrations and loads of suspended sediment and nutrients have increased substantially with catchment development, although the magnitude of the increases compared with natural conditions is not precisely known. Contemporary land uses differ in their export rates of these contaminants, and there are marked cross-regional differences, particularly between the Wet and Dry Tropics. Emerging results from long-term monitoring indicates increasing trends in nitrogen concentrations in two river systems. The widespread presence of certain herbicide residues in both surface waters and groundwater is further evidence of a decline in water quality.

1.a. Lines of evidence

1.a.i. Pesticide residues, particularly herbicides, are present in surface and groundwater in many locations in the catchments.

These substances do not occur naturally in the environment.

1.a.ii. Concentrations of nitrate and nitrite are elevated in groundwater in areas under intensive agriculture.

A portion of this groundwater is believed to enter the coastal waters.

1.a.iii. River loads of nutrients, sediments and pesticides are higher than in pre-European times.

Inferred from changes in land use and estimated through monitoring and modelling, although with significant uncertainty (in models and monitoring). Long-term datasets in the Tully River show upward trends in concentrations of particulate nitrogen and nitrate from 1987 to 2001.

1.a.iv. Concentrations of contaminants in waterways are related to specific forms of land use.

Monitoring and modelling identify the main sources of nutrients, sediments and pesticides, and show strong regional differences. Evidence includes:

- Nitrogen – a strong relationship exists between the areas of nitrogen-fertilised land use in a catchment and the mean nitrate concentration during high flow conditions, implicating fertiliser residues as the source of nitrate. Elevated stream concentrations of nitrate indicate fertiliser application above plant requirements in sugarcane and bananas.
- Phosphorus – elevated concentrations of dissolved inorganic phosphorus are also related to fertiliser application above plant requirements in intensive cropping and to locally specific soil characteristics.
- Sediment – most sediment originates from grazing lands of the dry and sub-tropics. The influence of land use on sediment loads is now well known at a regional scale but more work is required to identify sources at finer scales, due to variability associated with hillslope, streambank and gully erosion within individual catchments.
- Pesticides – concentrations in waterways are highest in areas of intensive agricultural activity including sugarcane and cotton.

1.a.v. The priority source areas of contaminants are now relatively well known for GBR catchments.

Analysis of data on fertiliser use, loss potential and transport has ranked fertilised agricultural areas of the coastal Wet Tropics and Mackay Whitsunday as the hot-spot areas for nutrients (mainly nitrogen) that pose the greatest risk to GBR reefs.

In the Dry Tropics, high suspended sediment concentrations in streams are associated with rangeland grazing and locally specific catchment characteristics, whereas sediment fluxes are relatively low from cropping land uses due to improvements in management practices over the last 20 years.

In the Wet Tropics, sediment fluxes are comparatively lower due to high vegetation cover maintained throughout the year from high and year-round rainfall and different land management practices from Dry Tropics regions within industries such as beef grazing.

Urban development sites can be local high impact sources of suspended sediment.

Of the herbicide residues most commonly found in surface waters in the GBR region, diuron, atrazine, ametryn, hexazinone derive largely from areas of sugarcane cultivation, while tebuthiuron is derived from rangeland beef grazing areas.

1.b. The evidence base

1.b.i. Pesticide residues, particularly herbicides, are present in surface and groundwater in many locations.

The presence of pesticide residues, especially herbicides, is widespread in waterbodies of the GBR region, including streams, wetlands, estuaries, coastal and reefal waters (e.g. Hunter *et al.,* 2001; Packett *et al.,* 2005; Rohde *et al.,* 2006a, 2008; Faithful *et al.,* 2007; Lewis *et al.,* 2007a; 2007b). Residues commonly detected include atrazine, diuron, ametryn, hexazinone and tebuthiuron. Although most of the concentrations are very low, these substances would not have been present at all before agricultural development of the catchments. The leaking of these chemicals from cane paddocks has been confirmed by paddock scale studies throughout the GBR catchment, including Bundaberg (Stork *et al.,* 2008) and the lower Burdekin (Ham, 2006; 2007). Atrazine residues have been found in the groundwater of many regions including the lower Burdekin (Bauld, 1994), Mackay (Baskeran *et al.,* 2002), Bundaberg (Bauld, 1994) and Bowen (Baskeran *et al.,* 2001). Where this water is used for drinking water supplies, the detection of atrazine means that the water fails to meet Australian and New Zealand Environment Conservation Council (ANZECC) requirements for drinking water.

1.b.ii. Concentrations of nitrate and nitrite are elevated in groundwater in areas under intensive agriculture.

High concentrations of nitrogen have been found in groundwaters of many regions, and these have been linked to fertiliser sources (Weier, 1999; Thorburn *et al.,* 2003a). The final fate of the elevated nitrate concentrations found in groundwater is still uncertain (e.g. in the Burdekin delta refer to Thayalakumaran *et al.,* 2008). Drainage of nitrate below the root zone in sugarcane in the Johnstone catchment has been shown to produce a nitrate 'bulge' below the surface (Rasiah and Armour, 2001; Rasiah *et al.,* 2003a) and it has also been shown that this nitrate is likely to move laterally in subsoil to adjacent streams and rivers (Rasiah *et al.,* 2003b). However, a high degree of uncertainty exists in the role of groundwater transported contaminants (especially nitrate) in material transport from paddocks to coastal waters.

1.b.iii. River loads of nutrients, sediments and pesticides are higher than in pre-European times.

Evidence of changes in river concentrations of contaminants over recent decades is only available for a few rivers. The most complete long-term monitoring data set is from the Tully River (Mitchell *et al.,* 2001; 2006) where particulate nitrogen concentrations increased by 100% and DIN concentrations by 16% between 1987 and 2000. This occurred during a period of increasing fertiliser use in the catchment, although a direct cause-effect association has not been established. Further, an increase in ammonia and phosphorus in the Daintree River over the period 1994–2000 was measured by Cox *et al.* (2005).

It is to difficult to pick up short- or medium-term trends in water quality at large scales due to climate variability and inherent difficulties in logistics associated with monitoring at the right spatial and temporal scales. See also discussion in Section 5.

Changes in loads and concentrations of suspended sediment and the various forms of nitrogen and phosphorus since European settlement have been estimated using models such as SedNet and ANNEX (Brodie *et al.,* 2003; Cogle *et al.,* 2006) and other models (e.g. Furnas, 2003). The models have incorporated water quality data collected from sites with extensive agricultural and urban land uses and compared with data from areas with little or no development (Brodie and Mitchell, 2005). The SedNet and ANNEX model group has been widely used at the catchment and sub-catchment scale for the entire GBR catchment area and has also been repeated and developed for regional catchments (e.g. Brodie *et al.,* 2003; Cogle *et al.,* 2006; Armour *et al.,* 2007a; Kinsey-Henderson and Sherman, 2007; Dougall *et al.,* 2006a) to predict sediment and nutrient generation, transport and delivery to the GBR lagoon; and at small subcatchment scales to determine sources and sinks of sediment at a scale suitable for grazing land management (Kinsey-Henderson *et al.,* 2005; Bartley *et al.,* 2007a; 2007b; 2007c).

In some cases, estimates have been supported by comparison with monitoring results (Fentie *et al.,* 2005; Armour *et al.,* 2007a; Mitchell *et al.,* 2007a; Sherman *et al.,* 2007). Results from such modelling studies indicate that in many rivers, suspended sediment loads (and hence mean concentrations) may have increased by a factor of 5–10 since European settlement, and loads of total nitrogen and total phosphorus, by factors of 2–5 and 2–10, respectively. These models also indicate that nitrate loads in these rivers may have increased twenty-fold over the same period (Armour *et al.,* 2007a). However, it is important to note the very high levels of uncertainty that are unavoidably associated with these types of estimates. Consequently, use of a different modelling approach may produce a contrasting set of estimates, depending on model assumptions, spatial resolution, and availability of data to feed into the models. This is highlighted by results for the Johnstone catchment, where a catchment model and a purpose-designed monitoring data set were used (Hunter and Walton, 2008) which suggested considerably lower increases in suspended sediment and nutrient loads since European settlement than those reported above (e.g. an increase in suspended sediment loads by a factor of 1.4 and nitrate loads by a factor of 6).

Steps in the transport pathway have now been better quantified; for example, studies on bedload storage have shown that sand-sized sediment may take decades to be transported to the river (Bartley *et al.,* 2007a). Estimates of overbank flow in the Tully catchment have shown that 43–50% of the sediment load and 35–46% of the nutrient load is from the river channel of the floodplain (Wallace *et al.,* in press; Karim *et al.,* 2008) and the dynamics of dissolved organic nitrogen are now also being considered (Wallace *et al.,* in press; Wallace *et al.,* 2007) and reported (Hunter and Walton, 2008).

1.b.iv. Concentrations of contaminants in waterways are related to specific forms of land use.

The sources of contaminants are now relatively well known for the GBR catchments. Current knowledge is based largely on information derived from modelling (e.g. using SedNet), with some of the model results supported by monitoring data. Large, detailed catchment-specific studies, such as the monitoring/modelling of the Johnstone catchment (Hunter and Walton, 2008) remain the exception, but results from monitoring programs now underway should enable similar detailed modelling to be carried out in the future for several other catchments.

Nitrogen

On average, about 50% of the total nitrogen loads transported annually in catchment waterways is associated with the suspended sediment fraction (Bramley and Roth, 2002; O'Reagain *et al.,* 2005; Bainbridge *et al.,* 2007; Faithful *et al.,* 2007; Hunter and Walton, 2008; Rhode *et al.,* 2008), which is associated predominantly with soil erosion processes. The remainder is present in various dissolved forms. Most dissolved inorganic nitrogen (DIN, primarily nitrate) in streams that drain cropping areas is considered to come from fertiliser residues (Rohde *et al.,* 2006a; Faithful *et al.,* 2005, 2007; Hunter and Walton, 2008) with 90% of the DIN attributed to this source in the Tully/Murray Region (Mitchell *et al.,* 2006; Armour *et al.,* 2007a). A strong relationship exists between the area of fertilised land use in a catchment and the mean nitrate concentration in high flow conditions proving that the source of nitrate is fertiliser residues (e.g. Mitchell *et al.,* 2006; Pearson and Stork, 2007). This is shown in Figure 1 (Mitchell *et al.,* 2006). However, it is worth noting that results from monitoring and modelling in the Wet Tropics (Johnstone catchment) have shown areas of non-sewered residential development to have the highest nitrate export rates of all land uses, on a unit area basis (Hunter and Walton, 2008). This may be locally important within the catchment, even if of lesser significance for the catchment as a whole, due to the relatively small proportion of the total catchment occupied by this land use. Associations between land use or land management and concentrations of other forms of nitrogen are less clear. The strong influence of climatic variability on annual loads of nitrogen (and other constituents) exported, highlights the potential challenges faced in detecting, with confidence, any future reduction in loads associated with the adoption of improved land management practices.

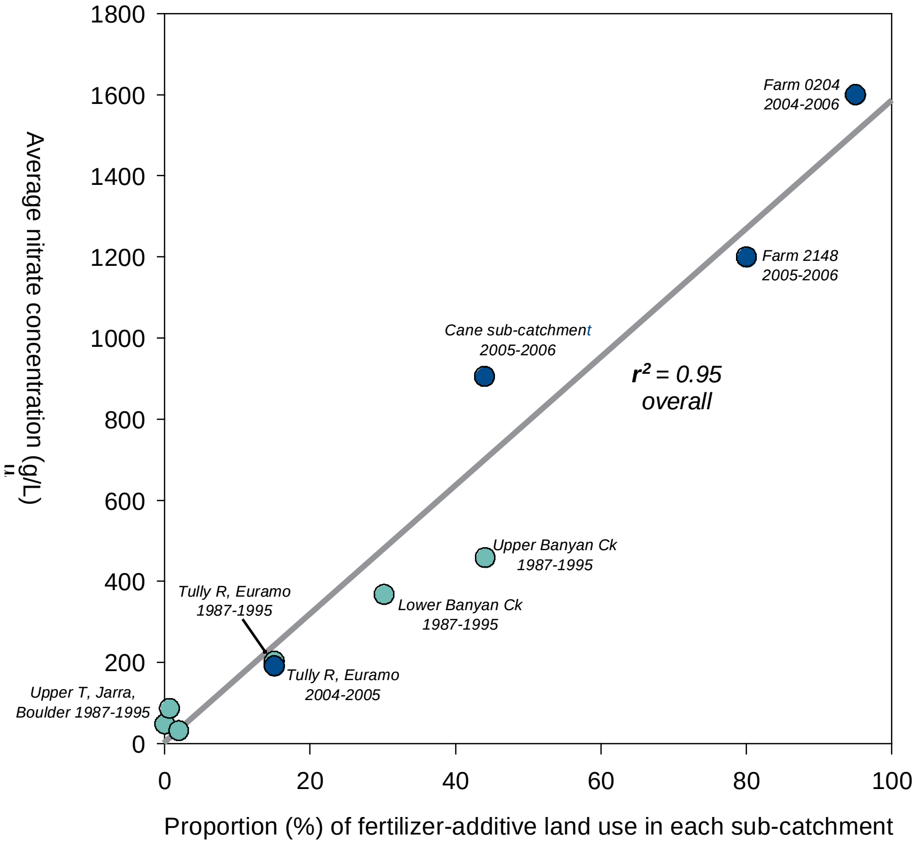

Figure 1. Relationship between fertiliser-additive land use and average (mean) nitrate concentration. Sourced from Mitchell *et al.,* 2006. Green symbols are AIMS-BSES data from wet-season. Blue symbols represent wet-season data from Faithful *et al.,* 2007 (Cane sub-catchment) and Faithful *et al.,* 2006 (Farm 2148 – 80% bananas; Farm 0204 – 95% sugarcane; Tully River, Euramo).

In the Tully catchment, where sugarcane production makes up only 13% of the catchment land use, 76% of the dissolved inorganic nitrogen discharged from the Tully River comes from sugar fertiliser losses, while about 85% is generated from sugar and bananas combined (Armour *et al.,* 2007a). Similarly, in the Johnstone catchment, sugarcane and bananas account for 75% of nitrate exported from the catchment (Hunter and Walton, 2008).

Increases in nitrogen concentrations in the Tully and South Johnston Rivers have also been associated with sugarcane production (Mitchell *et al.,* 2001; 2006; Hunter and Walton, 2008). Large amounts (up to 1000 kg/ha) of nitrogen have also been found in subsoils in the Bundaberg (Keating *et al.,* 1996), Innisfail (Rasiah *et al.,* 2003a) and Babinda (Meier et al. 2006) regions. High concentrations of nitrogen (N) have been found in groundwaters of many regions, and these have been linked to fertiliser sources (Thorburn *et al.,* 2003a). Nitrogen fertiliser management practices in sugarcane crops are consistent with these results on the presence of nitrogen in sugarcane areas. Rates of nitrogen fertiliser applications increased dramatically since the mid-1970s, and substantially more nitrogen fertiliser has been applied to sugarcane crops than removed from the cropped lands in either harvested cane or trash that was burnt. The difference between the nitrogen fertiliser applied and that removed is called the 'N surplus', which is an indicator of potential losses of nitrogen to the environment. Across the whole sugarcane industry, nitrogen surpluses have been in the order of

1 kg N/t cane since the early 1980s (Thorburn *et al.,* 2003b). Thus, for a crop yielding 80 t/ha, N surpluses are likely to be in the order of 80 kg/ha. Expressed at a regional scale, in a region producing 7 Mt of sugarcane per year (e.g. the Wet Tropics), there could be around 7000 t of surplus nitrogen annually. Reductions in nitrogen fertiliser use has occurred in some regions over the past five to ten years, but yields have also declined and as a result nitrogen surpluses are still close to 70 kg/ha (Thorburn *et al.,* 2007). Thus, the evidence of high stream concentrations of nitrogen in areas of sugarcane production described above is not unexpected.

While not studied as extensively, the situation is similar in some important horticultural crops. Nitrogen surplus is in the order of 200 kg/ha for bananas (Weier, 1994; Moody and Aitken, 1996; Prove *et al.,* 1997), although this has been reduced in recent years due to better fertiliser management regimes for bananas (Armour *et al.,* 2006, 2007b), and 100 kg/ha for capsicums (Moody and Aitken, 1996). Not surprisingly, large amounts (~200 kg/ha) of N have been found in subsoils following small crops in the Bundaberg region (Weier and Haines, 1998).

Phosphorus

Typically, most of the total phosphorus load in catchment waterways is associated with the suspended sediment fraction (and thus soil erosion processes), with <20% occurring in dissolved forms (e.g. Bainbridge *et al.,* 2007; Faithful *et al.,* 2007; Hunter and Walton, 2008). However, there are exceptions (e.g. the Mackay region), where relatively high concentrations and loads of dissolved phosphorus may occur, probably related to locally-specific soil characteristics (Bloesch and Rayment, 2006; Rhode *et al.,* 2008). The downstream fate of phosphorus sorbed onto suspended sediment is dependent on environmental conditions (e.g. pH, salinity, dissolved oxygen concentrations) as well as the geochemical properties of the sediment are still poorly understood. In certain situations, the phosphorus may be de-sorbed and released into the water column, as reported by McCulloch *et al.,* (2003a) for anoxic sediment offshore from the Johnstone catchment.

Sediments

In the Dry Tropics, high suspended sediment concentrations in streams derive from rangeland grazing and urban development sites (Bainbridge *et al.,* 2006a; 2006b; Rohde *et al.,* 2006b) whereas sediment fluxes are relatively low from cropping land uses (especially sugarcane cultivation). This is due to improvements in management practices over the last 20 years (e.g. minimum tillage and trash blanketing in cane) (Rayment, 2003; Bainbridge *et al.,* 2006b; Rohde *et al.,* 2006a; Faithful *et al.,* 2007). In the Wet Tropics (Johnstone catchment), sediment fluxes from grazing areas are low due to high vegetation cover maintained throughout the year, with sediment export rates similar to those from areas of native rainforest. By contrast, fluxes from cropping areas (sugarcane and bananas) in this catchment are around three to four times higher than those from areas of native rainforest (Hunter and Walton, 2008). Urban development sites can also be local high impact sources of suspended sediment.

Field studies in the Burdekin region (Virginia Park Station, Meadowvale Station and the Bowen catchment) have shown that river sediment and particulate nutrient concentrations in grazed areas are two to five times those in environmentally comparable non-grazed areas (Townsville Field Training Area managed by the Defence Department) (Post *et al.,* 2006a, 2006b). It is probable that hillslope and gully erosion are both major sources in the Dry Tropics, with bank erosion generally a smaller source of eroded sediment (Bartley *et al.,* 2007c). Roth (2004) and Hawdon *et al.,* (2008) have demonstrated evidence of changed hillslope hydrology in grazed rangelands that resulted in increased runoff. Further work showed that patches bare of vegetation are particularly prone to erosion, resulting in high hillslope sediment yields (Bartley *et al.,* 2007b, Bastin *et al.,* 2008). Improved monitoring techniques are now available to measure landscape leakiness and patchiness with respect to runoff and sediment (Abbott and Corfield, 2006).

There is reasonable understanding of spatial variation in the contribution of sediments and nutrients at the whole of GBR scale (McKergow *et al.,* 2005a; 2005b), which indicates that spatially targeted remediation will achieve greater reductions than a blanket approach (Wilkinson, 2008). However, considerable uncertainty still exists in the relative source contributions within individual river catchments;

for example, different SedNet runs in the Fitzroy basin have had a 30% range (uncertainty) in the predicted contribution of hillslope erosion (Wilkinson, 2008). In addition, there is limited knowledge on the relative importance of gully erosion compared with hillslope erosion in rangeland grazing, the primary causes of gully erosion in the landscape and the most effective remedial management practices to stabilise new and existing gullies. Broad assumptions are currently made in the sediment transport models on gully extent and behaviour leading to significant uncertainty in modelled predictions in some locations (Bartley *et al.,* 2007b; Herr and Kuhnert, 2007).

Sediment particle sizes influence delivery rates and system lags in delivery (i.e., different rates of delivery for sand versus silt versus clay). Lags vary from short (a few days) for clay to much longer timeframes (years) for silt and decadal timeframes for sand (Bartley *et al.,* 2007b; Bainbridge *et al.,* 2007). Different particle sizes are important components of different ecosystems; for example, sand is an important element of riverbed environments and beaches, while clay provides substratum for mangrove communities.

Pesticides

The herbicide residues most commonly found in surface waters in the GBR region (diuron, atrazine, ametryn, hexazinone) derive largely from areas of sugarcane cultivation (Rohde *et al.,* 2006a; Faithful *et al.,* 2007; Lewis *et al.,* 2007a) and for atrazine from cropping relatively specific to the Fitzroy (Packett *et al.,* 2005). At a local scale, diuron residues may also be associated with its use as an anti-foulant on boats (e.g. in marinas). Residues of tebuthiuron are associated primarily with the use of this product (Graslan) in grazing lands for woody weed control (Bainbridge *et al.,* 2007).

The capacity to predict contaminant loads through combined monitoring and modelling approaches is discussed further in Section 5.

Other

Other sources of contaminants that may be of concern to water quality in the GBR include disturbance of coastal areas and generation of acid sulphate soils (ASS) (Powell and Martens, 2005; http://www.nrw.qld.gov.au/land/ass/index.html). In recognition of these potential issues, the NRW has recently completed distribution mapping of ASS in Queensland.

1.b.v. The priority source areas of contaminants are now relatively well known for GBR catchments.

Several initiatives have attempted to identify the priority source areas of contaminants in GBR catchments; examples are described below. Further discussion of priority areas for management intervention is included in Section 5 (Part A).

Analysis of data on fertiliser use, loss potential and transport in the Nutrient Management Zones project (Brodie, 2007) has ranked fertilised agricultural areas of the coastal Wet Tropics and Mackay Whitsunday as the hot-spot areas for nutrients (mainly nitrogen) that pose the greatest risk to GBR reefs.

In the Dry Tropics, high suspended sediment concentrations in streams derive from rangeland grazing, locally specific catchment characteristics and urban development sites, whereas sediment fluxes are relatively low from cropping land uses due to improvements in management practices over the last 20 years (refer also to Section 5 of Part A). Projects have also identified catchment hot-spots for sediment delivery (erosion). For example, a modelling study on the Burdekin ranked the east Burdekin, Bowen River and NW Burdekin sub-catchments as areas of highest delivery (Brodie *et al.,* 2003; Fentie *et al.,* 2006; Kinsey-Henderson *et al.,* 2007). This analysis has been confirmed to some extent by monitoring studies that have identified very high concentrations of suspended sediment from the Burdekin sub-catchments Bowen River, Dry River and Camel Creek (Bainbridge *et al.,* 2007). In the Fitzroy catchment, modelled estimates suggest a significant proportion of the fine sediment delivered by the river to the estuary and coastal marine environment is derived from the basaltic soils of the western catchment (Douglas *et al.,* 2005; Smith *et al.,* 2006).

1.c. Key uncertainties related to decline in water quality and sources of pollutants

The following points summarise the key uncertainties associated with knowledge related to the decline in water quality and the sources of contaminants:

- Due to time lags in system response and relatively short-term monitoring information, estimates of contaminant loads generated by model predictions are subject to large uncertainties. Refinement of model approaches that predict contaminant loads by incorporating finer temporal resolution, characterisation of hydrological processes, nutrient speciation and better techniques for quantifying uncertainty is required.
- There is a need to review and integrate land-based modelling of sediment sources in the dry tropical catchments. In particular, the relative importance of gully erosion compared with hillslope erosion, the primary cause of gully erosion in the landscape and the most effective remedial management practices to stabilise new and existing gullies requires further work. Broad assumptions are currently made in the sediment transport models on gully extent and behaviour leading to significant uncertainty in modelled predictions in some locations.
- Identify major drivers, both natural (soils and geology, elevation and rainfall intensity and duration) and/or anthropogenic (land management such as stocking rates, fencing and spelling and resultant ground cover), of suspended sediment concentrations from different dry tropical sub-catchments (e.g. Burdekin and Fitzroy Rivers). Developing load models using available data has potential to identify the effect of climate and land management on loads.
- Knowledge of the residence times of different particle size fractions of suspended sediments transported through catchments and the implications and timescales for sediment delivery to the GBR lagoon.
- A high degree of uncertainty exists in the role of groundwater transported contaminants (especially nitrate) from paddock to coastal waters.

2. Review scientific evidence for the presence, nature and extent of land-derived contaminants in GBR waters

Conclusion: Land derived contaminants, including suspended sediments, nutrients and pesticides, are present in the GBR at concentrations likely to cause environmental harm.

Advances in monitoring and modelling techniques in recent years have enabled greater understanding of the presence, nature and extent of land-derived contaminants in GBR waters. Satellite imagery technology has enabled observation of the extent of flood plumes to distances substantially further than was previously understood. Recent efforts to collate long-term water quality data have identified some trends in water quality with strong regional differences and it is now clear that the presence of pesticides in GBR waters is widespread.

Coral cores have been demonstrated as a useful indicator of changes in the delivery of contaminants to the GBR and records show strong correlation of increases in contaminants with introduction of cattle and intensive fertiliser use.

2.a. Lines of evidence

2.a.i. Contaminants are dispersed widely within the GBR.

Remote sensing demonstrates the transport of river plume derived dissolved matter across and along the GBR lagoon, through the reef matrix and out to the Coral Sea. Particulate matter is dispersed less widely and tends to be trapped and deposited inshore.

2.a.ii. Pesticides are present in the GBR.

Pesticide residues, especially herbicides, are detected in many GBR waters. Pesticides at biologically active concentrations have been found up to 60 km offshore in the wet season and in low but detectable concentrations in the dry season.

2.a.iii. Contaminants may have long residency times in the GBR lagoon.

Most sediment is trapped near the coast and hence has decadal residence times in the GBR lagoon. Dissolved nutrients are dispersed more rapidly and may be trapped in the lagoon by biological uptake and persist in this particulate form for years; most pesticide residues have short residence times (at most a few years) due to their chemical breakdown.

2.a.iv. Large river discharge events (‘floods’) in the wet season are the major delivery mechanism of land-derived contaminants to the GBR.

In GBR waters, concentrations of dissolved inorganic nitrogen (nitrate, ammonium), suspended sediment and dissolved inorganic phosphorus are many times higher in flood plumes than in non-flood waters.

2.a.v. Correlations exist between river-discharged material and GBR lagoon water quality.

Phytoplankton biomass and pesticide concentrations in the GBR lagoon are directly correlated with river nutrient and pesticide loads, respectively. In inshore waters, long-term mean chlorophyll concentrations are high to the south compared with north of Port Douglas, coinciding with more intense land use south of Port Douglas. Offshore chlorophyll concentrations are similar south and north of Port Douglas, suggesting that the pattern is not due to latitudinal differences. Limited evidence exists for a relationship between regional turbidity and river suspended sediment discharge.

2.a.vi. Temporal changes are observed in contaminants in GBR waters.

Evidence of temporal change in contaminants in GBR waters is limited due to the small number of long-term monitoring programs; however, some examples include:

- Evidence for increasing concentrations of suspended sediments, dissolved organic nitrogen and dissolved organic phosphorus in Cairns lagoonal waters between 1989 and 2005 (the only long-term water quality monitoring program in the GBR lagoon).
- At Low Isles, water clarity (measured by Secchi disc transparency) is now half the value it was in 1928. However, the validity of this comparison is reduced as only two data sets are used for this assessment with little data produced between 1928 and the early 1990s.
- Coral cores record large increases in the delivery of suspended sediment and nutrients to the GBR, following the introduction of cattle and fertiliser to the catchments since the 1860s.

2.b. The evidence base

2.b.i. Contaminants are dispersed widely within the GBR.

The large increase in the availability of new satellite remote sensing platforms (e.g. MODIS, MERIS, ASTER, SPOT-5, QUICKBIRD, IKONOS, SEAWIFS) added to existing platforms (LANDSAT, AVHRR) allows daily tracking of flood plume dispersal in the GBR lagoon. The use of such images, combined with traditional concurrent surface vessel sampling and image analysis for parameters such as suspended sediments and chlorophyll a (A. Dekker, *pers comm.*) allows to quantify the spatial extent of exposure of GBR reefs and other ecosystems (Brodie *et al.,* 2006; Rohde *et al.,* 2006a; Brodie *et al.,* 2007a).

Figure 2 shows how remote sensing images can be used to support evidence of material transport in flood events. Of particular note in Figure 2a, is the presence in 2007 of an algal bloom and the presence of coloured dissolved organic matter (CDOM) derived from Burdekin and Wet Tropics river runoff dispersing completely across the mid and outer shelf reefs of the GBR between Townsville and Port Douglas and well into the Coral Sea (Brodie *et al.,* 2007a). Figure 2b shows the high sedimentation area near the mouth of the Burdekin River in 2005 where most of the suspended sediment drops out. This area, and the plume generally, is affected by wind over a 48-hour period. Figure 2c shows a plume extending offshore and to the north associated with Fitzroy River discharge in a large event in 2008; the movement of the body of discoloured water initially northwards and then to the south requires further explanation. Figure 2d shows the extensive algal bloom off nutrient-rich Mackay Whitsunday Rivers in 2005.

It is believed that only a small proportion (perhaps 5%) of the suspended sediment load of major rivers is transported large distances in the marine environment during major discharge events (evident from satellite images and flood plume monitoring). Limited knowledge exists on the specific origin in catchments of this small, but high risk, component and how geology, soil type and land management practices interact to produce this presumably fine-grained, washload (non-settling) suspended sediment. Areas of catchments producing this component of the suspended sediment load will be of high management priority. Further discussion of the correlation between river discharge water quality and GBR lagoon water quality is included in Section 2 in Part A.

Marine water quality monitoring is undertaken as part of the Reef Plan Marine Monitoring Program established in 2004 and led by the Great Barrier Reef Marine Park Authority (GBRMPA). Monitoring at inshore sites includes: collection of water column nutrients and suspended sediment concentration data around inshore reefs during the wet and dry seasons; deployment of automated long-term water quality loggers at several regional locations; sampling of pesticides in the water column at >10 inshore reef and island sites; collection of chlorophyll a samples in the water column at more than 50 sites from Cape York to the Burnett Mary regions; and monitoring of seawater temperature using continuous loggers at 28 sites (Prange *et al.,* 2007). Some of these tasks are assisted by community groups and tourism operators. A flood plume monitoring program was also initiated in 2007 to measure water quality conditions in flood plumes in as many regions as possible. Remote sensing techniques to measure chlorophyll, turbidity, colour dissolved organic matter and temperature are also being developed under the program.

Models have been developed to estimate the exposure of Great Barrier Reef inner-shelf reefs to terrestrial runoff using ratings of volume and frequency of discharge from major rivers, the predominant distribution of river plumes in GBR waters, loads of riverine contaminants, and distance of reefs to river mouths (Devlin *et al.,* 2003; Maughan *et al.,* 2008). Coastal and island areas at high risk of exposure to terrestrial runoff were identified adjacent to the Wet Tropics region, from Tully to north of Cairns, and in the Whitsunday region. This model has a number of limitations; for example, it assumes single, average river discharge events and does not deal with temporal dynamics; and it only assessed coral reefs as exposed ecosystems. The model is currently the only available marine exposure analysis that covers the entire GBR and is a useful representation of the spatial extent of the coastal areas that are likely to be regularly exposed to land runoff. However, the model did not consider the consequences of this exposure – for example to coral reefs – which should be part of a complete risk assessment. Research findings that could contribute to a future risk assessment are included in Section 3.

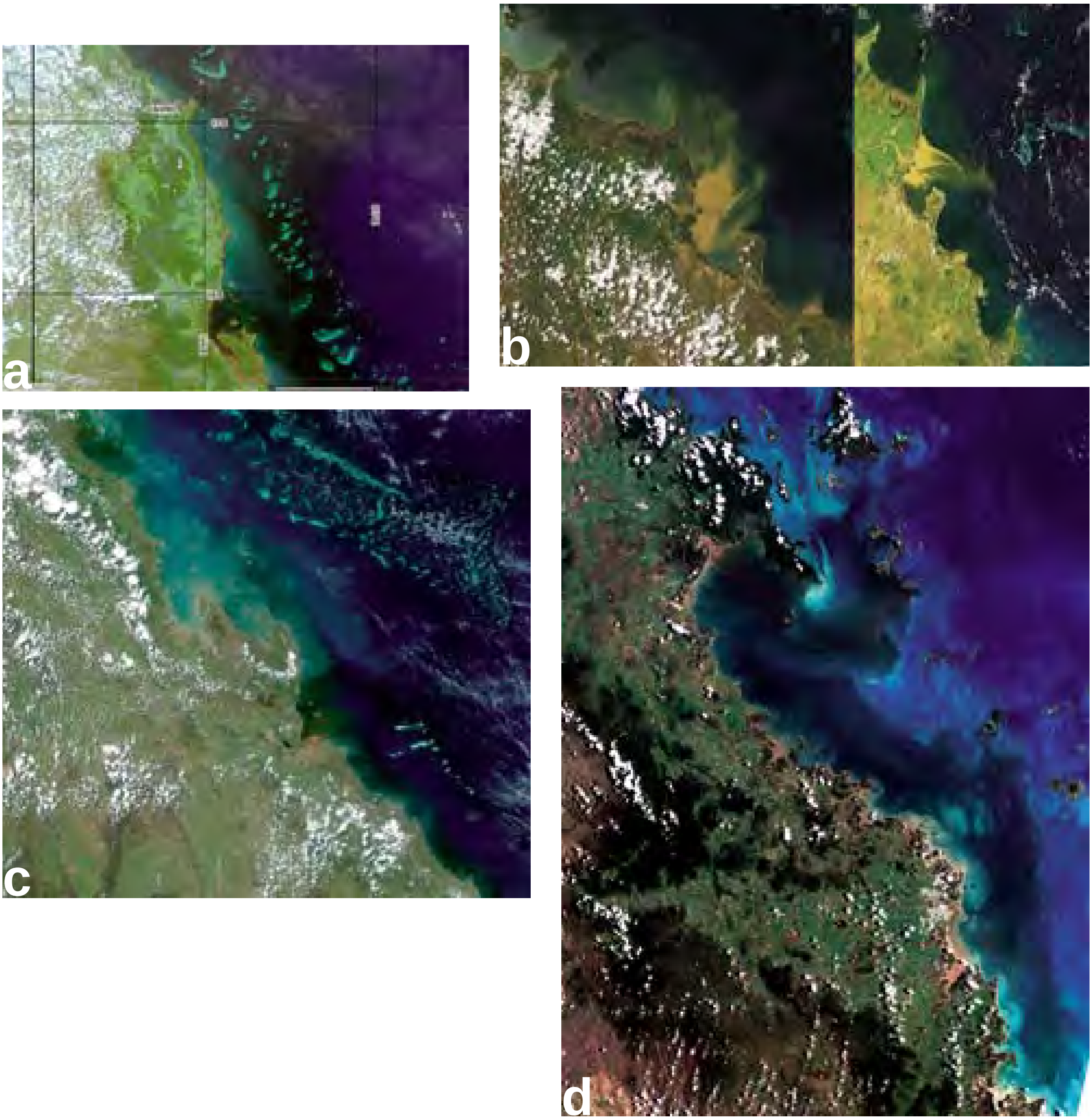

Figure 2. Satellite images of the GBR coast in flood conditions in a) Burdekin and Wet Tropics rivers in 2007 (MODIS image, 13 February 2007: CSIRO); b) Burdekin River in 2005 (MODIS image, 28 and 29 January 2005: CSIRO); c) Fitzroy River in 2008 (MODIS image, 22 February 2008: ACTFR); d) Mackay Whitsunday Rivers in 2005 (Landsat (7) image, 2005: NRW).

2.b.ii. Pesticides are present in the GBR.

As most of the pesticides of concern to marine ecosystems mix conservatively during flood plumes, the concentration in marine waters is closely related to the concentration discharged from the river (Rhode *et al.,* 2006a). Pesticides have recently been recognised as a greater potential threat to GBR ecosystems (mangroves, wetland plant communities, seagrass, coral reefs, phytoplankton communities) than was realised before 2003. Pesticide residues, especially herbicides, are ubiquitous in many GBR region waterbodies including streams, wetlands, estuaries, coastal and reefal waters (e.g. Packett *et al.,* 2005; Rohde *et al.,* 2006a; Faithful *et al.,* 2007; Lewis *et al.,* 2007a). In marine waters, residues at biologically active concentrations have been found up to 60 km offshore (Rohde *et al.,* 2006a) in the wet season and in low but detectable concentrations in the dry season (Shaw and Muller, 2005; Prange *et al.,* 2007).

2.b.iii. Contaminants may have long residency times in the GBR lagoon.

The GBR Lagoon is a system that receives contaminant inputs, moves these around, stores some of it by burying it or incorporating it into living matter, transforms some of the material and ultimately exports the remainder. Our understanding and ability to model transport processes including currents and mixing which are responsible for transporting contaminants is relatively well understood (Webster *et al.,* 2008a). Hydrodynamic models have been developed on the scale of the GBR Lagoon to predict water movement (Legrand *et al.,* 2006; Lambrechts *et al.,* 2008) and investigate the fate of flood plumes (King *et al.,* 2002) and to examine exchange times through the year (Luick *et al.,* 2007). Most sediment is trapped near the coast (Orpin *et al.,* 2004; Devlin and Brodie, 2005) and hence has decadal residence times in the GBR lagoon. Dissolved nutrients are dispersed more rapidly and may be trapped in the lagoon by biological uptake and persist in this particulate form for years (Furnas *et al.,* 2005). Most pesticide residues have short residence times (at most a few years) due to their chemical breakdown (Haynes *et al.,* 2000).

Smaller-scale hydrodynamic models have been used to estimate current transport and mixing of contaminants in Keppel Bay (Herzfeld *et al.,* 2006). Cross-shelf mixing, which is important to move contaminants from the coast out to mid-shelf reefs, has been measured indirectly using radium isotopes (Hancock *et al.,* 2006) and salinity (Wang *et al.,* 2007).

Hydrodynamic modelling of the GBR Lagoon has recently been reviewed in a study of the adequacy of existing receiving water models for the GBR (Webster *et al.,* 2008a). It was concluded that while hydrodynamic modelling is in a moderately advanced stage, the applications of fine-sediment and biogeochemical models are much more limited. These latter models are more complex and much more difficult to calibrate and verify than hydrodynamic models. Process studies are needed to support their development as well as data collection strategies that can be used for calibration and validation. Studies and analyses designed to address these issues are required to understand both the acute and chronic impacts of contaminants on the GBR Lagoon and how reducing catchment loads might provide benefits to the biogeochemical and ecological function of the GBR.

2.b.iv. Large river discharge events ('floods') are the major delivery mechanism of land-derived contaminants to the GBR.

The highest concentrations of land-based contaminants are found in GBR waters during flood plume events. Concentrations of dissolved inorganic nitrogen (nitrate and ammonium), suspended sediment, dissolved inorganic phosphorus are found at levels many times those in non-flood conditions, including upwelling offshore waters (Devlin *et al.,* 2001; Furnas, 2003; Devlin and Brodie, 2005; Rohde *et al.,* 2006a, 2008; Packett, 2007) and many times the concentrations that would have occurred in these river plumes before catchment development. Pesticide residues, especially herbicides, are almost ubiquitous in GBR estuaries, coastal and reefal waters (e.g. Packett *et al.,* 2005; Rohde *et al.,* 2006a; 2008; Faithful *et al.,* 2007; Lewis *et al.,* 2007a). In marine waters, residues at biologically active concentrations have been found up to 60 km offshore (Rohde *et al.,* 2006a; 2008) in the wet season flood plume conditions.

Most of the sediment discharged from rivers, especially the coarser fraction, is deposited and trapped on the shelf close to the river mouth. This has been clearly shown for the Fitzroy River (Bostock *et al.,* 2007; Ryan *et al.,* 2007) and the Burdekin River (Orpin *et al.,* 2004). Subsequently to deposition, sediment is resuspended by tidal and wind driven currents and carried northward by the long shore current and eventually trapped in northward facing bays (Lambeck and Woolfe, 2000). However, a small proportion (13%) of riverine sediment output is delivered across the shelf to the Coral Sea (Queensland Trough) (Francis *et al.,* 2007).

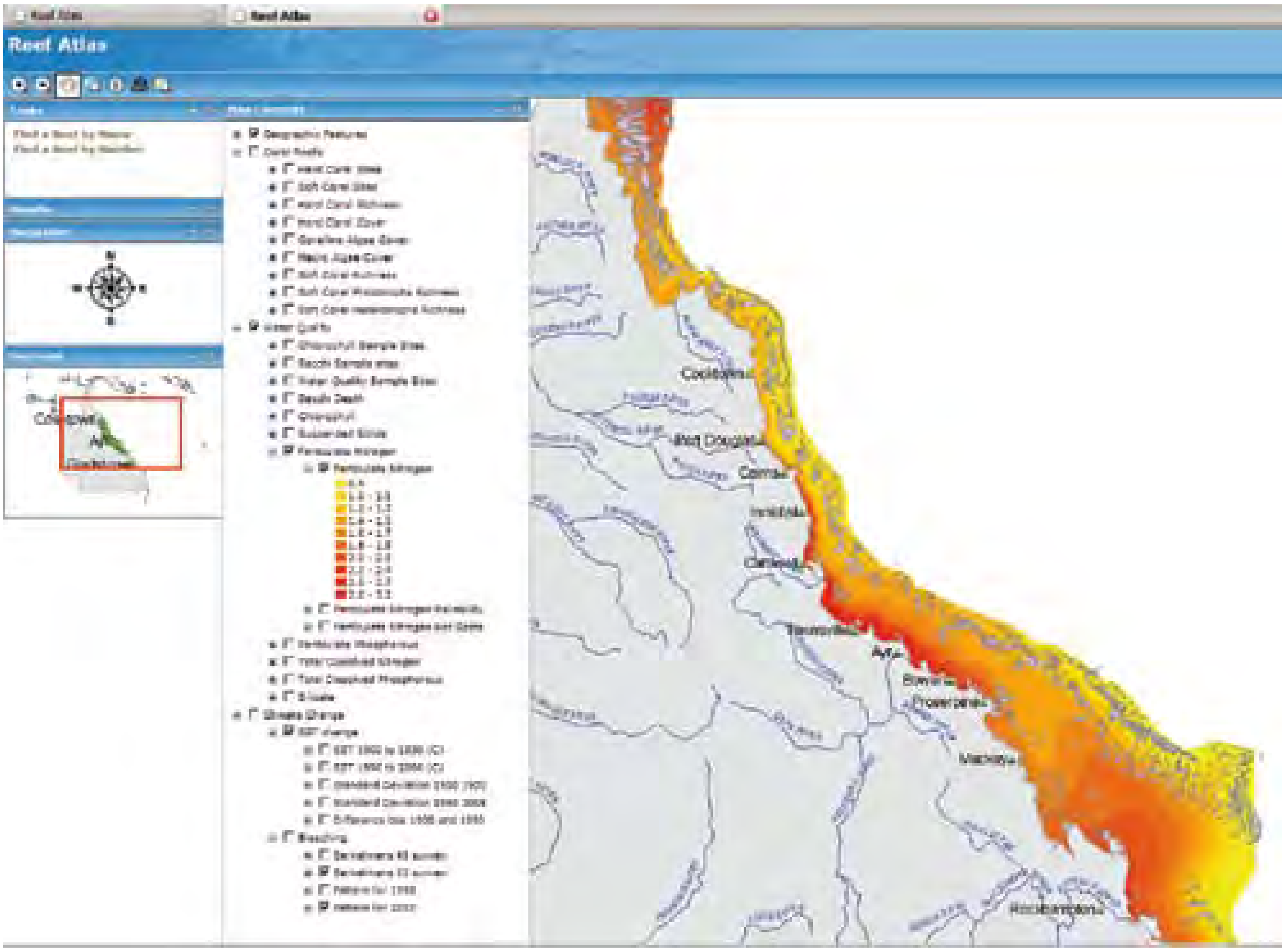

Figure 3. Map of the spatial distribution of particulate nitrogen in the GBR (De'ath and Fabricius, 2008).

2.b.v. Correlations exist between river discharged material and GBR lagoon water quality.

Nutrient loads can be related to chlorophyll concentrations in marine waters. Results from chlorophyll a monitoring in the GBR lagoon show that chlorophyll a is currently (1991–2006) low (mean 0.2 μg/L) in Cape York inshore waters and higher (0.3–0.7 μg/L) in central and southern GBR inshore waters (Brodie *et al.,* 2007b). The assumption is that inshore central and southern waters have increased in chlorophyll concentrations due to enhanced nutrient inputs from a position similar to Cape York waters more than 100 years ago. Offshore concentrations of chlorophyll also vary from south to north, but insufficient evidence exists to indicate that this is directly related to terrestrial influence over external factors such as upwelling, currents and tidal mixing.

Water quality data from the GBR lagoon have been spatially analysed and integrated into a series of maps (De'ath, 2005; De'ath and Fabricius, 2008), which are being made available through the Marine and Tropical Science Research Facility (MTSRF) Risk Resilience and Response Atlas. The maps show the spatial distribution of mean concentrations of all major water quality parameters, indicating distinct areas of long-term elevated concentrations of particular parameters (Figure 3 shows particulate nitrogen distributions, and Figure 4 shows spatial distribution of water quality variables across the six NRM regions).

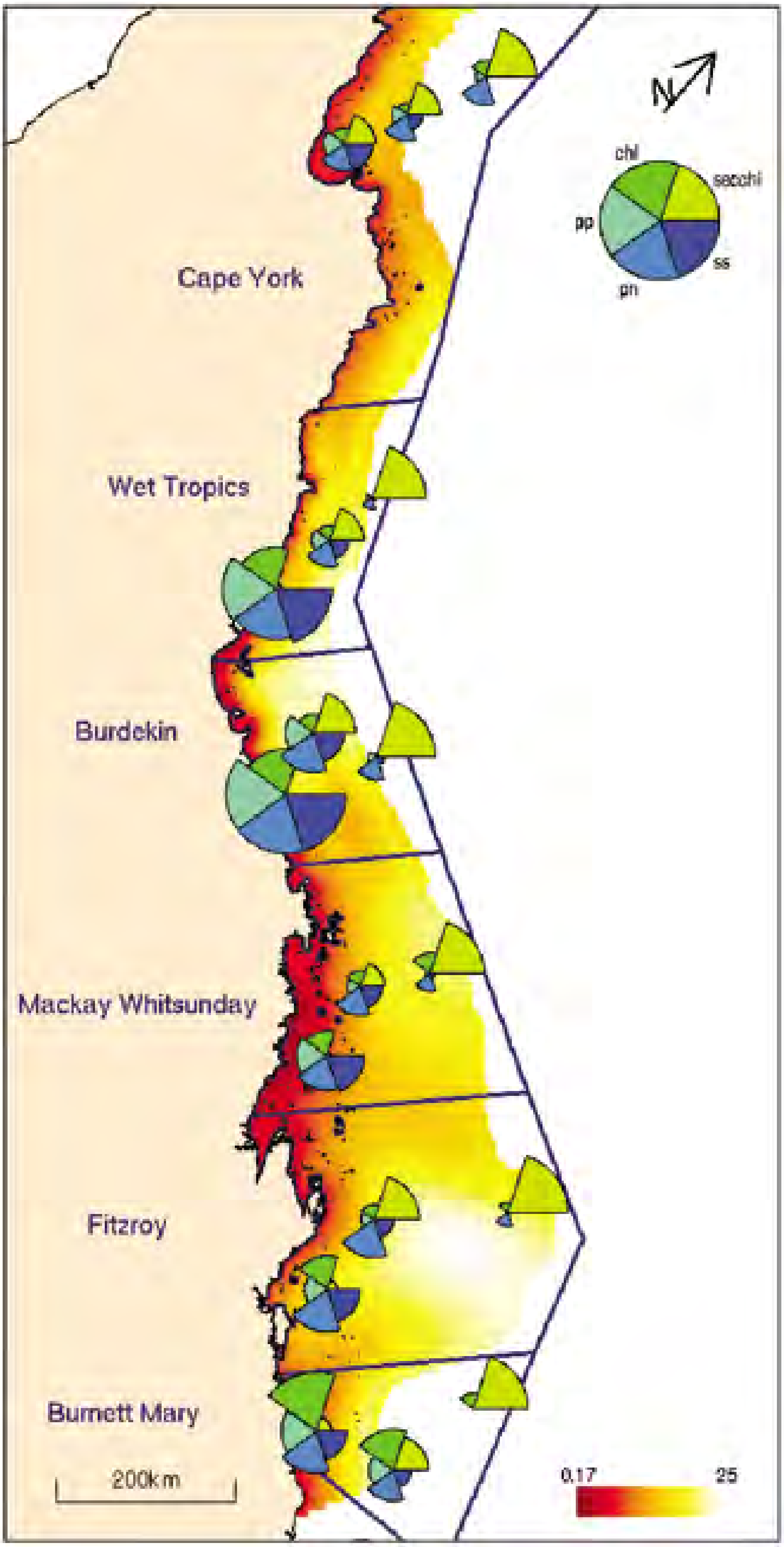

Figure 4. Map of the spatial distribution of water quality variables across the six NRM regions, for coastal (0–0.1 relative distance across), inshore (0.1–0.4 relative distance across), and offshore waters (0.4–1.0 relative distance across) (from De'ath and Fabricius, 2008). The colour ramp represents Secchi disk depth, the pie charts the mean values for each of the 18 NRM × cross-shelf regions of: chl = chlorophyll, Secchi = Secchi disk depth, ss = suspended solids, pn = particulate nitrogen, and pp = particulate phosphorus. Of note are the high concentrations of ss, pn and pp in the Burdekin and Wet Tropics regions, and the high chlorophyll values in the Burnett Mary region and the low values in the coastal regions of Cape York.

The fate of nutrients following the cessation of flood plumes is not clear-cut. High DIN concentrations in plumes are associated with elevated phytoplankton concentrations (Wooldridge *et al.,* 2006; Devlin and Brodie, 2005). What is less well understood, is how the discharge of nutrients might cause a chronic impact on inshore reefs. Dissolved nutrients will be carried and mixed by currents, but some will fuel the growth of sessile organisms such as micro- and macroalgae and so be retained by the system. Nutrients associated with particles will follow dynamics of settling, resuspension, burial, and diagenesis processes that might ultimately release these nutrients in forms suitable for plant growth. Measurements in Keppel Bay suggest that ~1/3 of the input particulate nitrogen and phosphorus is buried in sediments, presumably in refractory form (Radke *et al.,* 2006). Further, the biogeochemical modelling work in Keppel Bay (Robson *et al.,* 2006a) suggested a significant missing source of bioavailable nitrogen was necessary in Keppel Bay in order to close the budget of this nutrient. Laboratory experiments on sediment cores collected from the bay suggest that the source may have been benthic nitrification (Radke *et al.,* 2006). For phosphorus, river inputs appear to be retained close to the coast in the central GBR and phosphorus inputs due to upwelling events are a greater contribution to shelf phosphorus budgets than local river inputs over an average year (Monbet *et al.,* 2007).

Recent research by Wallace *et al.,* (2007) has also raised questions regarding the fate of the dissolved organic nitrogen (DON) fraction of the nitrogen load from agriculturally developed catchments of the GBR catchment area. DON was previously considered to be relatively refractory and non-bioavailable on a very limited theoretical basis. However, DON is a large component of the nitrogen load in many rivers and the degree of its bioavailability will be a critical factor in assessing the risk to both fresh and marine ecosystems from nitrogen driven eutrophication. In addition, the bioavailability of particulate nitrogen and phosphorus needs to be further investigated in the GBR catchments and lagoon.

Fine sediments introduced to the GBR lagoon by flood events undergo cycles of settling and resuspension by the winds and tides and can be dispersed far from the river mouth. Larcombe and Woolfe (1999) argue that chronic turbidity at coral reefs due to suspension of fine sediments by tides and winds will not be significantly affected by changes in sediment inputs due to catchment management since the sediments pool in the lagoon is large. Measurements in Keppel Bay (Radke *et al.,* 2006) suggest that there is a relationship between turbidity and river discharge of sediment suspended associated with flood events. In the mouth of the Fitzroy Estuary, where suspended sediment concentrations show a strong tidal cycle, these concentrations are higher in the period following riverine inputs than later in the year when riverine inputs have ceased for six months. It would appear that freshly introduced sediments are more readily suspendable. Later, much of this suspendable sediment moves into zones where it is less readily suspended, such as in northern facing bays or in the tidal creeks. Fine-sediment transport is very difficult to model effectively. The question as to whether increased suspended sediment loads from increased erosion from agricultural and urban development in major rivers lead to increased regional turbidity generated by resuspension in inshore areas of the GBR lagoon (with depths generally less than 10 m) is also being examined in a current Marine and Tropical Sciences Research Facility (MTSRF) research program. Initial results from the Tully and Burdekin regions suggest there is a period of increased turbidity for several months following each flood plume event (Wolanski *et al.,* 2008).

Pesticide concentrations in plume waters are directly correlated to pesticide concentrations in river discharge as the main process affecting plume concentrations is dilution. This notion is best supported by the information on mixing curves investigated in the Mackay Whitsunday region (Rohde *et al.,* 2006a).

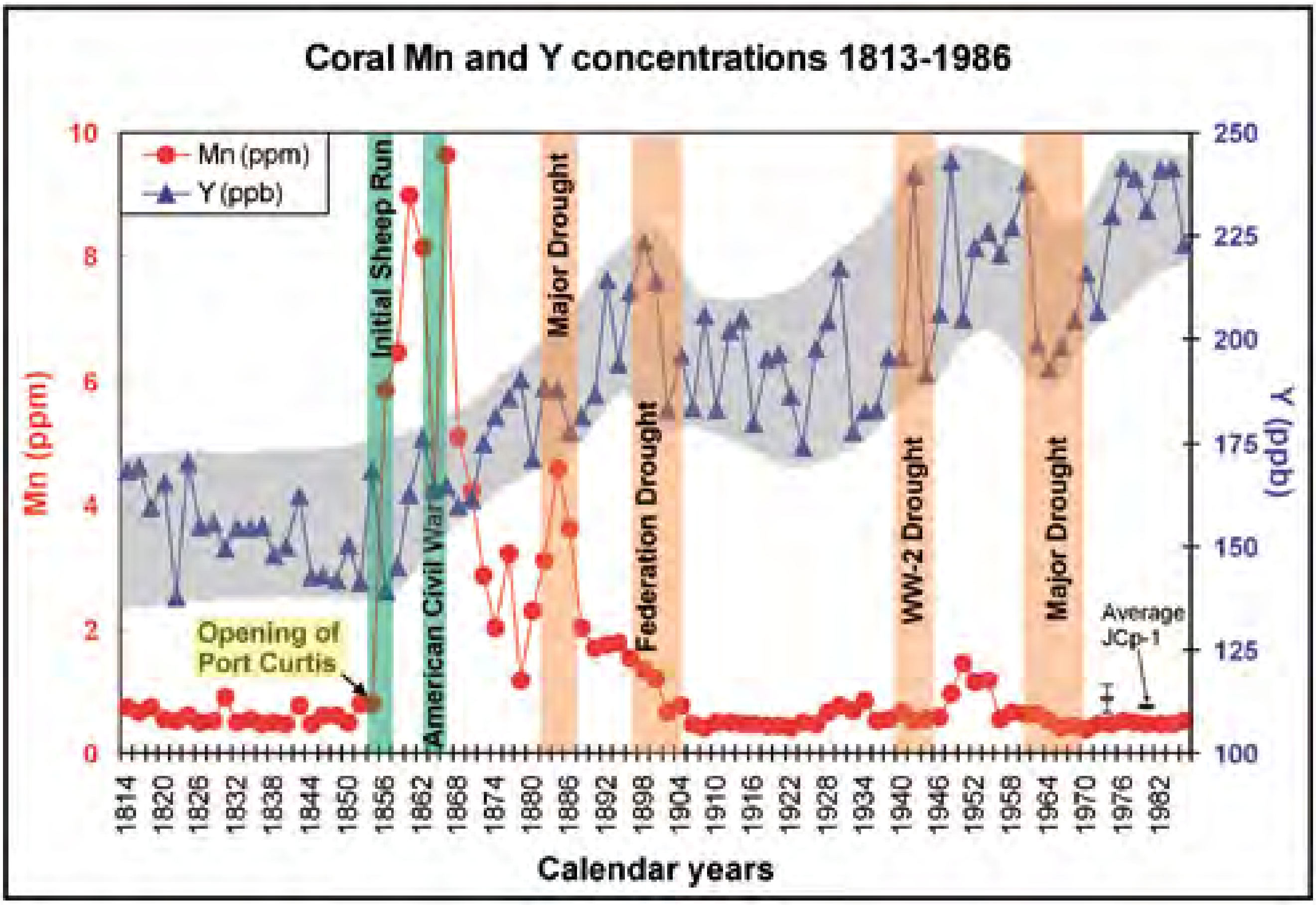

Figure 5. Mn and Y concentrations in the coral core from 1813–1986. Yttrium concentration, like Ba, is interpreted to be an erosion indicator, steadily increasing after 1860–70. Manganese defines a different history. Elevated Mn concentrations coincide with major land settlement in the Burdekin catchment. The initial Mn spike in 1855–1856 is related to the establishment of the first sheep run in the southern Burdekin catchment. The peak Mn concentration coincides with the end of the American Civil War and the climax of rapid expansion of the sheep industry in the Burdekin catchment. The second major Mn peak in 1883–1884 coincides with, and may thus be related to, the expansion of the cattle industry or the beginning of the sugarcane industry on the lower Burdekin catchment. The return of Mn concentrations to pre-1850 levels coincides with the Federation Drought, which devastated sheep and cattle numbers throughout the catchment. An increase in Mn after World War II may be related to the further development of the cattle industry. Reproducibility of Mn by our method is shown for the (slightly heterogeneous) G.S.J. coral standard JCp-1. Also shown for comparison, are average and standard deviation of Mn in a mid-Holocene coral recovered from Nelly Bay, Magnetic Island. Source: Lewis *et al.,* (2007b).

2.b.vi. Temporal changes are observed in contaminants in GBR waters.

Increasing concentrations of suspended sediment (TSS), dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP) are evident in the only long-term repeated sampling program in the GBR lagoon for nutrients – the Cairns transect of Miles Furnas (AIMS). Concentrations of TSS increased from 1.6 to 3.7 mg/L, DOP from 1.1 to 16 µg/L and DON from 68 to 91 µg/L in the period 1989 to 2005 (Furnas *et al.,* 2005). At Low Isles, Secchi disc transparency has almost halved from 11 in 1928 (during a 1-year study by the British Museum field expedition), to 6 m during current measurements (Wolanski *et al.,* 2004).

The use of coral cores to show the presence of a 'terrestrial signal' in the GBR, and hence changes in the delivery of materials from the land to the GBR with catchment development, are now well established. For example, the ratio of barium to calcium in corals offshore from the Burdekin River indicated a five- to ten-fold increase in suspended sediment loads following European settlement of the Burdekin catchment. This has been interpreted as indicating a large increase in erosion and delivery of suspended sediment to the mouth of the Burdekin River, where the barium adsorbed onto the sediment desorbs and is taken up by the coral. The barium replaces calcium in the coral structure, resulting in an altered ratio of Ba/Ca indicative of a land-based influence (McCulloch *et al.,* 2003b; Lewis *et al.,* 2007b). Other metals including yttrium and manganese, which are used as indicators of erosion and land settlement, also show changed concentration in coral cores after 1860 (Lewis *et al.,* 2007b). Figure 5 shows an example of results from Magnetic Island in the Burdekin region.

Additional proxies in coral cores of past water quality conditions are currently being developed (Alibert *et al.,* 2003; Wyndham *et al.,* 2004; Sinclair, 2005; Marion *et al.,* 2005). Changes in the amount of water discharged due to vegetation change/loss and soil compaction in catchments have also been investigated using coral cores, and some dispute currently exists over the interpretation of this record (McCulloch, 2006; Lough, 2007).

Increases in nitrogen delivery, up to four-fold, have also been demonstrated from coral cores off Mackay associated with increasing fertiliser use for sugarcane cultivation in the Mackay region (Jupiter *et al.,* 2007; Marion, 2007).

2.c. Key uncertainties related to presence, nature and extent

The following points summarise the key uncertainties associated with knowledge related to the presence, nature and extent of land-derived contaminants in the GBR:

- Our conceptual and quantitative understanding of the transport and fate of nutrients and sediments is highly imperfect, particularly during non-flood times.
- Hydrodynamic models of the GBR Lagoon are moderately advanced, but models of the transport and fate of fine sediments and biogeochemical models are much more limited. Process studies as well as data collection strategies that can be used for calibration and validation are needed to support their development. Current models need to link end of river to specific reef locations.
- Satellite images and flood plume monitoring suggest that some suspended sediment is transported over large distances in the marine environment during major discharge events. However, knowledge is limited of the specific origin of this presumably fine-grained, washload (non-settling) suspended sediment, and how geology, soil type and land management practices interact to produce it.
- While all terrigenous sediments and pesticides are land-derived, some of the dissolved nutrients are sourced from deepwater upwelling and from nitrogen fixing blue-green algae. Improved nutrient budgets are needed to quantify the relative contributions of all sources.
- Processes beyond gauging stations are poorly understood (i.e. what is entering the coastal/estuarine interface and material transformation in estuaries).
- It is unclear whether increased suspended sediment loads due to increased erosion from agricultural and urban development in major rivers leads to increased regional turbidity from resuspension in inshore areas of the GBR lagoon.
- Improved availability of high frequency, low cost data through the application of innovative monitoring techniques such as remote sensing will enable more comprehensive assessment of the presence and extent of contaminants in the GBR.

3. Review scientific evidence for causal relationships between water quality change and ecosystem health

Conclusion: There is strengthened evidence of the causal relationship between water quality and coastal and marine ecosystem health.

Our understanding of the effects of land-sourced contaminants on GBR species and ecosystems has been expanded enormously in the period since 2003. However, the size of the system and its temporal variability means that 'representative' monitoring and measurement of conditions in the water column and of ecosystem condition is difficult. The impacts of water quality on corals have been demonstrated through laboratory and field studies and data synthesis and integration has enabled the development of trigger values/thresholds of corals to water quality parameters. Knowledge related to the impacts of water quality on seagrasses has been synthesised. Efforts to understand the synergistic effects of multiple stressors on corals and seagrasses have commenced. However, the complexity of the relationship between nutrient enrichment, coral reef decline, macroalgal proliferation, grazing fish abundance (and other grazers) still prevents there being a clear consensus view on these relationships.

3.a. Lines of evidence

3.a.i. Seagrass.

There is evidence of decline in seagrass health with increasing concentrations of herbicides. The effects of nutrient enrichment, turbidity, increased temperature and synergistic effects are still poorly understood, especially for sub-tidal and deep-water seagrass beds.

3.a.ii. Coral reefs.

The impacts of water quality on corals has been demonstrated through both field studies and laboratory experiments. Field studies have shown that:

- Macroalgae increase and coral richness declines with increasing turbidity and chlorophyll in the GBR (Lat 12–24º S).
- Links between nutrient enrichment and crown-of-thorns starfish population outbreaks are now well supported. Both the GBR and other reefs off high islands exposed to terrestrial nutrient enrichment, and northern Pacific systems exposed to non-anthropogenic nutrients show increased propensities for outbreaks of crown-of-thorns starfish.
- Coral reef development diminishes along a water quality gradient in the Whitsunday Islands. Changes include the decline in the depth limit for coral growth from 25 m to 5 m water depth and a three-fold decline in the density of young corals, while the density of coral-boring macro-bioeroders increases five-fold and macroalgal cover increases six-fold along this water quality gradient.
- Coral cores from reefs off Mackay show that increasing exposure to nitrogen from the Pioneer River is correlated with poor reef condition and high macroalgal cover.
- Inshore reefs off the Wet Tropics have lower coral and octocoral diversity than would be expected from their latitudinal location.

Laboratory studies have shown that:

- Stress and mortality in corals exposed to sedimentation increases with increasing organic content of the sediment.
- Coral calcification decreases with elevated phosphate concentrations.
- The presence of muddy marine snow (aggregates of planktonic organic matter and fine sediment) increases sedimentation stress and mortality in coral recruits.
- Many pesticides found in the GBR exert detrimental effects on zooxanthellae photosynthesis and coral reproduction at trace concentrations.
- There are negative synergistic effects between herbicides and sediments on crustose coralline algae that are essential for successful coral recruitment.

3.a.iii. Mangroves.

There is conflicting evidence concerning the cause of mangrove dieback in the Mackay region. Early research attributed an association with diuron, but affected mangroves have recovered despite diuron levels remaining high at some sites. This suggests that the complexities of cause and effect relationships for such diebacks are yet to be fully resolved.

3.b. The evidence base

3.b.i. Seagrass.

The distribution and growth of seagrasses is dependent on a variety of factors such as temperature, salinity, nutrient availability, substratum characteristics, and underwater light availability (turbidity). Terrigenous runoff, physical disturbance, low light and low nutrients, respectively, are the main drivers of each of the four seagrass habitat types found in Queensland and changes to any or all of these factors may cause seagrass decline (Waycott *et al.,* 2005).

The most common cause of seagrass loss is the reduction of light availability due to chronic increases in dissolved nutrients which leads to proliferation of algae, thereby reducing the amount of light reaching the seagrass (e.g. phytoplankton, macroalgae or algal epiphytes on seagrass leaves and stems), or chronic and pulsed increases in suspended sediments and particles leading to increased turbidity (Schaffelke *et al.,* 2005). In addition, changes of sediment characteristics may also play a critical role in seagrasses loss (Mellors *et al.,* 2005).

Herbicides (principally diuron) have been found in coastal and intertidal seagrasses adjacent to catchments with high agricultural use at levels shown to adversely affect seagrass productivity (McMahon *et al.,* 2005; Haynes *et al.,* 2000). For example, diuron toxicity trials on three tropical seagrass species (Halophila ovalis, Cymodocea serrulata and Zostera capricorni) using Pulse-Amplitude-Modulated (PAM) fluorometry indicated that environmentally relevant levels of diuron (0.1–1.0 µg/l) exhibited some degree of toxicity to one or more of the tested seagrass species (Haynes *et al.,* 2000). These are comparable with diuron concentrations detected in several GBR regions (Prange *et al.,* 2007). Seagrasses are known to accumulate heavy metals, but appear to be moderately resistant to the direct effects of metals. However, the fauna associated with seagrass meadows is considered to be highly sensitive to metal exposure (Ward, 1989).

The effects of nutrients on GBR seagrass health have proved more complex to understand but it is now clear that the effects are different to those shown for temperate seagrass and the threat from increased nutrients may be less in tropical cases (Mellors *et al.,* 2005; Schaffelke *et al.,* 2005; Waycott *et al.,* 2005). To date, no major decline in seagrass abundance in the GBR region has been recorded or attributed directly to increased nutrient availability, though localised declines have occurred in the Whitsunday and Hervey Bay areas. In both cases, light deprivation was implicated, by (i) algal overgrowth caused by nutrient enrichment from sewage effluent (Campbell and McKenzie, 2001) and (ii) smothering by settling particles and high suspended particle load from flood plumes (Campbell and McKenzie, 2004; Preen *et al.,* 1995; Longstaff and Dennison, 1999).

The presence of high or low concentrations of nutrients in the environment is one of the stressors on seagrass survival. Field research to date in the GBR suggests that nutrients do not have a negative effect on seagrass growth and distribution, as reported in temperate regions (Mellors *et al.,* 2005). On the contrary, Udy et al. (1999) observed an increase in seagrass cover at Green Island between 1936 and 1994, and attributed this increase to a net increase in the total nutrient pool available over 50 years of gradual build-up of nutrients in the Cairns region. Recent data on seagrass tissue nutrient content (*Halophila ovalis*) collated by Mellors (2003) and Mellors *et al.,* (2005) in Cleveland Bay shows an increase in tissue nutrients over a 25-year period, which circumstantially reflects increases in fertiliser usage in the adjacent Burdekin catchment.

Direct effects of higher nutrient availability on seagrass have been observed in laboratory experiments. Moderate levels of nitrate additions (3.5 to 7.0 µM) promoted the decline of the temperate seagrass species *Zostera marina* (Burkholder *et al.,* 1992; Short *et al.,* 1995). Increased levels of ammonia (1.85–5.41 µM) and phosphate (0.22–0.50 µM) lead to a reduction in shoot density and biomass of Z. *marina* (Short *et al.,* 1995). The concentrations measured in water samples taken in flood plumes have consistently recorded elevated dissolved inorganic nitrogen concentrations of 0.6 to 10 µM and phosphate levels of 0.13 to 1.98 µM (Brodie and Mitchell, 1992; Steven *et al.,* 1996; Brodie and Furnas, 1996; Devlin *et al.,* 2001). These nutrient levels have remained high in the inshore lagoon for periods of several days to weeks. Approximate ranges for (non-flood) inshore water nutrient concentrations have been measured between non-detectable and 2 µM for dissolved inorganic nitrogen (predominantly ammonia) and non-detectable and 0.2 µM for phosphate (Furnas *et al.,* 1995; Brodie and Furnas 1996; Devlin *et al.,* 1997).

Other studies have shown that in the GBR seagrass growth is limited by nitrogen (Udy *et al.,* 1999; Mellors, 2003). Both studies assessed the response of seagrass to enhanced nutrient levels and saw a response to both nitrogen and phosphorus, but nitrogen was the primary limiting element. Thus, at present, seagrasses have the capacity to absorb additional nutrients enhancing their growth and it would appear that the current nutrient loadings in the GBR have not yet reached critical levels for seagrasses. However, the limits of the ability of seagrasses to continue to absorb nutrients is not known and additional experiments on interactions between sedimentation, nutrients, light and temperature as other important drivers of plant growth are required. In addition, nutrient analyses have been conducted primarily on the smaller more ephemeral species. Larger more persistent species may be more sensitive to additional nutrients in this region and this should be assessed (CRC Reef Consortium, 2005).

The Reef Plan Marine Monitoring Program includes a seagrass monitoring component, which involves monitoring of intertidal seagrass meadows at 14 sites along the GBR coast for percent cover, species composition, reproductive health (through seedbank monitoring) and seagrass tissue nutrient status. Seagrass surveys are undertaken at the end of winter in October and following the wet season in April. Additional information is also collected on sediment pesticide and absorbed nutrient concentrations within seagrass meadows and seagrass tissue nutrients (Prange *et al.,* 2007). This task is assisted by the community-based Seagrass-Watch program (www.seagrasswatch.org).

3.b.ii. Corals.

Corals and water quality – field studies.

Strong links between coral reef health and water quality conditions have been shown at local scales (reviewed in Fabricius, 2005), at regional scales (van Woesik *et al.,* 1999, Fabricius *et al.,* 2005), and recently at a GBR-wide scale (De'ath and Fabricius, 2008). The effects of corals have been most frequently studied and effects of water quality on coral reproduction have been reported repeatedly. However, abundances of a range of other reef associated organisms have also been shown to change along water quality gradients. Figure 6 summarises the results of a review of existing reef studies from around the world to identify the main effects of nutrient and sediment related parameters on key coral reef organism groups. The data suggests that nutrient enrichment can lead to macroalgal dominance if light levels are sufficient, but lead to a dominance by heterotrophic filter feeders if light becomes a limiting factor for macroalgae (Johannes *et al.,* 1983; Birkeland, 1988). It also shows that crustose coralline algae, which are essential settlement substratum for coral larvae, are negatively related to sedimentation (Fabricius and De'ath, 2001), as later confirmed by laboratory experiments (Harrington *et al.,* 2005).

Studies where the predicted ecological effects of poor water quality (elevated delivery and/or concentrations of suspended sediment, nutrients or pesticides) have been borne out in the field in the GBR include:

- Deepest depth of coral growth reduced from 25 m to 5 m depth, the number of young corals decreased three-fold, the density of coral-boring macro-bioeroders increased five-fold and macroalgal cover increased six-fold along a water quality gradient in the Whitsundays (Cooper and Fabricius, 2007, Fabricius *et al.,* 2008, Cooper *et al.,* 2008).
- Poor reef condition correlated with poor water quality conditions in Wet Tropics inshore reefs compared with reefs in similar physical locations near Cape York, but which have good water quality (Fabricius *et al.,* 2005).
- A sag in coral biodiversity in the region between Townsville and Cooktown correlated with poor water quality conditions in this area (Devantier *et al.,* 2006).
- Links between nutrient enrichment and crown of thorns starfish population outbreaks are now well supported in both anthropogenically enriched systems such as the GBR (Brodie *et al.,* 2005) and naturally enriched systems such as the northern Pacific (Houk *et al.,* 2007).
- Reduced coral reef development in a water quality gradient through the Whitsunday Island group (van Woesik *et al.,* 1999).
- A raft of physiological changes in corals have been documented along a water quality gradient in the Whitsunday Island group (Cooper and Fabricius, 2007). These sub-lethal changes are now being developed into a bioindicator system to investigate changes in the water quality conditions and ecological status of inshore coral reefs.
- The species composition of foraminifera (the ration between large, symbiont bearing and small, heterotrophic foraminifera) is being developed into a bioindicator system for the GBR. The Foraminifera in Reef Assessment and Monitoring Index metric, previously developed for coral reefs in the Caribbean, shows a relationship with water quality conditions along the Whitsunday water quality gradient (Uthicke *et al.,* 2006; Uthicke and Nobes, 2007).
- The delivery of nitrogen from the Pioneer River to coastal reefs in the Mackay area as shown through coral core records is correlated with poor reef condition in areas of higher nitrogen delivery and a high proportion of macroalgal cover (Jupiter *et al.,* 2007).

	Dissolved inorg. nutr	POM*	Light reduction	Sedimentation
Crutose coraline algae	↓			⬇
Bioeroders	↑	⬆		↓
Macroalgae	⬆	↑	⬇	↓
Heterotrophic filter feeders		⬆	⬆	↓
Coral diseases	↑			↑
Coral predators		⬆		

* including phytoplankton

Figure 6. Effects of the four main parameters of terrestrial runoff on organisms that interact with corals. High abundances crustose coralline algae as settlement substrata promote coral populations, whereas high abundances of the other groups are assumed to negatively affect coral populations. The arrows indicate the relative strength and direction of the response (arrows pointing up or down = increasing or decreasing, thick arrow = strong, medium = moderate, thin = weak effect); empty cells indicate that insufficient data are available. From Fabricius (2005).

While pollution effects on coral reefs at local scales are well understood, links at regional scales between increasing sediment and nutrient loads in rivers, and the broadscale degradation of coral reefs, have been more difficult to demonstrate (Fabricius and De'ath, 2004). This is due to a lack of large-scale historic data and the confounding effects of other disturbances such as bleaching, cyclones, fishing pressure and outbreaks of the coral eating COTS, and is further complicated by the naturally high variability in monsoonal river flood events. In addition, the relationship between macroalgal proliferation, nutrient enrichment and the abundances of grazers (fishes and invertebrates) is complex and far from understood, and subject to scientific debate (McCook, 1999; McCook *et al.,* 2001; Bellwood *et al.,* 2006; Hughes *et al.,* 2005; Littler *et al.,* 2006). The full extent of organism responses are poorly understood, as each of the numerous inshore species has its own tolerance limit at every life stage, and interactions between the organisms add to the complexity.

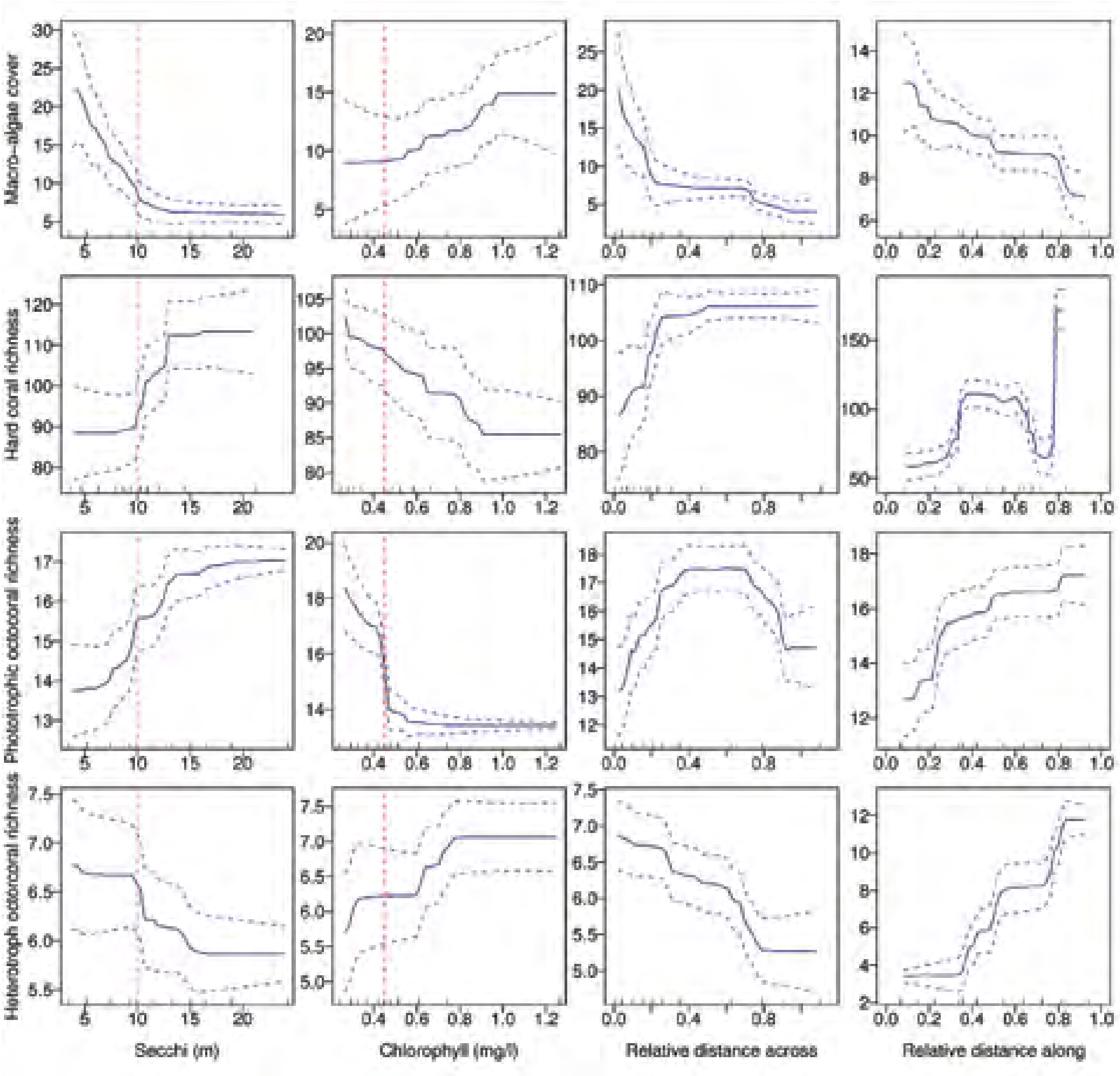

Figure 7. Relationship of macroalgal cover, and the taxonomic richness of hard corals, phototrophic and heterotrophic octocorals (soft corals and sea fans with and without zooxanthellae, respectively), along gradients in water clarity (measured as Secchi disk depth) and chlorophyll, while also controlling for relative distance across and along the shelf (from De'ath and Fabricius 2008). Substantial increases in macroalgal cover and losses in coral biodiversity are being observed at <10 m Secchi disk depth, and >0.45 µg L-1 chlorophyll. The red lines show the proposed water quality guideline values (10 m Secchi disk depth, and 0.45 µg L-1 chlorophyll).

However, recently relationships between data sets of water quality, and macroalgal cover and the richness of hard corals and phototrophic and heterotrophic octocorals, were investigated at a GBR-wide scale (De'ath and Fabricius, 2008). The study showed that the four biotic indicators chosen are significantly related to GBR water quality. Macroalgae increased and hard coral richness and the richness of phototrophic octocorals declined with increasing turbidity and chlorophyll, after cross-shelf and long-shore effects were statistically removed (Figure 7). Heterotrophic octocorals slightly benefited from high turbidity. Mean annual values of >10 m Secchi depth and <0.45 g L-1 chlorophyll were associated with low macroalgal cover and high richness of phototrophic octocorals and hard corals. The study suggested these values to be useful water quality guideline values. These guidelines are presently exceeded on 650 of the 2800 gazetted reefs of the GBR. The models showed that compliance with these guideline values (e.g. minimising agricultural runoff would likely reduce macroalgal cover by ~50% and increase hard coral and octocoral richness by 40% and 70%, respectively, on these 650 reefs). GBRMPA is in the process of refining the existing water quality guidelines that have previously been developed for three GBR regions (Moss *et al.,* 2005; De'ath and Fabricius, 2008; GBRMPA, 2008).

This synthesised information could support the completion of a comprehensive risk assessment for the ecosystems of the GBR that should include consideration of the relative risk of different contaminants to GBR ecosystems. Currently, the risk modelling (such as Maughan *et al.,* 2008; Wolanski and De'ath, 2005) assumes that all contaminants of concern are of equal risk, which is clearly not the case. This lack of knowledge prevents prioritisation of management options for each of the individual contaminants in the catchments, or at a cross-regional scale. To conduct a meaningful prioritisation, knowledge of the degree of deviation from some assumed 'natural' condition and elevation above trigger values/thresholds, and potential consequences of such enrichment need to be understood. Currently, contaminant management is prioritised based on deviation from assumed 'natural' only.

In terms of ongoing monitoring of coral reef health, the Reef Plan Marine Monitoring Program includes an inshore reef monitoring component. Annual underwater photographic surveys are undertaken along transects established at 35 inshore reef sites. These surveys are an effective way of monitoring benthic cover and reef community demographics. Coral settlement rates are also measured after the annual coral spawning (using settlement plates) in the Wet Tropics, Burdekin, Mackay-Whitsunday and Fitzroy regions. Adult corals can tolerate poorer levels of water quality than new coral recruits, thus one of the ways in which water quality is likely to impact reef communities is through an effect on coral reproduction and recruitment (Prange *et al.,* 2007).

Corals and water quality – laboratory studies.

A number of ecotoxicology-style experiments exist to investigate the effects of various contaminants on selected target organism groups. Such studies include the investigation of nutrients on corals (Koop *et al.,* 2001) and of sedimentation stress on corals (Philipp and Fabricius, 2003). Herbicides found in GBR waters have biological effects on coral zooxanthellae at concentrations below 1 µg/L (e.g. Jones and Kerswell, 2003; Jones *et al.,* 2003; Jones, 2005; Negri *et al.,* 2005; Markley *et al.,* 2007; Cantin *et al.,* 2007). The long-term effect on ecosystem performance of the continuous presence of such residues is not known, but evidence is emerging that some pesticides not only affect the photosynthesis of the endosymbionts but also coral reproduction (Jones, 2005; Negri *et al.,* 2005; Markley *et al.,* 2007; Cantin *et al.,* 2007). Lastly, first evidence is emerging that the existence of synergistic effects may have to be carefully considered in estimates of tolerance thresholds (and hence water quality targets). For example, sedimentation effects on crustose coralline algae are significantly worsened when trace concentrations of herbicides occur in the sediments (Harrington *et al.,* 2005). Other studies have demonstrated that sedimentation effects on corals worsen with increasing organic enrichment of the sediments (Weber *et al.,* 2006), and with enrichment with marine snow (Fabricius *et al.,* 2003; Wolanski *et al.,* 2003).

Though considerable knowledge has been gained from single species exposure experiments in the laboratory, it is important to relate such laboratory studies to field settings and ecosystem responses. Detailed surveys at relatively fine taxonomic resolution, when cautiously interpreted in the context of available biophysical environmental data and biological knowledge of key species, can provide important information on the health and status of inshore coral reefs (Fabricius *et al.,* 2005; Devantier *et al.,* 2006), and laboratory experiments may then be used to investigate causal relationships between water quality and the patterns observed in the field.

Recently, several conceptual models have been developed to articulate known relationships to better underpin monitoring programs and form the basis for numerical modelling (Prange, 2007; Webster *et al.,* 2008a; Haynes *et al.,* 2007; Fabricius, 2007).

3.b.iii. Mangroves.

The responses of marine plants (mangroves, seagrass and macroalgae) to changes in water quality in the GBR is reviewed in Schaffelke et al. (2005). The limited information of these responses limits the ability to make conclusions about responses across community types; however, there are clear indications that declining water quality negatively affects GBR macrophytes. In addition, loss or disturbance of habitat-building macrophytes such as mangroves and seagrasses has serious downstream effects for coastal water quality due to their capacity to assimilate nutrients and to consolidate sediments.

Mangrove responses to nutrients are complex, with examples of both enhanced growth and associated dieback found in locations outside of the GBR (e.g. Laegdsgaard and Morton, 1998; Environmental Protection Agency [EPA], 1998). As with the nuisance algae, nutrients enhance growth of mangrove plants. This has been demonstrated in nutrient enrichment experiments, which also showed that nitrogen and phosphorus were growth-limiting differently at lower and higher intertidal positions (Boto and Wellington, 1984). Nutrients derived from sewage discharge can be beneficial for growth and productivity of mangroves (Clough *et al.,* 1983). However, under high nutrient demand other chemicals, such as herbicides, may be taken up at greater rates along with extra nutrients (Duke *et al.,* 2003a). This synergistic effect of increased nutrients has resulted in the increased phytotoxicity of specific herbicides (Hatzios and Penner, 1982). High nutrient levels may also alter faunal communities that might affect the vulnerable trophic links between mangrove trees and fauna (Robertson *et al.,* 1992).

Increased sediment loads in runoff from catchments affect mangrove distributions within estuaries as well as water quality (Duke *et al.,* 2003b). In recent decades, there have been unprecedented gains in mangrove areas at the mouths of at least four GBR river estuaries, Trinity Inlet (Duke and Wolanski, 2001), Johnstone River (Russell and Hales, 1994), Pioneer River (Duke and Wolanski, 2001) and Fitzroy River (Duke *et al.,* 2003b). Although these rivers occupy a broad range of climatic and geographic conditions, they each have characteristic and significant new mangrove stands. At the mouth of the Fitzroy River, the area of mangroves had been relatively constant for a century but increased rapidly after the 1970s. The increases were correlated with concurrent human activities including increased clearing of vegetation in the catchment, which increased sediment loads in runoff, and the construction of a major river barrage, which reduced river flows and flushing.

An unusual species-specific dieback of Avicennia marina has been observed in the Mackay region since the mid-1990s (Duke and Bell, 2005; Duke *et al.,* 2005). By 2002, it was estimated that 97% of the A. marina trees in the Pioneer River estuary were affected by moderate to severe dieback (Duke *et al.,* 2003a). Laboratory studies have shown that mangroves are sensitive to the root application of atrazine, diuron and ametryn (Photosystem II inhibiting herbicides) and Avicennia marina is more sensitive than other mangroves tested (Bell and Duke, 2005). Although the Mackay dieback was associated with the levels of diuron and other herbicides present in mangrove sediments and pore water, and in stream/drain waters flowing into mangrove areas (Duke and Bell, 2005), two recent surveys of mangrove communities in the Pioneer River estuary have shown an overall improvement in the health of A. marina although herbicide levels in sediments and pore water have remained high at some sites (Wake, 2008).

The dieback has also been attributed to sedimentation (Kirkwood and Dowling, 2002).

These findings indicate that the causes of such diebacks require further investigation and the complexities of cause and effect relationships are yet to be fully resolved.

3.c. Key uncertainties related to causal relationships between water quality and ecosystem health

The following points summarise the key uncertainties associated with knowledge related to the causal relationships between water quality change and ecosystem health.

- While a limited number of models exist that attempt to link marine ecosystem health to end of catchment loads, further development is required as a matter of urgency to assess the influence of catchment management actions on GBR health in a comprehensive way.
- Synergistic effects of contaminants and external influences on GBR ecosystems.
- Definition of acceptable/desired thresholds for key indicators (i.e. coral, seagrass and biodiversity).
- Drivers of seagrass change and health, in particular the influence of declining water quality, especially nutrients and turbidity.
- The specific impacts of pesticides (particularly herbicides) on the GBR ecosystems. Presently there is a lack of toxicity data for organisms specific to the GBR. Much of the current research has been focused particularly on corals with comparatively little data on mangroves, seagrass and micro-organisms. In addition, the synergistic effects of mixtures of pesticides are relatively unknown, as well as the effects of long-term exposure.
- Understanding the response of estuarine systems to floods and the role of the coastal floodplain.
- Knowledge of the response of the GBR ecosystem to different events in different areas, and the ability to recover. Understanding the implications of combined scale and frequency of disturbance to GBR ecosystems.
- The relative risks to GBR ecosystems of individual terrestrial-sourced contaminants.
- The complexity of the relationship between nutrient enrichment, coral reef decline, macroalgal proliferation and abundances of grazing fishes (and other grazers) still prevents there being a clear consensus view on this specific relationship.

4. Review existing scientific evidence for a decline in the quality of water in GBR catchment waterways leading to reduced instream ecosystem health

Conclusion: The health of freshwater ecosystems is impaired by agricultural land use, hydrological change, riparian degradation and weed infestation.

Waterways of the GBR catchment include streams that drain forested uplands and the cultivated tablelands of the Wet Tropics, intermittent dry-land streams, lowland rivers and estuaries, and the lagoons and swamps of the floodplains. In the Wet Tropics, most systems are perennial, but in the Dry Tropics, streams and wetlands may be intermittent, and even large rivers may contract to isolated waterholes in the dry season.

Our understanding of the ecosystem health of GBR waterways has been greatly enhanced by recent reports on Wet Tropics streams (e.g. Arthington and Pearson, 2007) and floodplain waterways (Pearson *et al.,* 2005), and on the riverine waterholes and floodplains of the dry tropics (e.g. Perna and Burrows, 2005). The GBR catchments support high biodiversity and many endemic species of freshwater fish (Pusey *et al.,* 2004), some of the highest diversity of freshwater invertebrates in the world (Pearson *et al.,* 1986; Vinson and Hawkins, 2003; Pearson, 2005), and many species of aquatic plants (Mackay *et al.,* 2007).

While the diversity of information on catchment freshwater health is increasing, much work is unpublished. Recent reviews on within-catchment water quality and ecosystem health have focused on the Wet Tropics (e.g. Pearson and Stork, 2007; Connolly *et al.,* 2007a, 2007b; Pusey *et al.,* 2007; Faithful *et al.,* 2006); there has been less work on the Dry Tropics, highlighting an important information gap, although reports on the Burdekin and the Fitzroy systems are advancing our understanding of those systems.

4.a. Lines of evidence

4.a.i. Priority factors affecting instream ecosystem health are riparian vegetation condition, aquatic and riparian weed prevalence, vegetation removal and habitat loss.

These factors have been shown to be more important factors reducing instream ecosystem health than water quality per se.

4.a.ii. Concentrations of nutrients in fresh waters in many catchments are proportional to the area of land under agriculture.

Elevated nutrient inputs from agricultural sources are known to contribute to enhanced weed growth, vegetation change and associated changes in instream community structure.

4.a.iii. Agricultural development has led to substantial damage to riparian and wetland health in many catchments.

These influences have negative consequential effects on water quality and hence detrimental effects on instream biota.

4.a.iv. Concentrations of pesticides in waterways are highest in areas of intensive agricultural activity.

The implications of elevated pesticide concentrations for community structure in freshwater ecosystems are potentially severe but our knowledge is incomplete.

4.a.v. The condition of riverine waterholes in the Dry Tropics is largely determined by cattle access.

Cattle contaminate and disturb the waterholes causing deoxygenation from excretia, increased turbidity, and consequent loss of biodiversity.

4.a.vi. The condition and biodiversity of floodplain waterways are adversely affected by irrigation inputs and drainage.

Sediments, nutrients from fertilisers and organic material have been shown to lead to oxygen depletion, enhanced weed growth, turbidity and hence biodiversity loss.

4.b. The evidence base

4.b.i. Priority factors affecting instream ecosystem health are riparian vegetation condition, aquatic and riparian weed prevalence, vegetation removal and habitat loss.

As described in Section 1, water quality conditions in the GBR catchments in runoff events are reasonably well documented; water quality in the catchments through the non-event periods is much less well documented. It is this ambient or chronic water quality that is of greatest importance to the ecology of the rivers and wetlands, as opposed to the short-term events that appear to drive water quality in coastal waters. The relative importance of ambient inputs to coastal ecosystem processes is also not known.

However, the most serious factors affecting health in Wet Tropics streams and wetlands are changes to habitats, including invasion by exotic weeds and loss of riparian vegetation, which can cause major changes to waterway morphology, habitat complexity, food availability, gas exchange with the atmosphere and, therefore, biodiversity. Organic effluents have been shown to cause fish kills and a major decrease in biodiversity as a result of oxygen depletion; and deposition of fine sediments derived from agriculture and other sources reduce biodiversity in streams.

The multitude of human impacts that might affect catchment and GBR health is summarised in Figure 8. The most important of these potential impacts is land clearing (Pearson and Stork, 2007).

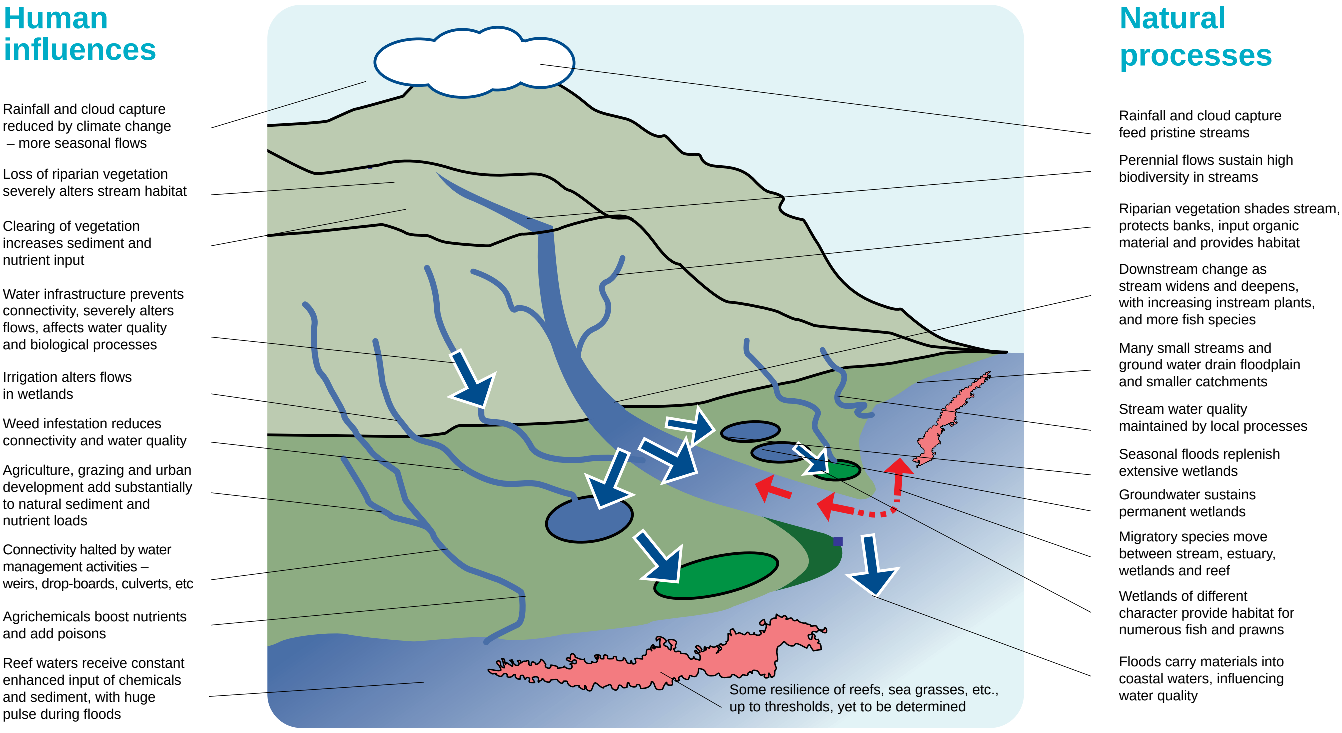

Figure 8. Outline of processes from catchment to reef (adapted from Pearson and Stork, 2007).

However, in the Wet Tropics, there is little available land left to clear, so the issue is more one of management of cleared land. Changing land use is a growing concern because, as climate changes and as the economics of particular crops changes, new land uses may bring problems that have not yet been experienced. Even the change in sugarcane harvesting, from the old method of burning first to remove trash, to the current approach of green cane harvesting, had unpredicted impacts. Leaving the trash on the land had the major benefits of retaining organic material, removing smoke impacts and protecting the soil against erosion, but the interaction of rainfall with trash can produce organic pollution in streams, leading to fish kills. Fine-scale land and water management can alleviate such problems.

Long-term turbidity in the water is often caused by loss of riparian vegetation or cattle access, such as occurs in the Burdekin River Dam (Lake Dalrymple) and in the river downstream, and may have a long-term detrimental effect on normal processes. Moreover, if that suspended material settles to the substrate it can have major effects on benthic habitats and organisms, by clogging substrate interstices and microhabitats, and smothering plants and small animals (e.g. Connolly and Pearson, 2007).

Organic inputs to aquatic systems, such as effluents from sewage works or dairies, typically cause oxygen depletion through bacterial respiration of organic materials, with subsequent loss of hypoxia-intolerant species of invertebrates and fish. In the Wet Tropics, sugar mill effluents were once the main source of problems (Pearson and Penridge, 1987), but there has been substantial effort to remove or clean up discharges to waterways.

Disturbance of riverbanks also occurs by access of feral animals, including pigs that can severely disturb the sediments and benthic fauna of shallow wetlands, and also several species of fish, for example Tilapia (Webb, 2006).

In the Wet Tropics, of major concern are tilapia (*Oreochromis mossambicus*) and other related cichlid fishes of African origin that, it is feared, might displace native species (Burrows, 2004). Currently it appears that introduced fishes do especially well in disturbed habitats, but are not yet implicated in displacement of natives in more pristine systems (Webb, 2003).

The dynamics of oxygen (and, incidentally, pH) in catchment waterways are complex and dependent on a range of natural and human-influenced variables (Pearson *et al.,* 2003). Natural oxygen status can best be achieved by maintaining riparian zones, curtailing weed growth; by preventing the input of nutrients and by removing blockages to flow. While the tropical Australian invertebrate and fish fauna appear extremely resilient to low dissolved oxygen status (Pearson *et al.,* 2003; Connolly *et al.,* 2004), their tolerance thresholds can be breached, as evidenced by the occasional fish kills that occur in floodplain waterways. Prolonged high sediment levels reduce diversity and abundance of stream biota such as fishes (Hortle and Pearson, 1990).

4.b.ii. Concentrations of nutrients in fresh waters in many catchments are proportional to the area of land under agriculture.

The concentrations of dissolved nutrients in stream water correlates with the proportion of agricultural land use in the catchments (e.g. Dillon and Kirchner, 1975; Smart *et al.,* 1985; Jordan *et al.,* 1997). Although streams are well flushed in Wet Tropics waterways, nutrient supplements from fertilisers are reflected by algal productivity and consequent changes in the fauna. In many disturbed streams the effects of increased nutrients are exacerbated because the clearing of riparian vegetation increases light levels and encourages vigorous growth of invasive weeds and the instream growth of algae and larger plants.

For example, water hyacinth (Eichornia crassipes) and salvinia (Salvinia molesta) are two plants introduced for their ornamental values, but which have become major weeds in the GBR catchment waterways. They infest lagoons and slow-flowing waterways, eventually covering the whole water body in a thick mat that blocks out light and prevents gas exchange, rendering the waterway hypoxic and uninhabitable for native plants, fish and other animals. This growth is accelerated by increased nutrient input. In the Wet Tropics, the major weed problem is para grass (Brachiaria mutica), which grows in profusion wherever there is sufficient light and appropriate substrate. Its growth is enhanced by nutrients in the water. It now infests most minor drainage channels, small streams and river banks. It is a severe impediment to normal drainage, and has substantial effects on the morphology of waterways (Bunn *et al.,* 1998).

Pearson and Penridge (1987) found high abundances of macroinvertebrates below the outfall of a sugar mill in the Wet Tropics. They associated the increase in macroinvertebrate production with high levels of nutrients and organic matter in mill effluent. In experiments using artificial stream channels on the bank of a first order rainforest stream Pearson and Connolly (2000) were able to increase macroinvertebrate abundance by 75%.

Aquatic macroinvertebrates offer a time-integrated sample of environmental conditions over their lifetime (weeks to years) and consequently have been regularly used as indicators of water quality and ecosystem health (Rosenberg and Resh, 1993). They are numerous and ubiquitous, occurring in nearly all water bodies and are easily sampled using cheap, readily available equipment, making them ideal for this purpose. The aquatic macroinvertebrates are typically diverse, with different species having specific requirements for biophysical conditions. As a consequence, their distributions follow natural gradients in environmental conditions and they have been shown to respond to changes in water quality and physical parameters associated with anthropogenic disturbance (Connolly and Pearson, 2004). For example, they have been demonstrated to be sensitive to changes in water chemistry, including dissolved oxygen concentration (e.g. Connolly *et al.,* 2004), pH (e.g. Rutt *et al.,* 1990), salinity (e.g. Metzeling, 1993) and to be vulnerable to toxic contaminants such as insecticides (e.g. Liess, 1994; Shultz and Liess, 1995). They have also been shown to respond to organic pollution (e.g. Pearson and Penridge, 1987) and nutrient enrichment (e.g. Økelsrud and Pearson, 2007; Pearson and Connolly, 2000). The clearing of riparian vegetation and increases in sedimentation have also been shown to be detrimental to macroinvertebrate assemblages (e.g. Ryan, 1991; Connolly and Pearson, 2007; Harrison *et al.,* 2008).

4.b.iii. Agricultural development has led to substantial damage to riparian and wetland health in many catchments.

Various estimates of loss of freshwater wetlands in developed catchments along the GBR coast range between 70–90% (EPA, 1999) while the condition of the remaining 10–30% range from moderate to no value as fisheries resources (Veitch and Sawynok, 2005). The most significant reason for the reduction in the value of remaining wetlands to fisheries is changed catchment hydrology resulting in loss of connectivity, habitat modification, poor water quality and poor habitat quality. Wetland loss affects species whose lifecycle includes a marine phase (Veitch and Sawynok, 2005).

Floodplain lagoons are affected by inputs of nutrients (from fertilisers) that promote aquatic plant growth, and consequent nocturnal oxygen depletion and loss of biodiversity. Floodplain lagoons are also affected by inputs of organic materials (e.g. cane field wastes) that promote bacterial production and further oxygen depletion.

The loss of riparian vegetation in the GBR catchments is documented throughout Queensland in the Statewide Landcover and Trees Study (SLATS) (e.g. Queensland Department of Natural Resources and Water [QNRW], 2007), and at a local or regional scale through specific, mostly short-term, assessments. Natural riparian (riverbank) vegetation in GBR catchment typically includes forest trees, shrubs and, with sufficient light penetration, some grasses and herbs. Where drainage is poor, species that are tolerant of waterlogging may dominate. The benefits of riparian vegetation to normal ecosystem function are well documented (e.g. Pusey and Arthington, 2003). They include: habitat and habitat corridors for terrestrial animals and plants; habitat for semi-aquatic animals; shade; filtration mechanisms; organic inputs; bank stability; instream habitat via roots and snags and basking sites for reptiles. In the past, farmers were often encouraged to clear land right up to the river banks. It is now acknowledged that this policy was ill-conceived as the lost amenity values greatly outweighed the value of the land exposed. Despite broad acceptance of this assessment, restoration of riparian zones is only occurring very slowly.

As part of the Queensland Wetlands Programme established in 2003 under the Reef Plan, Queensland's wetlands have been mapped digitally by building on existing information, including water body mapping derived from satellite imagery, regional ecosystem mapping and a springs database (EPA, 2005). Wetlands have been classified according to a range of criteria, including the type of ecological system (riverine, estuarine etc), their degree of water permanency, and salinity. The result is a consistent wetland map at a scale of 1:100 000, with finer detail in some parts of Queensland (mainly coastal regions) where appropriate mapping data exists. A wetland inventory is also being developed to describe the listing and storage of wetland information from a range of sources including tenure, climate, population, land use and field data.

4.b.iv. Concentrations of pesticides in waterways are highest in areas of intensive agricultural activity.

Some monitoring of pesticide concentrations has been done in the Wet Tropics that shows that the concentrations of pesticides in waterways are highest in areas of intensive agricultural activity (e.g. Bainbridge *et al.,* 2006a) but there is very little information on the impacts of pesticides on native biota (exceptions include Kevan and Pearson, 1993). Clearly, our understanding of the fate and impacts of pesticides is a major knowledge gap that needs addressing.

Weeds such as paragrass, which become a nuisance to farmers as a result of accelerated growth through increased nutrient availability, are often managed by mechanical or chemical means. This results in direct pesticide application to waterways. The implications of these applications for instream or downstream ecosystem health have not been adequately investigated.

4.b.v. The condition of riverine waterholes in the dry tropics is largely determined by cattle access.

The condition of riverine waterholes reflects their local surroundings. In the dry tropics, the condition of riverine waterholes is largely determined by the availability of access to cattle, which contaminate and greatly disturb remnant and refugial ecosystems, causing, among other things, deoxygenation and consequent loss of biodiversity (Burrows, 2003).

4.b.vi. The condition and biodiversity of floodplain waterways are adversely affected by irrigation inputs and drainage.

Condition and biodiversity of floodplain waterholes are affected by irrigation inputs and drainage, particularly sediments, nutrients from fertilisers and organic material, which lead to oxygen depletion and biodiversity loss (Burrows and Butler, 2007).

4.c. Key uncertainties related to reduced instream health

The following points summarise the key uncertainties associated with knowledge related to decline in the quality of water in GBR catchment waterways leading to reduced instream ecosystem health.

- Understanding of the fate and impacts of pesticides in freshwater ecosystems.
- Quantitative assessment of the different requirements for catchment management for improved instream health.
- The greatest influence on streams and wetlands is caused by the ambient concentrations in the non-flood periods. The short, sharp flush of material in the flood periods have little influence on streams and wetlands, but produce the bulk of materials reaching the GBR; it is the regular supply of nutrients that occurs through the year on which weed growth (for example) is dependent. Those weeds are detrimental to instream health, smothering natural habitats, exacerbating hypoxic conditions and creating barriers to dispersal, but may provide an excellent filter, reducing contaminants being delivered to the GBR. This hiatus needs to be explicitly assessed and quantified. It is possible, for example, that these beneficial effects of weeds are short-lived, as they are over-run by wet season floods.

5. Review scientific evidence for the effectiveness of current or proposed management intervention in solving the problem

Conclusion: Current management interventions are not effectively solving the problem.

Knowledge related to the effectiveness of management interventions has moved forward in the last five years but there are still significant gaps that hinder the capacity to identify the priorities for investment and provide confidence in their likely water quality outcomes. The Water Quality Improvement Plans (WQIPs) in the GBR have provided a substantial driver to improve the availability and accessibility of this information, and in defining which practices are most appropriate in certain locations for the most efficient biophysical, social and economic outcomes.

Despite regional collaborative efforts between industry, research, government and the regional NRM bodies to develop Best Management Practices (BMP) for the major industries (sugarcane, grazing and horticulture) within the GBR catchments, there is still a lack of quantitative evidence linking these BMPs with water quality benefits to downstream waterbodies. The linkage between the adoption of BMPs and resultant improvements in water quality in a quantitative sense is unknown, and an understanding of the timeframes that changes in water quality are detected at different scales (i.e. paddock to sub-catchment monitoring).

There has been a small body of relevant social and economic research undertaken to inform the management of the GBR; evaluations of the existing social and economic research already undertaken in the GBR relating to water quality have indicated that the research is relatively limited. In addition, much of the research and development has often not been well integrated with physical research and development, or does not provide a comprehensive understanding of the social and economic issues across the GBR.

5.a. Lines of evidence

5.a.i. Priority contaminants for intervention are known for Water Quality Improvement Plan areas.

There is improved regional understanding of management practices associated with the presence of contaminants in waterways, including knowledge of variability in risks across and within catchments and industries. However, prioritisation between the regions and between industries at a GBR-wide scale is lacking.

5.a.ii. A range of measures for managing sediment, nutrient and pesticide loss are available for implementation across industries and across regions in the GBR catchments.

Agricultural industry land management systems such as Grazing Land Management and fertiliser efficiency techniques are established.

5.a.iii. Quantification of water quality outcomes of management practices is inadequate.

Management systems believed to be effective (based on limited information) are known for the sugarcane and grazing industries and some of these incorporate potential 'win-win' benefits (e.g. '6 Easy Steps' nutrient management system in sugarcane), although to variable degrees across regions and industries; less information is available for many of the regions' diverse horticultural industries.

5.a.iv. There are many social and economic impediments to the implementation of management interventions.

There are multiple economic and social impediments to the implementation of changes of management practices aimed at reducing contaminant loads to the GBR. While 'win-win' scenarios exist for some management interventions such as the '6 Easy Steps' nutrient management system in sugarcane, many practices involve net costs to producers, particularly in the shorter term. Economic and social impediments to practice change vary between regions, complicating the design of policies to achieve practice change.

5.a.v. Knowledge of the effectiveness of restoration techniques is insufficient to guide investment.

The effectiveness of riparian vegetation and wetlands as potential filters of sediments, nutrients and pesticides is known for some cropping locations, but is limited for grazing areas. The system understanding that is required to prioritise investment into riparian and wetland rehabilitation, taking into account social and economic factors, is extremely limited. Potential lags in system responses to management interventions are beginning to be quantified.

5.a.vi. Targets have been set at regional scales based on best available science but GBR-wide targets are lacking.

Targets for management actions, end of catchment loads and resource condition have been set through the GBR Water Quality Improvement Plans. The targets are thus far more robust than previously set but still require modification in the light of new information. However, no targets have been set at the GBR scale that would allow trade-offs in management actions across the GBR region to be considered.

5.a.vii. The capacity to measure effectiveness of management interventions has improved.

Several major monitoring and modelling partnerships have been established to measure water quality condition in the

GBR catchments, including the Short Term Modelling Project led by NRW and the Reef Plan catchment and marine monitoring programs. Integration of these programs at the GBR paddock – to catchment to reef scales – is lacking.

5.b. The evidence base

5.b.i. Priority contaminants for intervention are known for WQIP areas.

Substantial variability exists in the biophysical, social and economic characteristics across the GBR catchments which influences the suitability and application of management priorities. A priority for recent research has been identification of the primary sources of terrestrial contaminant runoff to the GBR through more detailed regional assessments to target management interventions; the outcomes of these assessments is addressed in Section 1a. The most recent information has largely been generated through the WQIP process undertaken for 17 of the 35 major river catchments in the GBR region. For example, in most of the Burdekin and Fitzroy catchments where grazing is the predominant land use, sediment is identified as the contaminant of greatest concern (Burdekin WQIP – Mitchell *et al.,* 2007a; Fitzroy – Johnston, 2006), while in the Tully catchment within the Wet Tropics, where intensive sugarcane and banana cropping is dominant, nitrogen and pesticides are the key concern (Tully WQIP – Kroon, 2008). Nutrients and pesticides are also of greatest concern in the lower Burdekin catchments (Mitchell *et al.,* 2007a) and Mackay Whitsunday region (Drewry *et al.,* 2008) where land use is dominated by intensive cropping, predominantly sugarcane. The Burnett-Baffle catchments incorporate a range of land uses including intensive cropping and grazing; the WQIP process has identified sediments, nutrients and pesticides as important contaminants. The Black Ross WQIP is dominated by urban land uses where nutrients, pesticides, sediments and heavy metals are of concern.

Improved management techniques in intensive wet tropic areas have already reduced sediment generation through practices such as minimum tillage and green cane trash blanketing (Prove *et al.,* 1997; Rayment, 2003), although there remain relatively minor sediment issues in horticultural crops such as bananas. Substantial issues still exist for sediment management in grazing lands.

The focus for sediment control and reduction of erosion associated with rangeland grazing is in the Burdekin and Fitzroy catchments, and to a lesser extent catchments in the Cape York and Burnett regions and upper parts of the Wet Tropics catchments (Joo *et al.,* 2005; Brodie *et al.,* 2003; Furnas, 2003; Cogle *et al.,* 2006). Hillslope, streambank and gully erosion dominate sediment delivery processes, although further studies are required to demonstrate predominant erosion mechanisms in the catchments. Particulate nutrients are also sourced from soil erosion in grazing lands and can therefore be managed through soil erosion control.

Dissolved inorganic nutrients are largely associated with fertiliser application in intensive cropping industries. For the GBR region as a whole, management of these nutrient losses is essentially about reducing fertiliser losses from sugarcane and to a lesser extent, horticulture (but noting that horticulture may be of major importance in some catchments).

Herbicides are mostly derived from sugarcane applications (Rohde *et al.,* 2006a) with some contributions from cropping in the Fitzroy catchment (Packett *et al.,* 2005), and woody weed control in grazing lands.

5.b.ii. A range of measures for managing sediment, nutrient and pesticide loss are available for implementation across industries and across regions in the GBR catchments.

The principles for effective management of sediment, nutrient and pesticide generation are well known and these are incorporated into management practices being implemented across the GBR catchments. However, large uncertainties exist regarding their profitability and short- and long-term impacts of implementation upon industries. Examples of methods designed and currently applied for targeting specific problems are provided below.

There are several schemes available for managing fertiliser application in the intensive cropping industries and these have been examined on a regional basis for each WQIP (e.g. Roebeling and Webster, 2007; Thorburn *et al.,* 2008). Examples include '6 Easy Steps' (Shroeder *et al.,* 2005) where cane farmers are encouraged to follow a series of steps that tailor the fertiliser application rate to the plant and soil requirements, and has benefits for productivity such as reduced fertiliser application. Thorburn et al. (2003b) developed the N-Replacement system and this system has been trialled in several sugar areas within the GBR catchments (Thorburn *et al.,* 2007; Webster *et al.,* 2008b). Field trials have been positive, suggesting the assumptions behind the system are often valid. The main assumption is that soil nitrogen stores can buffer the difference between the amount of nitrogen needed by the crop and the amount of nitrogen fertiliser applied. For example, if the yield of the coming crop was larger than that of the previous crop, additional nitrogen requirements would be supplied from soil nitrogen stores. Conversely, these nitrogen stores would be 'topped up' when a small crop followed a large one. This assumption means the concept of a 'target yield', as used in programs such as '6 Easy Steps', is no longer necessary in determining fertiliser rates. Target yields are generally related to possible production, not actual production, and so can be a significant driver of high fertiliser application rates (relative to actual production) and high fertiliser and high fertiliser surpluses (Beaudoin *et al.,* 2005). The success of the N-Replacement system is a potential saving in nitrogen fertiliser applications of up to 40%, and a reduction in the overall nitrogen surplus across the whole sugarcane industry of up to 60%. The N-Replacement research is currently in the 'proof-of-concept' phase and plans are underway for developing the concept into a practical management system.

However, in contrast to recent developments for sugarcane, little consideration has been given so far to similarly update fertiliser and other management practices for most of the region's horticultural industries. A review of fertility management in horticulture and associated environmental issues (Hunter and Eldershaw, 1993) provides information and priorities for improving fertiliser and pesticide management in these industries across Queensland, including the GBR region. This review should be updated and its recommendations implemented so that up-to-date information is available on optimal fertiliser and pesticide management practices for horticultural industries in the region.

In addition, the information needs to be provided for each industry and should take into account cross-regional differences (e.g. in production systems and climate).

Sediment control in the grazing industry is guided by the industry-led initiative, Grazing Land Management, or 'GLM'. This initiative has developed regionally-specific best management practices (BMPs). As with practices for fertiliser management, each region has also conducted an assessment of management practices suitable for reducing sediment runoff in priority catchments; for example, BMPs for grazing in the Burdekin are assessed and prioritised in Coughlin *et al.,* (2007). Sediment control in these areas requires increased vegetation cover, as well as improved pasture condition and soil health to retain water, sediments and nutrients on the land (Nelder, 2006; Gordon, 2007). In principle, this means applying the appropriate utilisation rates of vegetation through better management of stocking rate (particularly in regard to rainfall variability), wet season spelling to improve pasture condition, forage budgeting to ensure cover levels are adequate from year to year and preventing selective overgrazing of preferred areas in the landscape (Chilcott *et al.,* 2003; Gordon and Nelson, 2007). However, recent unpublished work by Bartley *et al.,* (2007c) suggests that the majority of the sediments flowing into the creeks and rivers come from streambank and gully erosion which will sometimes need engineering solutions such as contour banks or ripping (as opposed to retaining walls or sediment traps) and fencing riparian and gullied areas to provide reduced grazing pressure, rather than changes in grazing land management. Current practices largely address hillslope erosion and further work is required on management and restoration techniques for gully erosion.

There are also other means of addressing sediment runoff in grazing lands. Maintaining soil health, for example through reduced stocking pressure, is also identified as an important contribution to improving soil infiltration, and therefore reducing surface water runoff and sediment loss (Dawes-Gromadzki, 2005). The importance of off-stream watering as a means of reducing cattle impact on waterholes and lagoons has also been demonstrated by Burrows (2003). However, there has been little work on managing grazing in riparian areas (with the exception of fencing) and direct management is unlikely to be financially viable in extensive grazing areas. Ongoing research (field experiments and modelling) is required regarding the influence of variable groundcover levels and patterns for major landscapes within each region, and improved understanding of the impact of significant flood events on sediment loads and defining the threshold of various management practices in these events, is necessary to identify the best sediment management practices for water quality outcomes.

Herbicide management is focused on better and more effective delivery techniques which reduce losses and integrated pest management programs focused on reducing use. Current practices include zonal application and the use of hooded sprayers, and the replacement of residual herbicides such as diuron by other less residual herbicides such as glyphosate.

There are some examples of incidental interventions that have had benefit to water quality outcomes, such as green cane trash blanketing, which while introduced to improve harvesting and organic carbon content of soils, had the incidental benefit of reducing soil erosion. A second example is evident with fertiliser application rates – in the last 10 years, at a time of reducing cane prices, fertiliser prices have risen, while fertiliser application rates have reduced.

5.b.iii. Quantification of water quality outcomes of management practices is inadequate.

While water quality outcomes are expected from the implementation of the management practices outlined above, there is limited evidence of measured water quality outcomes from particular practices in particular locations.

A major limitation in detecting improvements in practices and measurable outcomes in GBR ecosystem health is the ability to detect the signal of change in the system. This noise in the signal is due to system variability, natural occurrence of sediments and nutrients in the system and limitations of the capacity to monitor and model material transport and fate. A good example of demonstrated time lags in system response to management changes is recorded in the Tully catchment. The Tully catchment is the least variable river in the GBR catchments, and yet very large changes in fertiliser use (increases) took 14 years to be manifest as increasing nitrogen levels in the lower Tully River to a statistically robust trend (Mitchell *et al.,* 2001, 2006). This highlights the importance of the need for innovative monitoring and modelling techniques, and an improved understanding of the system dynamics to inform management decisions. These issues are also discussed in Section 1.

The response of the system to these land management changes is significantly influenced by system dynamics, depending on the contaminant and catchment systems. The major influences are summarised below (Waterhouse *et al.,* in press).

- Sediment control mechanisms and targets in large catchments such as the Burdekin are likely to encounter long lag times in the system, depending on the soil and flow characteristics, and the time for riparian vegetation to grow. However, fine sediments such as clays, which present the highest risk to GBR ecosystems, experience the least system lags in transport. In addition, the variability in the systems in terms of hydrology (decadal events) and climate mean that responses in the system are likely to be in decadal time scales (Lewis *et al.,* 2007b; Bartley *et al.,* 2007a).
- Fertiliser management in intensively cropped areas such as the Wet Tropics and the Mackay Whitsunday Region will also experience significant lag times in system response because of the sugar crop cycles (six to seven years) and storage in soil and groundwater stores. Responses are likely to be multiple years (i.e. five to ten years). Lags in groundwater transport and sub-surface transport (Rasiah *et al.,* in prep; Rasiah *et al.,* 2007; Armour *et al.,* 2006) and floodplain trapping (Wallace *et al.,* in press; Karim *et al.,* 2008; McJannet, 2007) also have a significant influence on the system.
- Herbicide management is expected to be characterised by limited time lags because most of the herbicides of concern have half-lives of less than

one year (e.g. 50 days). Significant reductions in loads are expected to be evident within two years of practice change involving reductions in use and loss. Changes in the presence of herbicides due to improved practices are also easier to identify in the system as they are not present naturally, generating a clearer signal related to practice change.

While vegetation management through maintenance or rehabilitation of vegetated areas is considered to be a beneficial practice for water quality outcomes, direct measurements of long-term outcomes are difficult to find. However, vegetation management in Queensland is probably one of the few examples of documented evidence of the effectiveness of a management action in Queensland through introduction of the Vegetation Management Act 1999. The legislation restricted the amount of tree clearing that could be undertaken on freehold and leasehold land. Figures from the Statewide Landcover and Trees Study (SLATS) showed the statewide average annual rate for clearing of woody vegetation in 2004–05 was 351 000 hectares. This is 27% lower than in 2003–04 (482 000 ha) and 54% lower than the peak measured clearing rate in 1999–2000 (758 000 ha). Reductions in clearing of more environmentally significant remnant woody vegetation are even greater – 35%, down from 267 000 ha in 2003–04 to 172 000 ha in 2004–05 (QNRW, 2007). These figures demonstrate the effectiveness of the introduction of the legislation and in the short term, assumptions are made about the outcomes in terms of water quality and biodiversity values.

5.b.iv. There are many social and economic impediments to the implementation of management interventions.

Similarly to the variability in the physical impacts on loads from practice change across and within industries of the GBR, there is significant evidence of variability in the economic and social characteristics of regions across the GBR, between sectors, and often within sectors within regions. This variation applies to both industries contributing to loads with the catchments such as grazing, sugar and horticulture (Marsden Jacob Associates, 2008a; Greiner *et al.,* 2003) and industries that are largely within receiving environments such as tourism and recreational fishing (Access Economics, 2007; Campbell and Murphy, 2005; Marsden Jacob Associates, 2008b). This variability in social and economic makeup further complicates the measurement of the effectiveness of proposed management interventions. While the understanding of cost effectiveness of alternative management interventions is still relatively rudimentary, it is generally better understood in grazing and sugar environments (Rolfe *et al.,* 2007, Donaghy *et al.,* 2007, Roebeling, 2006; Roebeling *et al.,* 2004, 2007; Alam *et al.,* 2006). For example, Roebeling *et al.,* (2007) analysed the water quality efficacy and the economic dynamics of management practices in the Tully-Murray catchment.

Based on the proposition that regional (i.e. private and social) benefits are maximised where marginal private costs equal marginal social benefits, the studies showed that the cost-structure around BMPs is such that a certain level of improvement in water quality can be made at no cost (e.g. for sugar – a 25% to 40% gain depending on adoption of new fertiliser practices) but beyond that point, costs for water quality improvement rise sharply. It showed that the current BMPs do not yet balance both production and environmental goals. In addition, the spatial arrangement of industries in the catchment was not optimal for improved water quality outcomes. Subsidies, incentives and/or regulations will be needed to provide the business case for industries to develop and implement improved management practice settings and to guide spatial change in this, and many other GBR catchment locations.

There are significant barriers to the adoption of practices that could materially reduce loads into GBR catchments. These barriers are economic such as the private cost of changing practices and social such as attitudes towards particular practices, skills required and attitudes towards risk (Cary *et al.,* 2001; Preston *et al.,* 2007; Donaghy *et al.,* 2007). These constraints are often not well understood. Because of the multiple types of constraints to change and the variability of the constraints between managers, a number of regulatory, suasive and economic tools are being used to address water quality in the GBR, with the use of market-based instruments providing significant opportunities as they specifically integrate bio-physical and economic information (revealed by managers) of the benefit, costs and cost-effectiveness of alternative management interventions (Marsden Jacob Associates, 2008a).

There has been a small body of relevant social and economic research undertaken to inform planning and management of water quality in the GBR (e.g. Windle and Rolfe, 2006; Hug and Larson, 2006; Larson and Stone-Jovicich, 2008; Larson, in press), although many of the studies have been regionally specific including socio and economic assessments completed to support water quality planning in the Tully Murray catchments (Bohnet *et al.,* 2007; Larson, 2006, 2007), Burdekin region (Greiner *et al.,* 2003; Greiner and Hall, 2006; Greiner *et al.,* 2006), Mackay Whitsunday (Strahan, 2007) and Fitzroy (Preston *et al.,* 2007). These studies have highlighted the substantial variability in the socioeconomic characteristics of the GBR catchment that ultimately influence the choice of management interventions for water quality outcomes. Integrating targeted social and economic analysis and research into the implementation of the Reef Plan should provide significant improvements in the understanding of the cost effectiveness of alternative management interventions (including variability) and the impediments to change over time.

The Reef Plan Marine Monitoring Program includes a socio-economic component. This involves reporting on: market values of GBR industries and their inputs to regional economies; patterns of human use of the GBR particularly non-commercial recreational activities, tourism and commercial fishing; and community and visitor perceptions of, and satisfaction with, GBR health (Prange *et al.,* 2007).

A suitable indicator for assessing the performance of management interventions is the adoption rates of various practices and tracking extension efforts by region and industry. At this stage, limited effort has been made to benchmark these indicators (with some exceptions at a regional scale). This is a critical information need to inform the evaluation of Reef Rescue Plan investments.

5.b.v. Knowledge of the effectiveness of restoration techniques is insufficient to guide investment.

Rehabilitation of riparian zones and wetlands and management in extensive grazing lands is considered a priority activity for improving water quality, particularly focused on the function of these areas as filters of sediment, nutrients and pesticides. Rehabilitation is not an economic option for vast areas in the rangelands – these riparian areas still need to be managed under grazing (Coughlin *et al.,* 2007). Large areas of riparian forest have been cleared over the last 30 years in the Burdekin (Lymburner and Dowe, 2006) and over the last 50 years in the Fitzroy (Lymburner, 2001).

From a management perspective, resources for rehabilitation are best directed to those parts of the catchment where they can have greatest effect, recognizing that the functions and capabilities of riparian and wetland areas may differ depending on their position in the landscape (Hunter and Hairsine, 2002). For example, where hillslopes drain directly into streams without the presence of a floodplain, the riparian zone will act to reduce sediment loads and associated contaminants carried by overland flow. In smaller, frequently ephemeral, streams the emphasis is on filtering of overland flow. In larger streams riparian vegetation has a major role in stabilising stream banks. Similarly, remedial management should target riparian areas where shallow groundwater discharge of nitrate occurs, most likely in small to medium sized streams (Hunter *et al.,* 2006). Careful management may be required to ensure these areas retain this capability and do not become contaminant sources; for example, as shown for phosphorus in constructed wetlands in the Burdekin region (Hunter and Hairsine, 2002).

In general, scientific knowledge of these riparian and wetland buffering functions in cropping situations or in wetter more intensive environments is relatively well developed and the principles have now been incorporated into software that enables assessment of alternative management scenarios and identification of optimal locations for rehabilitation. For example, the Riparian Nitrogen Model (RNM) (Rassam *et al.,* 2008) enables users to identify sub-catchments and stream reaches where rehabilitation is likely to have greatest effect in reducing downstream nitrate concentrations, and it can also indicate the optimal buffer width required. The RNM has been successfully applied in the Tully catchment. A Riparian Particulate Model (RPM) has similarly been developed (Newham *et al.,* 2005). It is also clear that in Wet Tropics catchments that it is best to have a mixture of grass and trees to trap overland flow of fine particulate matter rather than just trees (McKergow *et al.,* 2004a, 2004b).

The lack of locally-relevant data sets is a significant limitation to reducing the uncertainty of these model outputs. At a systems level, there is currently only a limited capability to optimise prioritisation of sites for rehabilitation, not only from a biophysical perspective but also taking into account social and economic factors.

Despite the very considerable efforts made in riparian rehabilitation, both in the GBR region and elsewhere, there have been very few attempts to quantify the benefits of these investments in terms of improved water quality downstream. Long-term monitoring studies are needed at a sufficiently large (e.g. sub-catchment) scale to demonstrate that such benefits can be achieved following rehabilitation. However, some local examples of monitoring effectiveness of wetland systems do exist, for example in the Burdekin catchment (Burrows and Butler, 2007) and the Tully catchment (McJannet, 2007). Recent research by McJannet and others (unpublished) in the Tully catchment indicates that further investigation is required to substantiate preliminary data showing the filter function that wetland systems provide in a wet tropical floodplain environment.

5.b.vi. Targets have been set at regional scales based on best available science but GBR- wide targets are lacking.

In the last three years, targets have been set for management actions and resource condition to support water quality management in the Douglas, Tully-Murray, Burdekin, Black-Ross, Mackay Whitsunday, Fitzroy and Burnett-Baffle catchments, mostly through the WQIP process. A consistent approach, reflected in Figure 9, has been adopted across the regions and significant advances have been made in the rigour of the target setting process than earlier efforts (e.g. Brodie *et al.,* 2001).

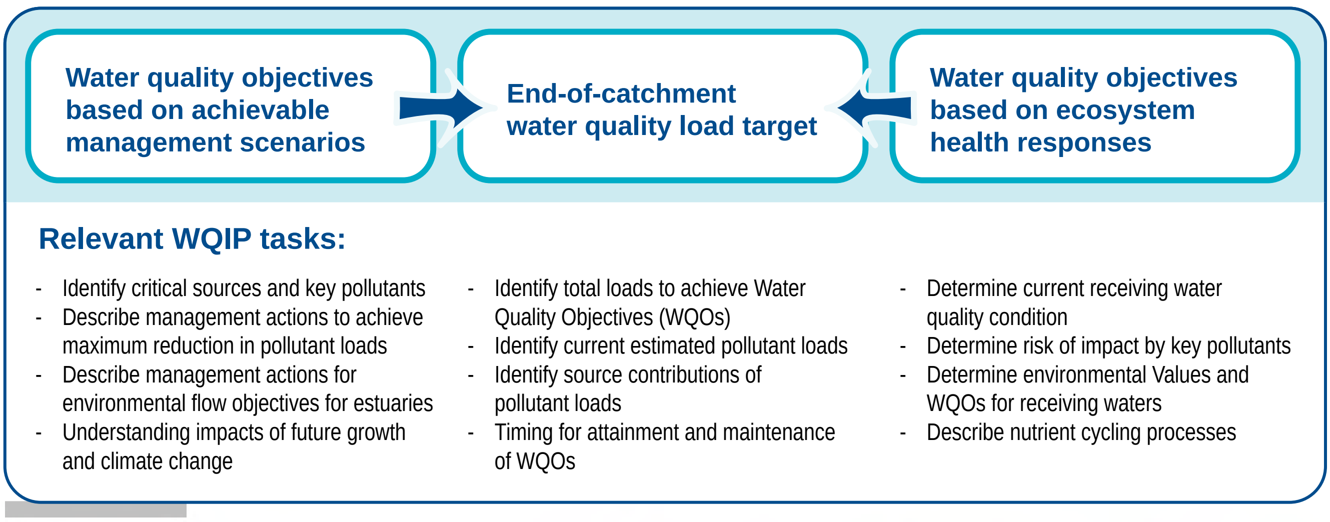

Figure 9: Water quality target setting within the GBR and relevant tasks within the WQIPs.

However, as a result of the limitations in monitoring and modelling capacity referred to in sections 1 and 3, water quality targets are at present largely driven by an understanding of what is achievable water quality change within current land use systems and practices. The environmental tradeoffs in this decision have not yet received much attention because of the low confidence in our understanding of what is actually being discharged from catchments and how this relates to requirements to sustain healthy GBR ecosystems. The implications for ecosystems of not meeting targets, and the lag time to change practices and realise water quality benefits for the target adopted, have high levels of uncertainty.

This is most apparent in the marine environment, where relationships between water quality parameters and the resilience of GBR ecosystems is still emerging (refer to Section 3). The establishment of the GBRMPA Water Quality Guidelines (GBRMPA, 2008) and the supporting science documentation (De'ath and Fabricius, 2008) provide a substantial advancement towards setting marine water quality targets; however, considerable work is required to define and measure desired water quality outcomes in the relatively short policy timeframes.

5.b.vii. The capacity to measure effectiveness of management interventions has improved.

Catchment and marine water quality monitoring programs have commenced in priority catchments of the GBR as part of the Reef Plan arrangements. Catchment and end of catchment load water quality monitoring is led by QNRW in collaboration with regional Natural Resource Management (NRM) bodies in 31 locations with a focus on sampling in major runoff events, when these exports predominantly occur (Hunter and Walton, 2008). A number of monitoring programs are undertaken at regional levels to support NRM planning and Water Quality Improvement Plans, with comprehensive programs established in the Burdekin (e.g. Bainbridge *et al.,* 2007), Mackay Whitsunday (e.g. Rohde *et al.,* 2008) and Fitzroy (e.g. Packett *et al.,* 2005) catchments for event monitoring. Many of these programs encourage community participation. The ecological risks associated with pesticide use in GBR catchments are currently being assessed and a monitoring program developed for high risk waterways by QNRW. Marine water quality monitoring is undertaken as part of the Reef Plan Marine Monitoring Program led by the GBRMPA (Prange *et al.,* 2007) described in Sections 2 and 3. A comprehensive overview of the location and extent of water quality monitoring currently undertaken in the GBR catchments is provided in QNRW (2008a).

Estimates of the loads of contaminants discharged to the GBR that are not captured in existing monitoring programs due to inadequacy of sampling sites and methods have been made in a number of catchments. In the Tully catchment Wallace *et al.,* (in press) showed that a large proportion of the total load of suspended sediment and nitrogen was present in waters in overbank flow on the floodplain and this was not included in load calculation made at Euramo (the lowest gauging station) in the river channel. Similarly it is clear that much of the nitrate lost from sugarcane fertiliser in the lower Burdekin reaches the GBR via small stream discharge and possibly groundwater discharge and is thus not included in loads measured at Home Hill in the Burdekin River (Brodie and Bainbridge, 2008). Similar 'missing' loads are obvious in Mackay-Whitsunday region through small stream discharge (Rohde *et al.,* 2008) and are likely in other regions. Similarly, there is poor understanding of the role of, or impact of, discharges of contaminants from the coastal floodplain in dry season conditions. These chronic discharges are likely to include natural stream discharge and drainage from irrigation.

SedNet modelling predicts that high levels of suspended sediment trapping will occur in dams such as the Burdekin Falls Dam (Fentie *et al.,* 2006) and the Paradise Dam (Henry and Marsh, 2006). This has significant implications for management of different parts of the catchment when considering overall sediment delivery; for example, management could be targeted in catchments areas below the dam wall. However, recent studies using monitoring data suggest that trapping in the Burdekin Falls Dam is lower than modelled (average 60% instead of the modelled 80%) (Lewis *et al.,* 2008) and therefore careful consideration is required regarding location of management efforts.

Much of the modelling performed to date has provided information on annual-average conditions based on long-term datasets and this type of modelling will continue to have its place (e.g. for assessing likely impacts of alternative planning/management options). However, the priority now is to develop more dynamic water quality models to analyse the large monitoring datasets being developed for several major catchments of the GBR (Bartley *et al.,* 2007b). The aims of such monitoring programs are to identify the sources of contaminants and to detect changes in contaminant concentrations and loads with time, in response to changes in land-management practices. Teasing out from the dataset the effects of changed land management is challenging particularly in large complex catchments, where many factors, including climate change, co-determine water quality (Grayson, 2007). Models have to be calibrated with locally relevant data to interpret the monitoring data (e.g. Hunter and Walton, 2008). Even so, because of the complexities and sizes of catchments involved and the inevitable limitations of the models, it may not prove possible to detect trends in the monitoring data over the short- to medium-term.

Model estimates that upscale from paddock to catchment scales are required to indicate the likely water quality improvements associated with changed management practices, even if these cannot be confirmed through monitoring at that time. The time lags for trends to be detected in the monitoring data likely vary between contaminants and between catchments, depending on factors such as the dominant transport pathways and transformation processes, the presence of contaminant sinks (stores) and the spatial distribution and extent of practice adoption. Field validation of modelled increases to sediment and nutrient yields is required using additional and more direct proxies (perhaps sediment dating, review of fertiliser application tonnages).

Improved understanding of the uncertainties associated with existing catchment transport modelling tools has been an important component of recent research, with the limitations summarised by Post et al. (2007) and Wilkinson et al. (2008).

For example, sediment tracing work underway in the Bowen River indicates much more gully erosion is occurring than model predictions, (Wilkinson, 2008). This illustrates the need for broader data collection on erosion rates and model validation. Limited gully mapping is an important source of model uncertainty in the Burdekin (Kuhnert *et al.,* 2007) and the Fitzroy (Dougall *et al.,* 2006b) catchments.

A comprehensive overview of the location and extent of water quality modelling activity undertaken in the GBR catchments to support Reef Plan planning and implementation is provided in QNRW (2008b).

A number of models are under development that can assist in predicting the biophysical, social and economic outcomes of various policy interventions, and therefore assist in assessing management effectiveness. For example, the 'SEPIA' model (Single Entity Policy Impact Assessment Model) is being tested in the Burdekin, Tully and Mossman catchments, and uses a range of input data including biophysical characteristics, economic drivers and landholder typologies to determine the probable outcome of a set of policy options (Smajgl *et al.,* 2008); however, further model validation is required. Bayesian approaches are also being used to combine various land use and economic scenarios for GBR water quality and climate change outcomes (Wooldridge, 2007), and to guide managers in prioritising investment (Lynam *et al.,* in review).

5.c. Key uncertainties related to management effectiveness

Key uncertainties related to the effectiveness of current or proposed management intervention in solving the problem include:

- Predictions of the efficacy and efficiency of management interventions exist but quantitative assessments based on field measurements are generally limited.
- Validation of effective and profitable management practices for the GBR region's agricultural industries, especially horticulture and grazing, including environmental, social and economic perspectives.
- Capability to determine the relative importance of the location of the works in the landscape in terms of material delivery.
- The relative importance of the type of groundcover maintained in grazing lands to minimise sediment loss, and the efficiency of different groundcovers in managing hillslope erosion (i.e. 'natural' cover of trees and shrubs or savannah, compared with pasture).
- Impact of different grazing management practices on health and functioning of riparian areas in extensive grazing lands, and management of riparian areas, especially with regard to grazing and spelling.
- The biophysical and economic effectiveness of gully erosion remediation and management measures to reduce gully sediment yields.
- The impact of woody weeds (e.g. rubber vine) and the use of fire to control weeds on sediment loss.
- Socioeconomic benchmarking of the current adoption rates, extension efforts and industry culture by region and commodity.
- Development of a specific metric for each sector group (e.g. grazing) aimed at measuring outcomes from actions to allow comparisons across sectors.
- Understanding the drivers that will lead land managers to change practices for water quality improvement.
- It is too difficult to pick up short-term or medium-term trends in water quality at large scales due to climate variability and inherent difficulties in logistics associated with monitoring at the right spatial and temporal scales. Further work is required to design and resource optimal monitoring and modelling programs in GBR catchments.
- Quantification of the downstream benefits of management change/ restoration efforts and the return on investment to land holders and funders, at appropriate temporal and spatial scales.
- Quantification of the function of wetlands and riparian vegetation as filters for land- based materials in different locations.

6. Discussing the implications of confounding influences including climate change and major land use change

Conclusion: Climate change and major land use change will have confounding influences on GBR health.

Comparisons of the degree of reef degradation and stage and severity of human activity for the GBR compared with other global reef systems shows that although the GBR is in relatively good condition, it is by no means pristine and some way along the path to the degradation seen in many other reef systems (Pandolfi *et al.,* 2003; Brodie *et al.,* 2007a; Bruno and Selig, 2007). The complexities between the impacts of water quality stresses compared with other stresses, such as climate change (bleaching, ocean acidification) and fishing/harvesting and their interaction, are yet to be resolved. The current paradigm considers that a major correlation exists between acute coral mortality following catastrophic events such as cyclones, crown of thorns outbreaks and bleaching mortality, and lack of coral recovery in poor water quality conditions. In good water quality conditions the coral recovers quickly; in poor water quality conditions coral recovery is slow or non-existent due to lack of recruits, poor juvenile survivorship and competition from other benthic organisms such as macroalgae and filter feeders.

The following section provides an overview of the current knowledge related to the implications of confounding influences on the GBR, with an emphasis on the primary confounding influences related to GBR water quality, climate change and major land use change.

Climate change, water quality and GBR health

The present state of knowledge about the vulnerability of GBR species and habitats to climate change has been reviewed in detail (Johnson and Marshall, 2007). Predicted changes in the climate both globally and for the GBR are an increase in the frequency of extreme weather events including heat periods and cold snaps, more intense cyclones, and more frequent droughts alternating with severe flood. Overall, the changing climate as observed and/or predicted within the GBR region will therefore increase the frequency with which coral reefs are being disturbed:

- Increasing concentrations of CO_2 in the atmosphere also lead to a reduction in the pH of the seawater, a phenomenon termed 'ocean acidification'. Ocean acidification reduces the ability of corals and other calcifying organisms to grow, and diminishes the capacity of coral reefs to withstand erosion (Guinotte and Fabry, 2008).
- Chronically warmer waters lead to changes in growth rates, altered food availability and ecological functions in most species groups and GBR ecosystems. Periods of extreme seawater temperatures (unusually high or low) lead to coral bleaching and to a greater susceptibility to diseases. It is also likely that ecotoxicological effects (e.g. from herbicide exposure are more severe when organisms are already stressed from high temperatures).
- Increased rainfall variability and intensity of weather events (droughts, floods etc) will make land management more difficult and increase the risk of soil erosion and loss, thereby resulting in increased loads of contaminants into the GBR lagoon. Droughts lead to reduced vegetation cover, making soils more prone to erode and wash into the ocean during floods. The nutrient injection from drought-breaking floods have been associated with the initiation of primary outbreaks of crown-of-thorns starfish (Birkeland, 1982; Brodie *et al.,* 2005). Changing hydrology may have severe effects on catchment water quality.
- Storm energy increases with the cube of wind speed and some forms of storm damage (e.g. the dislodgement of large massive corals) are only observed at cyclone categories three or higher (Fabricius *et al.,* 2008). Therefore, a predicted increase in the intensity of cyclones (Webster et al. 2005; Hoyos et al. 2006; Kossin et al. 2007) will likely lead to a greater frequency of severe reef damage at regional scales.

Successful coral reproduction and recruitment is needed to compensate for the predicted increase in coral mortality from bleaching events, cyclones, floods, and crown-of-thorns outbreaks. Good water quality is essential for successful coral reproduction and the survival of coral recruits on inshore reefs, and for keeping macroalgal cover low (reviewed in Fabricius, 2005; Wooldridge *et al.,* 2006; and De'ath and Fabricius, 2008). Protecting the reefs against high levels of nutrients, sediments and pesticides is therefore considered essential to facilitate resilience during climate change.

Another confounding influence is overfishing. Numerous studies have shown the important role of fishes in structuring benthic assemblages. Fishes strongly influence the balance between macroalgal and coral cover (e.g. Hughes, 1994). Recent research has shown that fish densities increase once reefs are being closed to fishing, clearly demonstrating that the densities of some targeted fish species are reduced way below 'pristine' levels in many parts of the GBR (Russ *et al.,* 2008). Although herbivorous fishes do not tend to be taken on the GBR, studies have shown that the removal of top predators can alter trophic structures in ecosystems (Graham *et al.,* 2003), and such flow-on effects are poorly understood. This has been shown to influence the rate at which coral reefs recover after beaching events (Hughes *et al.,* 2007).

Major land use change

Given the potential climate change scenarios and associated pressure for industries to seek alternative and viable ventures, major land use change in the GBR catchments is possible, which is likely to have implications for the amount of contaminants discharged to the GBR. A number of scenarios can be considered to be probable in the current settings, although longer term scenarios (e.g. to 2050) are highly uncertain but have been attempted by Bohnet *et al.,* (2008a, 2008b). Likely examples and the projected consequences (based on per hectare measure, not overall land area) are estimated below.

Projections are available regarding biofuel industries and indicate that they are not likely to grow substantially in terms of first generation biofuels. Peak oil and escalating petroleum prices are likely to have significant impacts on the land use and management of the GBR, which will present both challenges and opportunities to managing water quality.

The most significant management implication of these scenarios is the short-term planning approaches that typify the management systems relevant to GBR water quality. Longer term projections such as those piloted by Bohnet et al. (2008a) must be incorporated into planning.

Given the uncertainties associated with the long-term impacts of water quality on the GBR in combination with the confounding influences described above, the knowledge base to support management needs to be revisited on at least a five-yearly cycle. It is recommended that this discussion paper is updated in 2013, which coincides with the completion of the current planning cycle of the Reef Plan and the regional water quality plans.

Scenario	Loss of sediment, nutrients, and pesticides
A shift from: fertilised cropping to another fertilised crop	moderate change
A shift from: fertilised cropping to grazing, forestry or reserve	large change, generally reduced
A shift from: grazing or forest to fertilised cropping	large change, generally increased

Part B

Evaluate current research and advise on capabilities, gaps and priority research needs

The current gaps and key uncertainties related to water quality in the GBR have been highlighted in each of the Terms of Reference addressed above. However, there are also several issues that are relevant to whole-of-system understanding that have not been covered. Recent assessments of the critical gaps in knowledge to support Reef Plan (e.g. Ferrier, 2007) highlight that integration of the science is key to addressing the complexities and uncertainties of the GBR system.

The present approach of delivering components of the knowledge, without an overarching effort to collate, synthesise and integrate this knowledge, is likely to continue to fail to meet management needs. Currently coordination and integration of Reef Plan science is in a parlous state. Inadequate management of the large GBR water quality science budget has led to implementation of ad hoc projects, that are generally not coordinated or based on rational priorities, has resulted in information that is rarely integrated into knowledge or communicated to management. Establishment of a central point of science coordination is required as a matter of urgency to enable science investment to support and guide Reef Plan implementation.

Of utmost importance, integration of the science for Reef Plan is the key to informing management decisions, and requires additional skills in conceptual and quantitative design and interrogation that go beyond traditional fields of expertise. An integrated approach is required to understand the whole system that results in GBR water quality, and includes relationships:

- within and across catchments to the GBR, so that the linkages between catchment actions and GBR health, and within the components of the system (e.g. between water quality and coral health), can be quantified
- between biophysical, social and economic dimensions of the system so that realistic targets and implementation strategies can be developed and assessed
- across scales, so that the sum of catchment and regional activities can be assessed to determine whether the existing and proposed activities are sufficient to achieve the Reef Plan goal.

Further discussion of an approach to address these issues is provided in Eberhard *et al.,* (2008). The process of establishing a pilot Reef Water Quality Report Card in 2006–2008 (Vandergragt *et al.,* 2008) demonstrated the challenges of providing an integrated assessment to inform management at a GBR scale where science coordination is lacking.

Conclusion: Effective science coordination to collate, synthesise and integrate disparate knowledge across disciplines is urgently needed.

This section provides the following information for each of the areas of research identified in the Terms of Reference:

- Overview of the current major research projects. This is (not intended to provide an exhaustive listing but highlight key projects that were initiated or completed since 2003.
- Commentary on the adequacy of the existing research and capability.
- Identification of priority research needs.

Current major research projects

Project	Primary objectives
MTSRF Project 3.7.1: Marine and estuarine indicators and thresholds of concern Katharina Fabricius, AIMS	• To determine dose-response relationships and thresholds of potential concern for contaminant exposure of selected bioindicators; provide a better understanding of the significance of such thresholds for reef water quality and ecosystem condition. • To progress the development of a composite indicator system to interpret water quality monitoring data and their link to ecosystem condition, and to improve estimates of river contaminant loads from discharge concentrations. Further information: http://www.rrrc.org.au/mtsrf/theme_3/project_3_7_1.html
MTSRF Project 3.7.2: Connectivity and risk: tracing materials from the upper catchment to the reef Jon Brodie, ACTFR	• To characterise and obtain a distinct 'fingerprint' of the fine sediments (mud fraction) and dissolved materials entering the marine environment using their isotopic and elemental properties, and link these to their sources in the major terrestrial catchments. • To examine historical changes in the delivery of terrestrial materials, from the major river systems in the Townsville and Cairns regions, to the marine environment using coral and sediment cores. • To determine the transport mechanism, residences time and fate of terrigenous sediments, nutrients and pesticides in the inshore and mid-reef regions of the GBR, and develop and apply new technologies to specifically trace pathways of the key nutrient elements phosphorus and nitrogen from the terrestrial catchments, through estuaries, to inshore coastal zones and to the mid-reef of the Great Barrier Reef. Further information: http://www.rrrc.org.au/mtsrf/theme_3/project_3_7_2.html Davis et al. in press; Lewis et al. in press.
MTSRF Project 3.7.3: Freshwater indicators and thresholds of concern Richard Pearson, JCU Angela Arthington, Griffith University	• To develop physical, chemical and ecological indicators of freshwater ecosystem health in the Wet and Dry Tropics. • To identify thresholds of potential concern relating to land use, water quality, riparian condition, habitat and food web structure in freshwater ecosystems of the Wet and Dry Tropics. Further information: http://www.rrrc.org.au/mtsrf/theme_3/project_3_7_3.html

Reef Plan Marine Monitoring Program Multiple Providers, led by GBRMPA Coordination: Joelle Prange, RRRC	• To assist in the assessment of the long-term effectiveness of the Reef Plan in reversing the decline in GBR water quality, through four sub-programmes: River mouth water quality monitoring, inshore marine water quality monitoring, marine biological monitoring, and socio-economic monitoring. • Marine biological monitoring includes monitoring benthic cover (algae, hard and soft corals), taxonomic composition and coral demographics (the size classes of corals). Coral settlement rates are also measured at reefs in three regions. Intertidal seagrass meadows are monitored for percent cover, species composition, reproductive health and seagrass tissue nutrient status. This task is assisted by the community-based Seagrass-Watch programme (www.seagrasswatch.org). Further information: http://www.gbrmpa.gov.au/corp_site/key_issues/water_quality/marine_monitoring
Assessing the impacts of pesticides on marine ecosystems Andrew Negri, AIMS	To assess the effects of: • the herbicide diuron on the early life history stages of coral; • chronic herbicide exposure on reproductive output of reef-building corals; • herbicides on photosynthesis and growth of tropical estuarine microalgae; and • insecticides and a fungicide at multiple coral life stages. Further information: Negri *et al.,* (2005); Magnusson *et al.,* (2008); Markey *et al.,* (2007); Cantin *et al.,* (2007)
CRC Catchment to Reef Program – Complete Multiple Providers, coordinated by CRC Reef and Rainforest CRC	• To develop new tools to assess and monitor the health of catchments and aquatic systems in both the Wet Tropics and GBR World Heritage Areas. • The tools will enable land managers to mitigate the effects of human activities on water quality. • The three-year, $5 million project is now complete and is a joint initiative by CRC Reef and Rainforest CRC. Further information: http://www.reef.crc.org.au/research/catchment_to_reef/C2Rresearch.htm
National Action Plan Water Quality Program: Water quality impacts on ecosystem health (WQ06) – Complete Multiple providers	• To assess salinity and water quality impacts on Queensland freshwater ecosystems. Further information: http://www.wqonline.info/index.html

Adequacy of existing research and capability

- Substantial progress has been made on indicator development and assessment of marine water quality impacts since 2003.
- Long-term funding commitments are required to continue to assess water quality impacts and confounding influences.
- Very limited research connections between catchment activities and reef impacts.
- Most of the research has occurred at single geographic scale and is therefore addressing components of the system rather than connections between them.

Priority needs

- Development of a marine and estuarine material transport and biogeochemical model coupled with a detailed hydrodynamic and eco-physiological model for the GBR for improved understanding of the relationship between management actions and Reef ecosystem response.
- Investigation of the impacts of synergistic effects of influences on GBR ecosystem health including land based contaminants, climate change and other external drivers.
- Improvement in understanding of the interactions of pesticides in GBR catchment and marine ecosystems.
- Further development of understanding of cause and effect relationships between water quality and ecosystem health in freshwater ecosystems including quantitative assessment of the different requirements for catchment management for improved instream health.
- Understanding the response of estuarine systems to floods and the role of the coastal floodplain.
- The complexity of the relationship between nutrient enrichment, coral reef decline, macroalgal proliferation and abundances of grazing fishes (and other grazers) still prevents there being a clear consensus view on this specific relationship.

2. Quantify acceptable levels of pollution

Current major research projects

Many of the projects listed in Section 1 of Part B also attempt to quantify acceptable levels of pollution in determining water quality impacts.

Project	Primary objectives
GBRMPA Water Quality Guidelines development project Glenn De'ath and Katharina Fabricius, AIMS	• To provide technical background information and statistical data analysis for defining improved water quality guideline trigger values for the GBR Water Quality Guidelines. • To present spatial and seasonal characterisation of water quality conditions in the NRM regions, spatial characterisation of proxies used for reef ecosystem health, assesses relationships between water quality and reef ecosystem health, suggests trigger values for water quality to protect ecosystem health and assesses predicted improvement in ecosystem health if the trigger values are implemented. Further information: refer to De'ath and Fabricius (2008)

Adequacy of existing research and capability

- Targeted research on thresholds of concern for freshwater and marine ecosystems has commenced as part of the MTSRF program.
- Data integration has occurred for the first time to support the development of water quality guidelines.
- Substantial progress in last 12 months with publication of the report *Water Quality of the Great Barrier Reef: Distributions, effects on Reef biota and trigger values for the protection of ecosystem health*, (De'ath and Fabricius 2008) to support the establishment of GBR Water Quality Guidelines (GBRMPA, 2008).
- Additional capability is required on statistical integration of datasets.

Priority needs

- Refer also to 1 Assess water quality impacts.
- Completion of a risk assessment of the relative importance of sediments, nutrients and pesticides to marine ecosystems at a regional scale.
- Definition of acceptable/desired thresholds for key indicators (i.e. coral, seagrass and biodiversity).
- Knowledge of the response of the GBR ecosystem to different events in different areas, and the ability to recover. Understanding the implications of combined scale and frequency of disturbance to GBR ecosystems.

3. Locate and quantify the sources of pollution

Current major research projects

Many of the projects listed in Section 5 of Part B regarding assessments of the effectiveness of management practices also provide information relevant to locating and quantifying sources of pollution.

Project	Primary objectives
NRW I5 End of Catchment Load monitoring program David Roberts, NRW	• The ultimate goal of the program is to assess the effectiveness of management actions on reducing contaminant loads. • The project involves load monitoring at 31 sites in ten priority (high-risk) catchments – the Normanby, Barron, Johnstone, Tully, Herbert, Burdekin, O'Connell, Pioneer, Fitzroy and Burnett. • The project proposes a combination of water quality monitoring and modelling activities: monitoring of current condition of various scales within each catchment; determination of differences in measured water quality over time using various water quality and other climate and remote sensing information (modelling); determination of the long-term annual average relative contributions to water quality within each catchment; and determination of the level of land use change and the relative changes in water quality these different land use management options have had on a sub-catchment and catchment scale, compared with climatic and catchment condition variability influences (modelling). Further information: http://www.reefplan.qld.gov.au/whosinvolved/activities_monitoring_loads.shtm
Tully WQIP David Haynes, Terrain NRM	Various monitoring programs designed to assess contaminant sources and resource condition. Further information: Kroon, (2008); Terrain NRM (2008) http://www.terrain.org.au/index.php?option=com_content&task=view&id=141&Itemid=52
Sediment and nutrient transport on the Tully floodplain Jim Wallace, CSIRO	• The project describes measurements of sediment and nutrient concentrations in flood waters on the Tully and Murray floodplains, including overbank flow. • The concentrations of contaminants during floods are also assessed and compared with those recorded during channelised flow. The findings have potentially significant implications for future contaminant load monitoring and reporting programs. Further information: Wallace et al. (in press); Karim et al. (2008)

MTSRF Project 3.7.2: Connectivity and risk: tracing materials from the upper catchment to the reef Jon Brodie, ACTFR	See description above in 1 Assess water quality impacts. Includes assessments in the Tully, Burdekin and Mackay Whitsunday regions. Further information: http://www.rrrc.org.au/mtsrf/theme_3/project_3_7_2.html
Burdekin WQIP Ian Dight, Burdekin Dry Tropics NRM	Various monitoring programs designed to assess contaminant sources and resource condition including: event monitoring; current condition of regional water bodies; current condition and extent of riparian vegetation and wetlands, and their effectiveness in trapping contaminants; fate of contaminants in the GBR; and pesticide investigations in the Lower Burdekin. Further information: http://www.bdtnrm.org.au/cci/monitoring/
Burdekin Rangeland Condition Monitoring project Bob Karfs, DPIF; Brett Abbott, CSIRO	• The program identifies D condition lands in the Burdekin Rangelands using remote sensing and rapid assessment ground-truthing. • The project has also identified areas that are at risk of slipping into D condition, and this information will be used by BDTNRM to prioritise areas for future on-ground projects. Further information: http://www.bdtnrm.org.au/projects/nap0024.html
Black-Ross WQIP Chris Manning, Townsville Regional Council	Various monitoring programs were designed to assess contaminant sources and resource condition. Further information: http://www.creektocoral.org/cci/element2.html
Mackay Whitsunday WQIP Will Higham, Mackay Whitsunday NRM	Various monitoring programs were designed to assess contaminant sources and resource condition as part of the Healthy Waterways Integrated Monitoring Program. Further information: http://www.mwnrm.org.au/programs/
Fitzroy Regional NRM Plan Nathan Johnston, Fitzroy Basin Association	Various monitoring programs were designed to assess contaminant sources and resource condition. Further information: http://www.fba.org.au/programs/regional_water_quality_monitoring_and_reporting.html http://www.fba.org.au/programs/priority_neighbourhood_catchments_water_quality_monitoring_program.html
Burnett-Baffle WQIP Sandra Grinter, Burnett Mary NRM	Various monitoring programs were designed to assess contaminant sources and resource condition. Further information: http://www.bmrg.org.au/index.php
CRC for Coastal Zone Estuary and Waterway Management - Complete Multiple Providers	The project was initially part of the CRC for Coastal Zone Estuary and Waterway Management and studied biogeochemistry, primary production and material transport of various water quality parameters in the Fitzroy Estuary. Further information: http://www.ozcoasts.org.au/search_data/crc_pubs.jsp Webster *et al.,* 2006; Herzfeld *et al.,* 2006; Robson *et al.,* 2006a, 2006b; Douglas *et al.,* 2005; Margvelashvili *et al.,* 2003; Webster *et al.,* 2003
Receiving waters receiving model for the Fitzroy Estuary Barbara Robson, CSIRO	Recent work by CSIRO with the FBA aims to link catchment material transport models with these estuary models. Further information: Robson and Brando, 2008

DEWHA Project 9: Remote-sensing of GBR Waters to assist performance monitoring of Water Quality Improvement Plans in Far North Queensland Vittorio Brando, CSIRO	To assist GBR WQIPs by providing remote sensing capability to monitor chlorophyll, suspended sediment, water clarity and the colour dissolved organic matter. Involves the continued development of regionally appropriate algorithms for accurately reporting these parameters and the development of methods of reporting the information in ways useful to WQIP reporting and adaptive implementation. Further information: Vittorio.Brando@csiro.au
Reef Plan Nutrient Management Zones project (D8) Rebecca Paine, Department of Primary Industries and Fisheries	Nutrient Management Zones (NMZs) are geographical areas identified as high risk in terms of nutrient loss to waterways. By identifying NMZs, effort and assistance to improve nutrient management on farms can be focused to improve the quality of water entering waterways and the GBR lagoon. Further information: Brodie (2007); http://www.reefplan.qld.gov.au/library/pdf/D8_FAQs.pdf
NRW QScape Modelling Initiative Ken Brooks, Department of Natural Resources and Water	• The QScape project seeks to improve knowledge of how changes in land use, land management and climate affect land condition, water quality and ecosystem health, and additionally to contribute associated research products to other land, vegetation and water resources research. • QScape is virtual in organisation, integrating expertise from across existing NRW Natural Resource Sciences and regional science, with some direct supplementation of new remote sensing and modelling staff. QScape seeks to provide a flexible series of modular components for a variety of uses. Further information: Ken.Brooks@nrw.qld.gov.au
National Action Plan Water Quality Program: Modelling landscape processes, management impacts and catchment loads (WQ03) –Complete Multiple providers	To use spatial and temporal models to provide regions with user-friendly outputs related to landscape processes and the impacts of management practices on water quality. Further information: http://www.wqonline.info/index.html

Adequacy of existing research and capability

- Immense improvements in last five to six years through targeted monitoring and modelling programs in many catchments.
- Lack of whole-of-GBR approach for all contaminants even though knowledge may be adequate at some WQIP scales or across GBR catchments for a single contaminant (e.g. Nutrient Management Zones).
- Inconsistent information across regions and land uses.
- Long-term efforts are required.

Priority needs

- Refinement of model approaches that predict contaminant loads by incorporating finer temporal resolution, characterisation of hydrological processes, nutrient speciation and better techniques for quantifying uncertainty.
- Determination of the relative contributions of surface runoff and groundwater to loads and consideration of the role of groundwater transported contaminants (especially nitrate) from paddock to coastal waters.
- Investigation of the relative importance of gully erosion compared with hillslope erosion and whether targeted management is required, including review and integration of land-based modelling of sediment sources in the dry tropical catchments.
- Identification of major drivers of suspended sediment concentrations, both natural and/or anthropogenic, from different dry tropical sub-catchments, and identification of the specific origin of fine-grained, washload (non-settling) suspended sediment that may be transported large distances offshore.
- Improved nutrient budgets are needed to quantify the relative contributions of all sources in GBR waters; while all terrigenous sediments and pesticides are land-derived, some of the dissolved nutrients are sourced from deepwater upwelling and from nitrogen fixing blue-green algae.
- Understanding of the relationship between increased suspended sediment loads caused by increased erosion from agricultural and urban development in major rivers and increased regional turbidity from resuspension in inshore areas of the GBR lagoon.
- Improved conceptual and quantitative understanding of the transport and fate of nutrients and sediments in the GBR, particularly during non-flood times, through the development of process studies and implementation of supporting monitoring strategies.
- Analysis of the function of the coastal/estuarine interface in contaminant transport and transformation.
- Further development of high frequency, low cost data through the application of innovative monitoring techniques such as remote sensing to enable more comprehensive assessment of the presence and extent of contaminants in the GBR.

4. Identifying management practices to reduce pollution from key sources

Current major research projects

Refer also to Section 5 of Part B below regarding assessing management effectiveness.

Project	Primary objectives
DEWHA Project 11: The Model Farms Project: Systematic implementation of nutrient and sediment source controls on wet and dry tropical cane farms Multiple providers, led by Adam West, Department of Primary Industries and Fisheries	To make available to producers and management agencies model farming enterprises that demonstrate the economic and GBR water quality benefits of new generation farming systems, where those farming systems incorporating all applicable BMP and the development of new and evolving technologies, over a full sugarcane production cycle (three to five years). Case study areas – lower Burdekin and Tully. Further information: Adam.West@dpi.qld.gov.au
Wambiana grazing management: Impact of grazing strategies and variable rainfall on pasture composition Peter O'Reagain, DPI&F	• To compare grazing management strategies under variable rainfall conditions. • To demonstrate the benefits of sustainable management of grazing lands through trial of variable stocking rates and measurement of pasture condition, biodiversity, soil condition and surface runoff water quality. Further information: http://savanna.cdu.edu.au/publications/savanna_links_issue33.html?tid=250863
Improved environmental outcomes and profitability through innovative management of nitrogen (SRDC project CSE011; SRDC component complete) Peter Thorburn, CSIRO	• To test approaches to reduce nitrogen fertiliser application in sugarcane industry and to trial the N-Replacement concept. • The project involved on-farm experiments from the Wet Tropics of Queensland to northern New South Wales, covering a range of soil types and cane varieties. • Further validation of the approach is underway in GBR catchments. Further information: http://www.csiro.au/files/files/pjdh.pdf; Thorburn et al. (2003a, b; 2007), http://www.srdc.gov.au/ProjectReports/ViewReports.aspx?ProjectNo=CSE011
Adopting systems approaches to water and nutrient management for future cane production in the Burdekin (CSE012) – Complete 2008 Multiple providers, funded by SRDC	• To develop a range of proven farm management options for improved water, nutrient and crop management that will maintain or increase profitability, while controlling rising water tables, reducing the risk of irrigation-induced salinity and improving off-farm water quality. • To carry out assessments of the economic feasibility of the proven farm management options within the context of future water pricing and water allocation scenarios in the Lower Burdekin. • To establish industry reference sites with grower participation to provide robust benchmarks and to assist in the dissemination of project learnings. Further information: http://www.srdc.gov.au/ProjectReports/ViewReports.aspx?ProjectNo=CSE012

Sustainable grazing for a healthy Burdekin catchment – Complete 2006 (MLA project NBP.314) Multiple providers, led by David Post, CSIRO and Peter O'Reagain, DPI&F	To implement grazing land best management practices (full wet season spelling and forage budgeting) on Virginia Park Station in the Burdekin catchment in order to examine the impact of these practices on land condition recovery, landscape health and the consequent leakiness of water, sediment, and nutrients both from the hillslope and the catchment. Further information: Post *et al.,* 2006 http://www.clw.csiro.au/publications/science/2006/sr62-06.pdf
Accelerated adoption of best-practice nutrient management – Complete 2008 Multiple providers, funded by SRDC, led by Bernard Schroeder, BSES	• To improve on-farm profitability (reducing fertiliser costs by $60/ha or 65 c/t of cane) and ensure greater environmental accountability and responsibility through accelerated adoption of integrated nutrient management. • To improve knowledge of the constraints to the adoption of best-practice nutrient management using grower surveys. • To develop a Soil Capability and Management Package (SCAMP) for improving on-farm management decision-making and facilitate the use of nutrient management plans at block and farm scales and the implementation of soil/site specific fertiliser applications using a participative approach. • To assess the risks of on- and off-site impacts of land management practices using vulnerability maps at catchment scale. • To demonstrate the benefits of best nutrient management practices with on-farm strip trials. Further information: http://www.srdc.gov.au/ProjectReports/ViewReports.aspx?ProjectNo=BSS268
Sustainable Agriculture State-level Investment Program (AgSIP) – various projects – Complete 2007 Multiple providers	• AgSIP was a state-level investment program of the National Action Plan for Salinity and Water Quality. The program ran from August 2004 until June 2007. • To develop new processes, tools and frameworks to facilitate agricultural practice change where needed in order to help regional NRM groups design, refine, deliver and review their regional investment strategies and natural resource management plans. • The project involved looking at existing practices, developing new recommended practices where needed, filling data gaps, designing integrated landscape monitoring systems, and developing better training and decision-support tools across cotton, cane grazing and horticulture industries.

Adequacy of existing research and capability

- Substantial improvements in the last five years.
- WQIPs are the first attempt to target 'key contaminants' in a restricted area. Established qualitatively good practices but quantitative assessments are inadequate.
- Grazing land management practices will successfully deal with hillslope erosion, while riparian vegetation management is able to minimise streambank erosion, but practices related to management of gully erosion requires further investigation.

Priority needs

- Completion of robust triple bottom line evaluations of current and proposed management actions as a basis to design more cost-efficient management interventions in the future.
- Development of new land management practices for improved water quality outcomes.
- Investigation of the social/economic/institutional aspects of delivering practice change.
- Establishment of capability to determine the relative importance of the location of the works in the landscape in terms of material delivery.
- Assessment of the relative importance of the type of groundcover maintained in grazing lands to minimise sediment loss, and the efficiency of different groundcovers in managing hillslope erosion (i.e. 'natural' cover of trees and shrubs or savannah, compared to pasture).
- Development and testing of sustainable grazing and fire management guidelines for riparian and frontage country in the extensive dry rangelands.

5. Assess the effectiveness of actions to reduce pollution

Current major research projects

Refer also to Section 4 in Part B regarding identification of management practices, many of these projects test the effectiveness of the actions.

Project	Primary objectives
DEWHA Project 4.2: Implementing agricultural source controls through accredited Farm Management Systems in the Mossman Mill District Peter Bradley, Terrain NRM	To target components of the Douglas Shire Fertiliser Management Strategy and the Douglas Shire Cane Drain management Strategy as identified in the Douglas WQIP. These and other BMPs will be implemented and monitored. Further information: peter.bradley@DSC.qld.gov.au
Douglas WQIP Fertiliser management trials Tony Webster, CSIRO	To test variable nitrogen fertiliser application rates in sugarcane in Mossman and assess the water quality and economic benefits. Further information: Tony.Webster@csiro.au
Mackay Whitsunday management practices (rainfall simulator) experiment Ken Rohde, Department of Natural Resources and Water	To assess sediment, nutrient and herbicide runoff from canefarming practices in the Mackay Whitsunday region: a field-based rainfall simulation study of management practices Further information: Masters *et al.,* 2008
Wetland filter function David McJannet, CSIRO	To develop a detailed understanding of the potential for wetlands on the Tully-Murray floodplain to regulate and filter agricultural runoff before it drains to the GBR lagoon. Further information: http://csiro.au/science/ps3ox.html; McJannet (2007
MTSRF Project 3.7.5: Socio-economic constraints to and incentives for the adoption of land use and management options for water quality Martijn van Grieken, CSIRO	• Evaluate the socio-economic constraints to and risks associated with the adoption of land use and management options for water quality improvement at the private and social level. • Identify and assess instruments that are most cost-effective in promoting the adoption of these ‘best’ land use and management options by community embedded agents in rural and urban areas in North Queensland’s catchments. Further information: http://www.rrrc.org.au/mtsrf/theme_3/project_3_7_5.html
Case study applications of a Single Entity Policy Impact Assessment model Alex Smajgl, CSIRO	The SEPIA (Single Entity Policy Impact Assessment) model simulates land-use decision making enacted by agents involved in agricultural production. The current application includes sugarcane, tree fruit, and beef cattle (grazing) producers, and is applied in the Douglas Shire, Burdekin region and Tully catchments. Further information: http://www.csiro.au/news/newsletters/0411_water/story1.htm
DEWHA Project 6: Decision Support Tools for Nutrient Management in Tropical Horticulture Phil Moody, NRW	Reduce nutrient loadings to the GBR by working with producer reference groups and industry associations in the Johnstone, Tully and Don/Burdekin catchments to develop science-based tools for improved nutrient management in tropical horticulture. Further information: [redacted]

Adequacy of existing research and capability

- Significant gaps in quantitative knowledge of the effectiveness of practices – rudimentary knowledge across practices.
- Substantial uncertainty between the relationship of improved water quality at a paddock scale, reduced loads and the effect on the GBR, and therefore, uncertainty in exact target setting to achieve specific GBR outcomes.
- Limited investigation of the tradeoffs (if any) between BMPs, profitability and production, especially in extensive grazing lands.
- Major opportunity to measure the effectiveness of improvements through Reef Rescue investment.

Priority needs

- Establishment of a GBR-wide initiative to effectively validate management practices across land uses in the GBR catchments, including the efficacy of practices in regionally specific applications, from the perspective of water quality outcomes and profitability.
- Establishment of modelling and monitoring systems that quantify the responses of the catchment socio-ecological system to management interventions.
- Commencement of a GBR-wide monitoring program to undertake socio-economic benchmarking of the current adoption rates, extension efforts and industry culture by region and commodity.
- Development of a specific metric for each sector group (e.g. grazing) aimed at measuring outcomes from actions to allow comparisons across sectors.
- Assessment of the drivers that will lead land managers to change practices for water quality improvement.
- Investigation of the design of optimal monitoring and modelling programs in GBR catchments that enable detection of short- or medium-term trends in water quality at large spatial and temporal scales.

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Australian Government

Queensland Government

DPC1658

Assessment of relative risk of the impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under the Reef Protection Package

Stage 1 Report
April 2009

ACTFR REPORT NUMBER 09/17

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Important message from the Director-General

The Queensland Government's Department of Environment and Resource Management (DERM) commissioned the Australian Centre for Tropical Freshwater Research (ACTFR) to assess the relative risk from agricultural activities which may contribute diffuse pollution to deteriorating water quality in the Great Barrier Reef.

This work is only one aspect of the ongoing science program, which is informing and providing the platform for the implementation of Reef Plan and the roll-out of Queensland Government's Reef Protection Package.

This report is the first of two reports that present the outcomes of the project: *Assessment of relative risk of impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under Reef Protection Package*:

1. Assessment of relative risk of the impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under the Reef Protection Package, Stage 1 Report April 2009; and
2. Regional assessment of the relative risk of the impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under the Reef Protection Package, Stage 2 Report July 2009.

The reports are based on the best available science, with clearly stated parameters and reasonable assumptions. They also acknowledge any limitations in data and uncertainties.

The reports represent the best available science at the time of publication. They provide the Queensland Government with a relative risk assessment of the impacts of agriculture on the Great Barrier Reef in order to make policy decisions in terms of investment in extension, research, regulation and other efforts to improve reef water quality. The Queensland Government is committed to ongoing investment in Reef Protection science and as new information becomes available government policy will be adapted to take account of it.

It is important to understand the information in these reports in context and that reference to and excerpts from these reports are presented in an appropriate manner. Should you have any further enquiries, please do not hesitate to contact [redacted], Project Manager from the department on telephone [redacted]

[redacted]

John Bradley
Director-General
Department of Environment and Resources

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Acknowledgements

Funding for this project came from the Queensland Department of Environment and Resource Management (DERM) (formally the Environment Protection Agency). The authors would like to acknowledge the project team and funding agencies associated with the report, *Current loads of priority pollutants discharged from Great Barrier Reef Catchments to the Great Barrier Reef* (Brodie et al., 2009) which formed the foundation for many of the revised figures provided in this report. This project and the current contract was carried out in conjunction with parallel projects funded by the CSIRO Great Barrier Reef Water Quality Options project under Water for a Healthy Country, and the Marine and Tropical Sciences Research Facility administered through the Reef and Rainforest Research Centre.

Disclaimers

Introduction

A variety of evidence clearly indicates that exports of sediment, nutrients and pesticides from the catchments adjacent to the Great Barrier Reef (GBR) have increased substantially with catchment development, although the magnitude of the increases compared with natural conditions is not precisely known. Contemporary land uses differ in their export rates of contaminants, and there are marked cross-regional differences, particularly between the Wet and Dry Tropics. There is also well-documented evidence of the adverse impacts of these contaminants on GBR ecosystems, and the relationship between land use and catchment management, water quality and declining GBR ecosystem health. This led to a national policy response in 2003 with Federal and State government endorsement leading to the establishment of the Reef Water Quality Protection Plan (Reef Plan).

The GBR catchment area is defined by 6 Natural Resource Management (NRM) regions (Figure 1), each with different land use, biophysical and socio-economic characteristics. The Cape York region is largely undeveloped and is considered to have the least impact on GBR ecosystems from existing land based activities. In contrast, the Wet Tropics, Burdekin Dry Tropics, Mackay-Whitsunday, Fitzroy and the Burnett-Mary regions are characterised by agricultural land uses including sugar cane, grazing, bananas and other horticulture, cropping such as grains and cotton, mining and urban development, and contribute varying amounts of land based contaminants to the GBR in the wet season.

Current knowledge about the sources of contaminants from specific land uses, and priority source areas of contaminants was summarized in the recently released *Synthesis of evidence to support the Scientific Consensus Statement on Water Quality in the Great Barrier Reef* (Brodie et al., 2008). Key points from this document are included below.

Land use contributions of contaminants

Monitoring and modelling identify the main sources of nutrients, sediments and pesticides in the GBR catchment from different land uses, and show strong regional differences. Evidence includes:

- *Nitrogen* – a strong relationship exists between the areas of nitrogen-fertilised land use in a catchment and the mean nitrate concentration during high flow conditions, implicating fertiliser residues as the source of nitrate. Elevated stream concentrations of nitrate indicate fertiliser application above plant requirements in sugarcane and bananas.
- *Phosphorus* – elevated concentrations of dissolved inorganic phosphorus are also related to fertiliser application above plant requirements in intensive cropping and to locally specific soil characteristics.
- *Sediment* – most sediment originates from grazing lands of the dry and sub-tropics. The influence of land use on sediment loads is now well known at a regional scale but more work is required to identify sources at finer scales, due to variability associated with hillslope, streambank and gully erosion within individual catchments.
- *Pesticides* – concentrations in waterways are highest in areas of intensive agricultural activity including sugarcane and grains but also from grazing lands (tebuthiuron).

Anthropogenic loads of contaminants can be estimated from modelled results of pre-European estimates and current loads defined using monitoring and modeling. Based on the most recent estimates of DIN loads, it is estimated that the total current DIN load to the GBR is approximately 13,500 tonnes per year, the total anthropogenic load to the GBR is approximately 6,900 tonnes per year (approximately 52% of the total load). Of the 6,900 tonnes anthropogenic DIN load to the GBR, approximately 6,150 tonnes is estimated to be derived from sugar cane (approximately 89% of the anthropogenic load), 730 tonnes from horticulture (11% of the anthropogenic load) and 60 tonnes (approximately 1% of the anthropogenic load) other land uses including urban and other crops.

It would be beneficial to develop similar budget estimates of anthropogenic load for sediment and other nutrient species, however, the analysis is more complicated and the data is not readily available at this time. However, this analysis is being planned in a CSIRO Water for a Healthy Country Flagship project later in 2009 (Brodie et al., In prep).

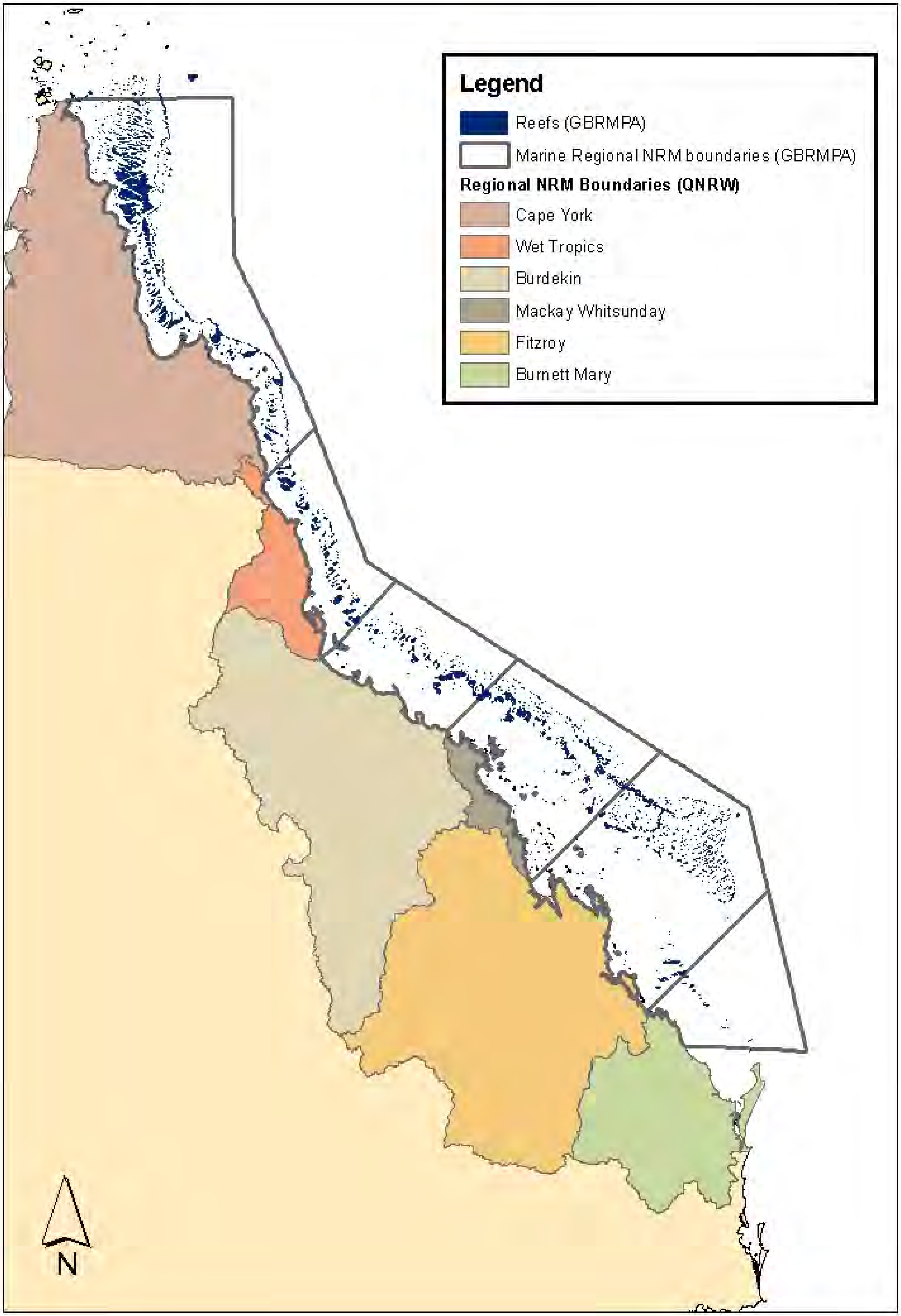

Figure 1. Regional Natural Resource Management Regions in the Great Barrier Reef catchments.

Regional sources of contaminants
Analysis of data on fertiliser use, loss potential and transport has ranked fertilised agricultural areas of the coastal Wet Tropics and Mackay Whitsunday as the hot-spot areas for nutrients (mainly nitrogen) that pose the greatest risk to GBR reefs (Brodie, 2007).

In the Dry Tropics, high suspended sediment concentrations in streams are associated with rangeland grazing and locally specific catchment characteristics, whereas sediment fluxes are relatively low from cropping land uses due to improvements in management practices over the last 20 years (Dight, 2009).

In the Wet Tropics, sediment fluxes are comparatively lower due to high vegetation cover maintained throughout the year from high and year-round rainfall and different land management practices (Kroon, 2008) from Dry Tropics regions within industries such as beef grazing.

Urban development sites can be local high impact sources of suspended sediment.

Of the herbicide residues most commonly found in surface waters in the GBR region, diuron, atrazine, ametryn, hexazinone derive largely from areas of sugarcane cultivation, while tebuthiuron is derived from rangeland beef grazing areas (Lewis et al., 2009).

Scope

The Queensland Government's recently released Reef Protection Package proposes to focus on the major catchments delivering the most probable impact on the GBR based on estimates of the quantity of land based contaminants discharged from the region, the proximity of the catchment to vulnerable reef ecosystems, the existing condition of the reef ecosystems and the nature of the industries contributing contaminant loads.

The Queensland Department of Environment and Resource Management (DERM) (formally the Environment Protection Agency) engaged the Australian Centre for Tropical Freshwater Research (ACTFR) to identify the relative risk of contaminant loadings from broad-scale agriculture in the GBR Catchments to GBR health, by completing the following tasks:

- Review the Queensland Government's initial identification of the relative risks of contaminant loadings from broad-scale agriculture (including grazing, cane-growing, bananas, other horticulture and other crops (cotton and grains)) to GBR Catchments (the Synthesis Table) as provided in Appendix 1. This was drawn from three sources of information:
    - Brodie J., L.A. McKergow, I.P. Prosser, M. Furnas, A.O. Hughes, H. Hunter. (2003). Sources of Sediment and Nutrient Exports to the Great Barrier Reef World Heritage Area. ACTFR Report No. 03/11. Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.
    - De'ath, G; K. Fabricius. (2007). Water Quality of the Great Barrier Reef: Distributions, Effects on Reef Biota and Trigger Values for Conservation of Ecosystem Health. Report to the Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science.
    - Maughan, M., J. Brodie, J. Waterhouse. (2008). Reef Exposure Model for the Great Barrier Reef Lagoon. ACTFR Report No. 07/19. Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

- Provide advice on the accuracy of the information presented, and any recent or updated information that should be considered. This should include recent analysis conducted through:
    - Multi-criteria analysis for Reef Rescue
    - Recent update of SedNet Version 2, Reef Exposure and the Nutrient Budget module (known as ANNEX[1])) modelling at catchment and sub-catchment level

- Update the Synthesis Table in Appendix 1 and provide advice on relative risk/impact of contaminant loadings from broad-scale agriculture in the GBR catchments on GBR health and the rationale.

[1] ANNEX – the Annual Network Nutrient Export module

Synthesis of Relative Risk Attributes

A number of amendments to the Synthesis Table provided by DERM are recommended and are outlined below. The methods used to support the assessment are also described, in addition to the data limitations.

1. Basins

All of the major basins for each region are listed; regions are defined by the Regional NRM boundaries.
Note that the Barron and Russell Mulgrave catchments were excluded from the Wet Tropics in the draft table provided by DERM and have been added.

2. Contaminants

Species: Based on the information included in the Introduction, the following contaminants were considered in this assessment:

- Total Suspended Sediment (TSS): Sourced from erosion, particularly in grazing lands.
- Dissolved Inorganic Nitrogen (DIN): Fertiliser nitrogen; bioavailable.
- Photosynthetic PSII Herbicides: Longer half life than other herbicides and widely used in cropping practices.

Estimates for PSII Herbicides were added to the Synthesis Table for each region, sourced from Brodie et al., (2009). The total pesticide loads – consisting of atrazine, ametryn, hexazinone, simazine, tebuthiuron and diuron, and called PSII Herbicides – derived from Maughan et al. (2008) are based on only two land use types – sugarcane and cotton – and don't include other land uses such as forestry, grazing, other cropping and urban. As a result, some herbicides associated with these land uses are not included in the calculations and the total loads are likely to be an underestimate.

Other parameters were not included in the assessment for the following reasons:

- Phosphorus is generally associated with TSS and therefore was not considered individually in this assessment.
- Dissolved Organic Nitrogen (DON) and Dissolved Organic Phosphorus (DOP) are not particularly relevant given the management options that are currently available.
- Current nutrient management options, e.g. 6 Easy Steps, will address nitrogen and phosphorus in combination.
- Dissolved Inorganic Phosphorus (DIP) is a low priority contaminant to the GBR (but maybe significant in some regions) in the context of agricultural runoff to the GBR.

Pre-European estimates: Pre-European estimates of contaminant loads are modelled in Brodie et al., (2003) and provide a basis to estimate the influence of land use change in the GBR catchment. The figures that were included in the Synthesis Table were checked against Brodie et al., (2003); no amendments were made.

Estimates of natural load for this study were taken from Brodie et al. (2003) and the SedNet model made assumptions that the catchment was in pre-European condition with natural vegetation cover, no gullies and no agriculture or urban development. However, these assumptions cannot be verified and potentially introduce large error margins, and therefore the estimates are uncertain. Given these uncertainties in the estimates of current loads, when the increase in current over natural load is calculated (i.e. the anthropogenic load) negative values may be obtained in cases where little real change has occurred. These negative values are a result of working with estimates that have large error margins and therefore should be considered as 'no net change' in load rather than an improvement in catchment condition or reduced loads.

Current estimates and Sources: The current load estimates and sources of each contaminant (proportional land use contributions) were sourced from Brodie et al., (2009), apart from the exceptions outlined below in relation to Dissolved Inorganic Nitrogen (DIN) loads. The land use contributions were calculated using the Brodie et al. (2003) study to calculate proportional contributions for each parameter (using land data from 1999) and then applied that to current load estimates. This is at best a crude estimate of the contribution of different land uses to the overall load. It is currently difficult to differentiate sources of contaminants from specific horticultural activities in each region due to limited data availability, however, where this information is available (e.g. bananas in Wet Tropics catchments) it has been included. Therefore, the figures for horticulture represent the collection of intensive fruit and vegetable cropping activities. Urban activities are incorporated into the land use type defined as 'Other', but are not explicitly addressed in this assessment in accordance with the scope.

a) Wet Tropics: Estimates for the proportion of DIN delivered by sugar land uses were modified to take into account more recent studies for the region included in Table 1.

Table 1. Estimates of the proportion of cane and horticulture contributions to the DIN load in Wet Tropics Region

Catchment	Source	Land use contributions to the DIN load
Johnstone	Hunter and Walton 2008 (Table 3)	60% from cane and 15% from horticulture (predominantly bananas)
Tully Murray	Armour et al., 2007	77% from cane and 8% from horticulture (predominantly bananas)

Using these estimates, and based on knowledge of land use areas in the Wet Tropics region, it is estimated that the sources of DIN in the region are approximately 75% sugar and 5% bananas, 12% grazing and forest, and 8% other crops / dairy and urban.

b) Burdekin: Updated figures for the sources of DIN to the regional load were published in Brodie and Bainbridge, (2009). Previous estimates reported by Brodie et al., (2003) did not include accurate modeling of the lower Burdekin sugar area. The method for the estimate is described on page 20 of that report, justifying the estimated surface and sub-surface annual losses of 3,000 tonnes (2,000 tonnes loss to GBR waters by surface pathway and 1,000 tonnes loss to GBR waters by groundwater pathway. Therefore, the overall total annual load estimate of DIN delivery to the GBR for the region is estimated to be 4,480 tonnes, as shown below.

Table 2. Revised estimates of the proportion of land use contributions to the DIN load in the Burdekin Region

Catchment	Estimated DIN (t)	Source
Lower Burdekin sugar area (includes Haughton R and Barratta Creek in additional to small coastal creeks)	3000	Brodie and Bainbridge 2009
Burdekin River (predominantly grazing)	1300	Bainbridge et al 2008
Don River (predominantly grazing and horticulture)	60	Post et al 2006
Ross River (predominantly grazing and urban)	70	Brodie et al 2003
Black River (predominantly grazing and urban)	60	Brodie et al 2003
Total	4480	

It is assumed that the majority of the DIN generated by sugar activities is within the lower Burdekin, therefore contributing approximately 67% (3000 / 4480) of the overall DIN load. The estimated contribution from grazing to the regional DIN load has been reduced substantially from previous estimates of approximately 80% to 18% to account for the above findings related to sugar (Brodie et al., In prep.). The remaining contributions are likely to be derived from forest (12% - Brodie et al., 2003) and other land uses including urban and other crops (3%).

c) Mackay Whitsunday: Figures for the estimated source of DIN loads in the Mackay Whitsunday region are updated with those included in the Mackay Whitsunday WQIP (Drewry et al., 2008 p.12) - see Table 3 below.

Table 3. Relative contribution of land uses of the Mackay Whitsunday region DIN load

Land use	Estimated DIN contribution	Category used for this report
National Parks and Reserves	1%	Forest
Grazing	12%	Grazing
Horticulture	1%	Other crops
Cane	77%	Sugar cane
Intensive Uses	4%	Other
Urban	4%	Other

d) Burnett Mary**:** Updated estimates of DIN loads for the Burnett Mary region have been revised from the draft target setting report for the Burnett/Baffle WQIP (Brodie and Grinter, In prep). Updated figures show that the amount of DIN generated from coastal sugar and horticultural activities is substantially higher than was previously estimated. The revised estimates are based on upper catchment (predominantly grazing) and coastal (predominantly sugar and horticulture) land use contributions in Table 4.

Table 4. Revised estimates of the proportion of land use contributions to the DIN load in the Burnett Mary Region

Catchment	Estimated DIN (t)	Source
Burnett and Baffle River coastal sugar and horticulture area	750	Brodie and Grinter, In prep
Upper Burnett catchment (predominantly grazing)	300	Brodie and Grinter, In prep
Mary River coastal sugar and horticulture area	300	Derived from Brodie et al., 2003
Upper Mary River (predominantly grazing)	150	Derived from Brodie et al., 2003
Total	1905	

Using these estimates, the proportion of DIN generated by sugar and horticultural land uses in the Burnett Mary region is estimated to be 55% (1050 / 1905), grazing 25%, forest 18% and other land uses 2%.

Other data limitations

In addition to the data limitations identified above, it should be noted that all models like SedNet have substantial limitations in accuracy of estimation of loads. Some of these limitations are discussed in Brodie et al., (2009) and in Shermann et al. (2007), Bartley et al. (2007), Bainbridge et al. (2007), Lewis et al. (2007b) and Hateley et al. (2007).

3. Current Reef Condition

The Reef Condition data used in the assessment is derived from the report prepared by De'ath and Fabricius (2008) to support the development of the Great Barrier Reef Marine Park Authority Water Quality Guidelines (GBRMPA, 2008). Current reef condition coupled with water quality data can provide an indication of the previous exposure of an ecosystem to declining water quality. It could also be considered to be a useful indicator of the resilience of a reef to future contaminant exposure. However, it is difficult to make assumptions about the likelihood of the impact of ongoing or increased contaminant exposure without considering more detailed data on a baseline or reference condition (generalised on a regional basis). Whilst this would produce a more robust assessment of the risk of contaminant exposure to particular reef assemblages, the effort involved is considered to be beyond the scope of this project. Therefore, the current condition of coastal and inshore reefs and water quality reported in De'ath and Fabricius (2008) will be used in this assessment, and any application of the results should acknowledge these limitations.

It should also be noted that the Burnett Mary region does not include any data for Inner Shelf Macroalgal Cover or Hard Coral Richness. This is true for the marine areas within the GBR Marine Park boundary which is the scope of the assessment completed by Death and Fabricius (2008), but it is probable that datasets for reefs south of the Marine Park boundary and still relevant to the Burnett Mary catchments are available (pers comm. Maria Zann, EPA). Sourcing these datasets was not considered to be within the scope of this assessment but is recommended for any future work.

For the incorporation of the Reef Condition data in this assessment, it is recommended that:

1. The 'Inner Shelf' data is also reported for each of the parameters (in addition to 'Coastal' data), as the extent of influence of land runoff extends to the areas defined as 'Inner Shelf' in most locations. Recent access to satellite imagery also indicates that the influence of river plumes also extends to offshore locations, but those ecosystems likely to be exposed to contaminants most frequently and most severely are those in the coastal and inner shelf assemblages.

2. Reference is made to the method applied in Death and Fabricius (2008) for defining the cross shelf boundaries. Page numbers have been added in the footnote. The following explanation for these

We have consistently found relative distance across the shelf to be the most meaningful measure to define offshore structure (De'ath 2007b; Fig. 5). It is a homogeneous measure across the 6 NRM regions and more practical than an absolute distance from the shore as it also considers the distance from the open ocean at the edge of the continental shelf. We set the boundaries at a relative distance of 0.1 and 0.4 across the shelf. These boundaries together with the coast (across = 0) and the outer edge of the continental shelf (across = 1) define three regions: (i) coastal = 0 – 0.1, (ii) inner shelf = 0.1 – 0.4, and (iii) offshore = 0.4 – 1.0 (Fig. 6). The coastal zone boundary is located 5 - 7 km off the shore (and hence similar to EPA's 3 nautical miles) in the Cape York, Wet Tropics and Burnett Mary Regions where the shelf width is 50 - 70 km, and ~20 km off the shore in the Fitzroy Region (Table 1).

Table 1: Approximate mean distances of the coastal boundary (0.1 across) and inner shelf-offshore boundary (0.4 across) from the coast in the 6 NRM regions.

	Mean shelf width (approximate, km)	0.1 across (km)	0.4 across (km)
Burnett Mary	70	7	28
Fitzroy	200	20	80
Mackay Whitsundays	150	15	60
Burdekin Dry Tropics	120	12	48
Wet Tropics	60	6	24
Cape York	60	6	24

3. The GBR mean is reported for each value to provide reference for categorising the Reef Condition values as low, medium or high. These have been added to the Synthesis Table.

Further explanation of the selection of the following parameters in the Synthesis Table is as follows.

Macroalgal cover: Macroalgal cover, reported as % cover, can be used as an indicator of exposure of reefs to poor water quality and reduced grazing (particularly fish) pressure. Research has shown that high levels of nutrients and sediments lead to high macroalgal cover, low coral biodiversity and low rates of coral recruitment on inshore reefs, slowing rates of coral recovery after disturbances, and increasing frequency of outbreaks of crown-of-thorns starfish.

Hard coral richness: Coral richness is the number of coral species present in a survey area. While hard coral cover is predominantly determined by disturbance history, the species richness of hard corals appears to be a sensitive indicator of the physico-chemical environmental conditions of a site. Data are based on surveys conducted on 110 reefs (599 transects) of the GBR between 1994 and 2001 (Devantier et al. 2006; Fig 3). The analyses presented here are based on reef averaged data.

Secchi Depth: Reported as metres (m), secchi depth provides a useful indicator of suspended sediment and particulate matter in the water column which is enhanced from land based runoff. High secchi depth generally reflects a light climate suitable for benthic coral growth, whilst low secchi depth reflects turbid water and a poorer light climate. The GBRMPA Water Quality Guideline for secchi depth is defined as >10 metres (GBRMPA, 2008).

Chlorophyll: Reported as micrograms per litre (µg/L), concentrations of the plant pigment "chlorophyll a" (which occurs in all marine phytoplankton) provide a useful proxy indicator of the amount of nutrients incorporated into phytoplankton biomass, because phytoplankton have predictable nutrient-to-chlorophyll ratios. Chlorophyll a is the most commonly used parameter for monitoring phytoplankton biomass and nutrient status, as an index of water quality (Brodie et al., 2007). The GBRMPA Water Quality Guideline for chlorophyll is defined as <0.45 µg/L (GBRMPA, 2008).

4. Reef Exposure

With regard to the draft Synthesis Table, reference to the regional maps included in Maughan et al., (2008) is not considered to be useful for the potential application of this table in terms of being user friendly, and the fact that the figures referred to were produced for WQIP areas and not complete regions. In addition, it is not recommended that the 'combined contaminant' figures are referenced because it is now realised (after review of the report) that combined coverages do not work because of the different values in the individual ranges of parameters.

An estimate of the exposure of individual reefs to various contaminants provides the basis of a vulnerability assessment of GBR condition from water quality influences. Ideally, an exposure criterion would factor parameters such as the proximity of the reef to the source of the contaminant, the likelihood and frequency of exposure of the reef to river plumes, and the amount of contaminant within the plumes at a range of distances. The best attempt of this kind of assessment for the GBR to date is the Reef Exposure model developed by Maughan et al., (2008). The model provides a relatively simple way of combining contaminant load estimates, river flow and variability characteristics with plume and contaminant behaviour, and the distance of every reef to each river mouth to give an estimated reef exposure class. The classes range from Low to Very High for each contaminant, and the classes are defined arbitrarily. There are some limitations with the model that should be acknowledged for the incorporation of the results in this assessment. In particular, the River Variability Index is currently given a higher weighting in the model that what is now considered to be appropriate. Essentially the low variable rivers like the Wet Tropics are given a high weighting which substantially over emphasizes this index against other more variable rivers such as the Mackay Whitsunday catchments. A revised version of the model that addresses this has been undertaken for the Fitzroy region (Maughan and Brodie, 2008). However, this same adjustment needs to be made to the model for the rest of the GBR.

A number of ways of applying Reef Exposure as a criteria in this assessment were considered:

a) An estimate of the area of each region in the 'Medium', 'High' or 'Very High' exposure classes from Maughan et al., (2008) for TSS, DIN and PSII Herbicides. Presently, this estimate is derived from visual judgement of the figures incorporating the extent of the regional boundaries to the outer reef, but given more time, results from spatial analysis could be incorporated. These percentages were then categorised and added to give a 'Reef Exposure Score'.
b) Calculation of the number of reefs in the exposure categories 'Medium', 'High' or 'Very High' from Maughan et al., (2008) for TSS, DIN and PSII Herbicides. These values were then categorised and added to give a 'Reef Exposure Score'.
c) Calculation of the number of reefs within 50km of the coast for each region (Figure 2). These values were then categorised to give a 'Reef Exposure Score'.

The final assessment incorporates method (b) for defining reef exposure, which is the number of reefs in the exposure categories medium to very high as defined in Maughan et al., (2008) for each region. This was considered to be more accurate than method (a) (visual assessment only), and incorporates additional factors (e.g. river variability) than method (c).

A synthesis of these parameters is presented in a table in Appendix 1.

5. Overall Reef Risk

The draft Synthesis table (as provided by DERM) included an initial identification of the relative risks of contaminant loadings from broad-scale agriculture to GBR Catchments (titled Appendix 1). This table contained an Overall Reef Risk category. A simple exercise has therefore been completed to provide a relative risk rating using the updated table. **It should be emphasised that this is a very simple and rapid assessment that may provide a starting point for a more sophisticated assessment. The categorisation of all of the parameters is <u>relative</u> - it is in no way an absolute risk assessment.** The method for the overall assessment is outlined below.

The parameters were grouped into 3 criteria: Anthropogenic Load, Reef Condition, and Reef Exposure. The final criteria contained the parameters listed below in Table 5.

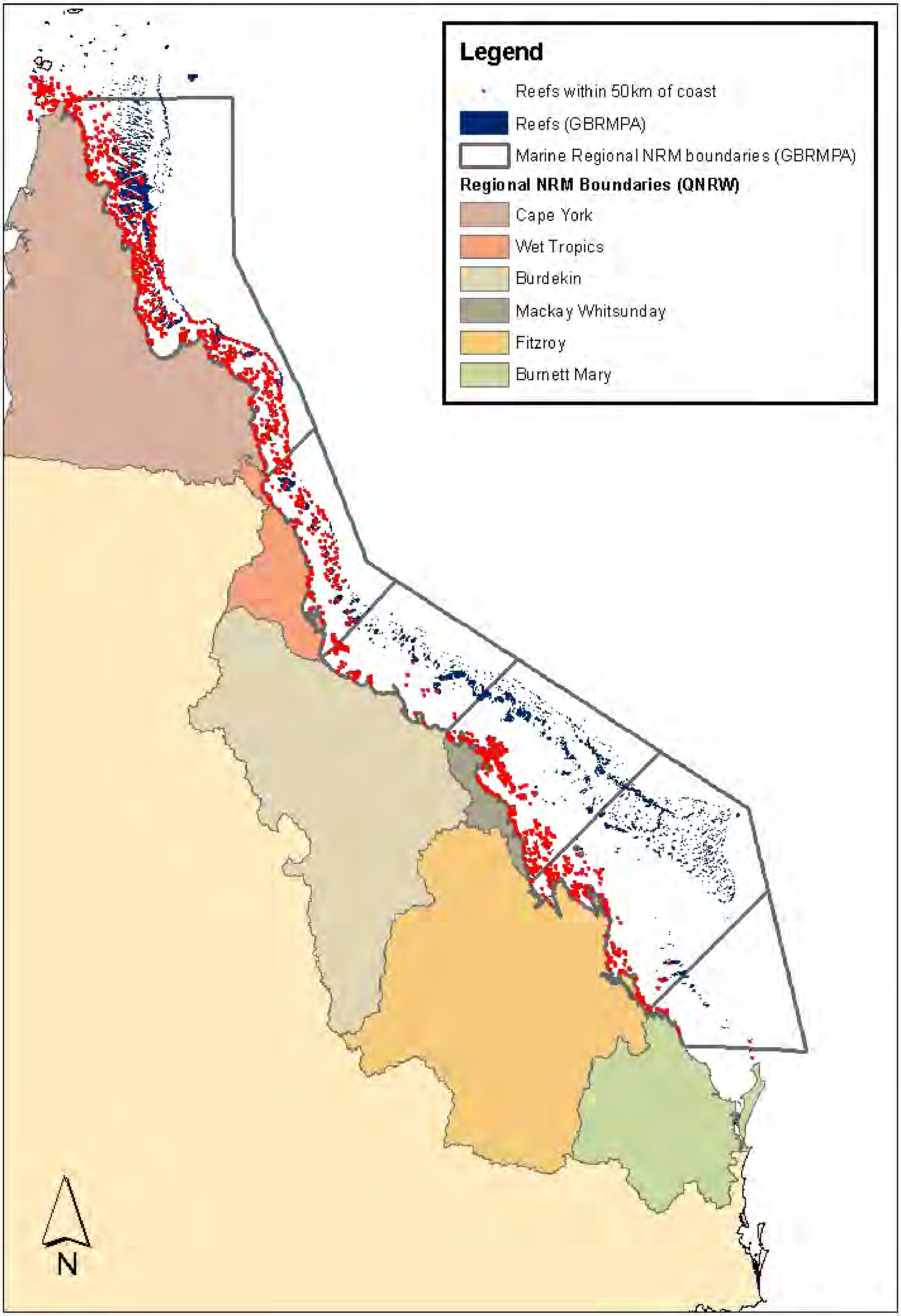

Figure 2. Reefs within 50 kilometres of the coast.

Table 5. Summary of criteria and parameters used in the Relative Risk Assessment

Criteria	Parameter
Anthropogenic load	Total Suspended Sediment (TSS) (tonnes)
	Dissolved Inorganic Nitrogen (DIN) (tonnes)
	PSII Herbicides (tonnes)
Reef Condition	Macroalgal cover (%)
	Coastal Macroalgal cover
	Inner Shelf Macroalgal cover
	Hard Coral Richness (Number)
	Coastal Hard Coral Richness
	Inner Shelf Hard Coral Richness
	Secchi Depth (m)
	Coastal Secchi depth
	Inner Shelf Secchi depth
	Chlorophyll (ug/L)
	Coastal Chl
	Inner Shelf Chl
Reef Exposure	TSS Exposure (No. of reefs in medium to very high exposure)
	DIN Exposure No. of reefs in medium to very high exposure)
	PSII Herb Exposure (No. of reefs in medium to very high exposure)

Each parameter was given a score between 1 and 5. The upper and lower boundaries of the classes were defined by the range of the parameter values and were then (arbitrarily) equally divided into 5 classes depending on the relationship between the parameter, and impact or risk. The range and classes for each parameter are provided in Table 6.

The scores for the parameters in each factor were summed, and the score for each of the 3 factors was used to calculate the Overall Score. The scores were categorised into 5 classes of Relative Risk where 1 = Low, 2 = Medium-Low, 3 = Medium, 4 = Medium-High and 5 = High. The boundaries for the classes were (arbitrarily) equally divided within the range from the Minimum Overall Score to the top of the range of the Overall Score. The final table is presented as Table 6. All data is also provided in Excel data tables in electronic form. It should be noted that it is the order of the scores across the regions that is of most interest in the context of undertaking a **relative risk assessment** between the regions, and that the final classes may be useful for communicating the results. However, a more sophisticated assessment should incorporate further investigation of regional differences and the relative importance of different pollutants to better inform future management priorities. Further discussion of this and other limitations of the approach used in this assessment are provided in the Conclusions and Limitations section of this report.

In summary, the Relative Risk is calculated in this assessment using the following formula:

Relative Risk = Anthropogenic Load Score (sum of scores for TSS, DIN, PSII Herbicide Anthropogenic Loads) **+ Reef Condition Score** (sum of scores for Coastal and Inner Shelf Macroalgal cover, Coastal and Inner Shelf Hard Coral Richness, Coastal and Inner Shelf Secchi Depth, Coastal and Inner Shelf Chlorophyll) **+ Reef Exposure Score** (sum of scores for TSS exposure, DIN exposure, PSII Herbicide exposure)

Table 6. Parameter ranges, assumed relationships and defined categories for determining the Relative Risk of parameters by NRM region in the GBR catchment.

			Category				
Parameter	Data Range	Relationship	1	2	3	4	5
Anthropogenic load							
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M
DIN	Range: 840 – 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500
PSII Herb	Range: 0.51 – 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6
Reef Condition							
Macroalgal cover	Range: 7 – 41%	High cover = High impact	0 to 8	8 to 17	17 to 26	26 to 35	35 to 41
Hard Coral Richness	Range: 121 - 7.3	Low richness = High impact	125 to 100	100 to 75	75 to 50	50 to 25	25 to 0
Secchi Depth	Range: 15 - 4.3m	Low depth = High impact	15 to 12.5	12.5 to 10	10 to 7.5	7.5 to 5	5 to 2.5
Chlorophyll	Range: 0.45 - 1.2ug/L	High Chl = High impact	0 to 0.25	0.25 to 0.5	0.5 to 0.75	0.75 to 1.0	1.0 to 1.25
Reef Exposure		High % exposure = High impact					
TSS Exposure	Range: 1 – 10%		0 to 2	3 to 5	6 to 8	9 to 11	12 to 14
DIN Exposure	Range: 0 – 65%		0 to 13	14 to 27	28 to 41	42 to 55	56 to 69
PSII Herb Exposure	Range: 0 – 40%		0 to 8	9 to 17	18 to 26	26 to 34	34 to 42
Risk Rating		Min score = 14 Max score = 70	14 to 19	20 to 25	26 to 30	31 to 36	37 to 42

Sensitivity of the Criteria

A simple sensitivity analysis of the criteria was undertaken to test the importance of each criteria, and the parameters within them, in determining the overall score. A series of alternative combinations of criteria, and ways of defining the criteria in terms of parameters (for Reef Condition and Reef Exposure), were tested and are included as Appendix 2. It was found that the pattern of the regional priorities is evident with many combinations of criteria, providing confidence to the final outcome. The following specific conclusions were drawn:

- *Exclusion of the Reef Condition criteria*: Consideration of only Anthropogenic Load and Reef Exposure resulted in a greater spread of the final scores, and a shift in the highest priority regions, i.e. The Wet Tropics become more prominent than Mackay Whitsunday because the Reef Condition scores for the Wet Tropics are lower. It was concluded that Reef Condition should not be excluded because it can be an indicator of previous exposure and reduced resilience to further impacts.
- *Exclusion of water quality parameters in the Reef Condition criteria*: The assessment was not particularly sensitive to changing the Reef Condition criteria to exclude the chlorophyll and secchi depth parameters. This is likely due to an internal correlation between chlorophyll and secchi depth, and Hard Coral Richness and Macroalgal Cover, i.e. Research shows that elevated chlorophyll concentrations and reduced secchi depth can lead to high macroalgal cover, low coral biodiversity and low rates of coral recruitment on inshore reefs, slowing rates of coral recovery after disturbances, and increasing frequency of outbreaks of crown-of-thorns starfish.
- *Adjustment of the Reef Exposure criteria*: An internal correlation exists between Anthropogenic loads and the Reef Exposure criteria derived from Maughan et al., (2008). The Reef Exposure model incorporates current contaminant loads as a factor, thereby essentially double counting the influence of contaminant load in the assessment. However, it is not considered to be a major concern because loads are considered to be a critical criteria in the assessment. This was tested by using an alternative measure of Reef Exposure - the number of reefs within 50km of the coast (described above). The results of the assessment using the two approaches were not substantially different, however, the Maughan et al., (2008) Reef Exposure model provides a more considered assessment as it factors in other aspects that influence exposure including river variability and plume direction which would help to differentiate the varying behaviour of the rivers in the wet and dry tropics.

Relative Risk Assessment

Using the methods described above, a Relative Risk Assessment to identify the relative risk of contaminant loadings from broad-scale agriculture in the GBR Catchments to GBR health is provided as Table 7.

The overall relative risk of the GBR regions considered for priority contaminants is summarised in Table 8 and presented in Figure 3. This is drawn from the Synthesis Table in Appendix 1, the Relative Risk Assessment in Table 7 and the recently developed Water Quality Improvement Plans (Kroon, 2008; Dight, 2009; Drewry et al., 2008; Johnson et al., 2008, Grinter et al., In prep).

The assessment indicates that the Wet Tropics and Mackay Whitsunday regions rank the highest priority (ranked High), with Burdekin and Fitzroy catchments relatively high priority (Medium-High) and the Burnett Mary catchments of moderate priority in terms of the contribution and influence of land based contaminants. This is conducive with several principles of the current understanding of priority contaminants and land uses in the GBR:

1. Sugar cane and horticultural land uses that generate large quantities of DIN and PSII Herbicides runoff per unit area are dominant in the coastal areas of the Wet Tropics, Burdekin, Mackay Whitsunday and Burnett Mary catchments.
2. The predominantly coastal location of intensive agricultural land uses in the GBR catchment results in efficient delivery of contaminants to the GBR.
3. A high number of reefs are located close to the coast in the northern parts of the GBR, particularly in the Wet Tropics, and the southern reefs tend to be located further offshore.
4. The assessment reflects the importance of dry tropics grazing activities and the contribution of sediment by erosion to receiving waters. A large proportion of the reefs in the dominant grazing areas of the Fitzroy and particularly the Burdekin catchments are located further offshore and thus may present a lower risk to reef habitats. However, suspended sediment risk to other important GBR ecosystems such as seagrass beds has not been included in this assessment and if this was done the importance of the Burdekin and Fitzroy regions could be enhanced

Table 7. Relative Risk Assessment of Reef impacts by catchments

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Anthropogenic load													
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M		1,301,000	5,164,000	292,000	3,707,000	1,637,000
TSS Score									2	5	1	4	2
DIN	Range: 840 - 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500		2,791	3,244	1,613	1,030	840
DIN Score									4	5	3	2	2
PSII Herb	Range: 0.51 - 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6		1.84	0.51	3.55	1.20	0.97
PSII Herb Score									3	1	5	2	2
Anthropogenic Load Score									9	11	9	8	6
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Condition													
Macroalgal cover	Range: 7 - 41%	High cover = High impact	0 to 8	8 to 17	17 to 26	26 to 35	35 to 41						
Coastal MAC								GBR mean = 26.8	17.6	23.3	41	33.3	20.3
Coastal MAC Score									3	3	5	4	3
Inner Shelf MAC								GBR mean = 17.1	7.3	7.4	26.6	31.3	Not avail.
Inner Shelf MAC Score									1	1	4	4	
Hard Coral Richness	Range: 121 - 7.3	Low richness = High impact	125 to 100	100 to 75	75 to 50	50 to 25	25 to 0						
Coastal HCR								GBR mean = 104.9	83.5	99.1	82.5	50.5	41
Coastal HCR Score									2	2	2	3	4
Inner Shelf HCR								GBR mean = 126.2	112	121	72.3	57.8	Not avail.
Inner Shelf HCR Score									1	1	3	3	
Secchi Depth	Range: 15 - 4.3m	Low depth = High impact	15 to 12.5	12.5 to 10	10 to 7.5	7.5 to 5	5 to 2.5	Target >10m					

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Coastal Secchi								GBR mean = 5.7	4.7	3.71	4.35	5.54	6.42
Coastal Secchi Score									5	5	5	4	4
Inner Shelf Secchi								GBR mean = 11.4	11	13.3	8.7	14.3	11.4
Inner Shelf Score									2	1	3	1	2
Chlorophyll	Range: 0.45 - 1.2ug/L	High Chl = High impact	0 to 0.25	0.25 to 0.5	0.5 to 0.75	0.75 to 1.0	1.0 to 1.25	Target <0.45					
Coastal Chl								GBR mean = 0.7	0.87	0.93	0.58	0.72	1.2
Coastal Chl Score									4	4	3	3	5
Inner Shelf Chl								GBR mean = 0.4	0.45	0.49	0.45	0.45	0.83
Inner Shelf Chl Score									2	2	2	2	4
Reef Condition Score									20	19	27	24	22
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Exposure													
No. of Reefs at Risk		High number of reefs in Mod-V High exposure areas = High impact	0 to 10	11 to 20	21 to 30	31 to 50	>50						
TSS Exposure # Reefs	Range: 0 - 9								9	0	2	6	0
% of Reefs in the Region									*5.7*	*0*	*0.4*	*0.8*	*0*
TSS Exposure Score									1	1	1	1	1
DIN Exposure # Reefs	Range: 0 - 123								123	4	2	10	0
% of Reefs in the Region									*78.3*	*2.2*	*0.4*	*1.4*	*0*
DIN Exposure Score									5	1	1	1	1
PSII Herb Exposure #	Range: 0 - 78								53	5	78	12	0

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reefs													
% of Reefs in the Region									*33.8*	*2.8*	*15.1*	*1.7*	*0*
PSII Herb Exposure Score									5	1	5	2	1
Reef Exposure Score									11	3	7	4	3
			1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Overall Score									40	33	43	36	31
								Max score = 70					
Relative Risk			14 to 19	20 to 25	26 to 31	32 to 37	38 to 43	Min score = 14	5	4	5	4	3
									HIGH	MED-HIGH	HIGH	MED-HIGH	MED

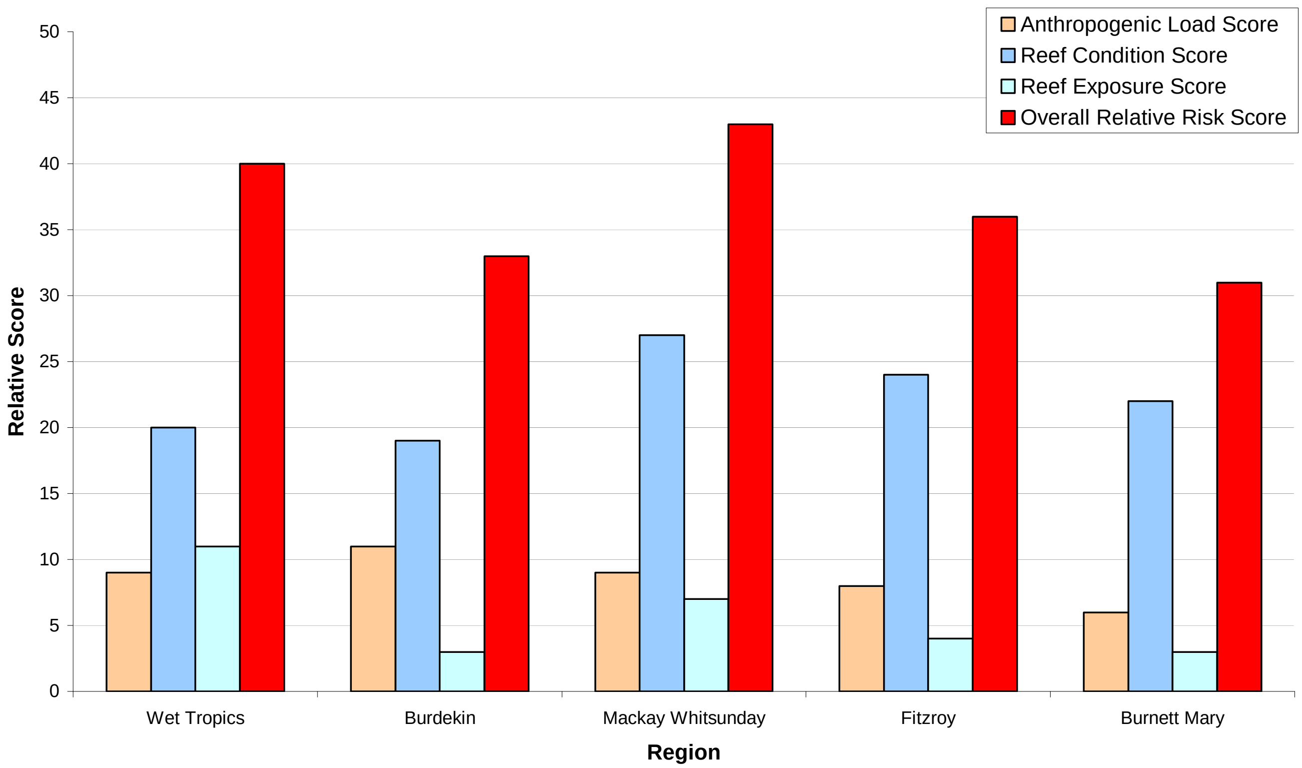

Figure 3. Relative Risk Assessment scores for the GBR catchments

Table 8. Results of the Relative Risk Assessment of priority contaminants in the GBR catchments

Region	Relative Risk	Dominant agricultural land use	Priority contaminants
Wet Tropics	High	Sugar cane	DIN, PSII Herbicides
Burdekin	Medium-High	Grazing with sugar cane in the lower Burdekin	TSS, DIN, PSII Herbicides
Mackay Whitsunday	High	Sugar cane	DIN, PSII Herbicides
Fitzroy	Medium - High	Grazing	TSS, PSII Herbicides
Burnett Mary	Medium	Grazing with sugar cane in the coastal areas	DIN, PSII Herbicides

Management Implications

From these results it is possible to develop a risk ranking incorporating both regions and land uses. Note that coastal grazing in the wetter catchments has been differentiated from other (extensive) dry tropics grazing as coastal grazing is characterised by continuous high pasture cover and hence low erosion potential. The dairy referenced in this report is intensive dairy and varies considerably from the extensive grazing but is a relatively limited source of diffuse runoff (by both area and loss per hectare) in the GBR catchments, hence not a high priority in any of the regions. This exercise results in the following relative risk ranking of the regions:

1) Wet Tropics sugar cane, Wet Tropics bananas, Burdekin sugar cane, Mackay Whitsunday sugar cane, Burdekin grazing, Fitzroy grazing
2) Burnett Mary sugar cane, Burnett Mary grazing, Fitzroy cotton and grains
3) Horticulture (except Wet Tropics bananas) across all of the regions, coastal grazing (Wet Tropics, Mackay Whitsunday, Burnett)
4) Intensive dairy

Within these rankings, subdivisions can be made based on 1) the likely speed at which improvements can be achieved from applied management in the different land uses and 2) the quantity of the contaminant load. In general, improvements in PSII Herbicide loads will be the quickest to eventuate, followed by improvements in DIN due to fertiliser management, with considerable times to reduce suspended sediment due to erosion management. In terms of quantity of load, Wet Tropics bananas are important, yet they are only still 5% of the DIN load and there is no doubt that Wet Tropics sugar cane (75%) as a whole is a more important priority for management. Coastal grazing and intensive dairy generally contribute small contaminant loads partly due to relatively low land use area. Based on both of these points, the first ranked priorities in the above list can be broken down in the following way:

1) Wet Tropics sugar cane, Burdekin sugar cane, Mackay Whitsunday sugar cane
2) Burdekin grazing, Fitzroy grazing, Wet Tropics bananas

The overall assessment is then:

1) Wet Tropics sugar cane, Burdekin sugar cane, Mackay Whitsunday sugar cane
2) Burdekin grazing, Fitzroy grazing, Wet Tropics bananas
3) Burnett Mary sugar cane, Burnett Mary grazing, Fitzroy cotton and grains
4) Horticulture (except Wet Tropics bananas) across all of the regions, coastal grazing (Wet Tropics, Mackay Whitsunday, Burnett)
5) Intensive dairy

Thus management could begin with herbicide and fertiliser management in sugar cane as reduction of loadings through application of best management practices e.g. 6 Easy Steps, will see reductions and in the shortest timeframes. This is also the case for horticultural industries where proven practices to manage contaminants are available, such as in bananas. To achieve the load reductions with respect to sediment over the longer term, grazing land management should be implemented in the Burdekin and Fitzroy as a priority.

Limitations of the Assessment

The assessment presented in this report has several limitations that must be considered in any application of the results. These include:

- The criteria are not deliberately weighted thereby assuming that the score from each parameter and criteria is equally important, and this is generally not believed to be the case. However as a result of the number of parameters counted within each criteria, the criteria have been weighted to some extent by default, for example Reef Condition is highly 'weighted' with 8 parameters compared to Anthropogenic load or Reef Exposure which only contain 3 parameters each. This is also emphasised by the application of a purely additive approach. It is recommended that more sophisticated ways to combine scores (e.g. a Multi Criteria Analysis) are investigated to improve the rigour of any future assessments.

- A total of 3 criteria and 14 parameters were selected in the assessment, however, it is important to note that with more time, further analysis of the parameters that should or could be included would be conducted. For example, a more depth assessment may include a river variability index. Presently it is assumed that water volume and variability is the same across the regions, which is incorrect, although it is factored into the criteria for Reef Exposure where the results of Maughan et al (2008) were used.

- It is not possible to differentiate 'Natural' conditions from anthropogenic influences in the Reef Condition criteria. For example, reduced secchi depth (e.g. from highly turbid coastal waters) and elevated chlorophyll (e.g. from oceanic upwelling) may occur naturally in some locations yet these are given a higher score. In response, Hard Coral Richness may also be naturally low, for example, there are naturally high levels of TSS in Broadsound, and naturally, no occurrence of reefs in that area (Kleypus, 199x). Whilst the scores may be high, the area is not necessarily at greater risk as the influence is not restricted to anthropogenic impacts. However, at the scale of this assessment (i.e. regional) these specific variations do not make significant differences but should be considered further in more detailed or regionally specific assessments.

- The assessment only includes reefs as the ecosystems at risk. While reefs may be the 'key' ecosystems of the GBR, seagrass meadows, mangroves, water column ecosystems are also important and a fuller analysis should attempt to take these into account.

Conclusions

In conclusion, this report and accompanying tables provide a relative risk assessment of TSS, nutrients and PSII Herbicides for the Regional NRM regions in the GBR catchments. The results should only be used in the context of the limitations and methods outlined in this report. This work is only one aspect of an ongoing science program, which is informing and providing the platform for the ongoing implementation of Reef Plan and the roll-out of the Queensland Government's Reef Protection Package.

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Appendix 1: Synthesis of Relative Risk Assessment Criteria and Parameters by GBR Catchments

BASIN	Contaminant Load[1]					Current Inshore Reef Condition[2]								Reef Exposure No. of Reefs with medium to very high exposure[3]	OVERALL REEF RISK
	Contaminant	TONNES - pre european	TONNES - current	SOURCE [a]	TONNES - Anthropogenic Load	Macroalgal cover (%)		Hard Coral Richness		Secchi depth (water clarity) Target: ≥10m [b] (m)		Chlorophyll Target: ≤0.45µg/L[b] µg/L			
					Difference btwn Current & pre-European	Coastal *GBR mean = 26.8*	Inner Shelf *GBR mean = 17.1*	Coastal *GBR mean = 104.9*	Inner Shelf *GBR mean = 126.2*	Coastal *GBR mean = 5.7*	Inner Shelf *GBR mean = 11.4*	Coastal *GBR mean = 0.7*	Inner Shelf *GBR mean = 0.4*		
WET TROPICS (Daintree-Mossman) (Barron) (Johnstone) (Russell-Mulgrave) (Tully-Murray) (Herbert)	Total Suspended Sediment	299,000	1,600,000	Sugar – 17% Other crops - 2% Grazing - 34% Forest - 45% Other - 2%	1,301,000	17.6	7.3	83.5	112	4.7	11	0.87	0.45	TSS: 9 DIN: 123 PSII Herb: 53	**HIGH**
	Total Nitrogen	4,398	14,256		9,858										
	Dissolved Inorganic Nitrogen[c]	1,109	3,900	Sugar – 75% Other crops - 5% Grazing & Forest - 12% Other - 8%	2,791										
	Dissolved Organic Nitrogen[d]	3,138	2,250	Sugar - 17% Other crops - 1% Grazing - 23% Forest - 56% Other - 3%	-888										
	Particulate Nitrogen	153	3,570	Sugar - 23% Hort - 1% Grazing - 24% Forest - 49% Other - 2%	3,417										
	Total Phosporus	501	2,008		1,507										
	Dissolved Inorganic Phosphorus	88	107	Sugar – 17% Other crops - 1% Grazing - 31% Forest - 50% Other - 5%	19										
	PS II Herbicides	0	1.84		1.84										

BASIN	Contaminant Load[1]					Current Inshore Reef Condition[2]								Reef Exposure % of Reef area with medium to very high exposure[3]	OVERALL REEF RISK
	Contaminant	TONNES - pre european	TONNES - current	SOURCE [a]	TONNES - Anthropogenic Load	Macroalgal cover (%)		Hard Coral Richness		Secchi depth (water clarity) Target: ≥10m [b] (m)		Chlorophyll Target: ≤0.45µg/L[b] µg/L			
					Difference btwn Current & pre-European	Coastal *GBR mean = 26.8*	Inner Shelf *GBR mean = 17.1*	Coastal *GBR mean = 104.9*	Inner Shelf *GBR mean = 126.2*	Coastal *GBR mean = 5.7*	Inner Shelf *GBR mean = 11.4*	Coastal *GBR mean = 0.7*	Inner Shelf *GBR mean = 0.4*		
BURDEKIN DRY TROPICS (Burdekin) (Haughton) (Black) (Ross) (Don)	Total Suspended Sediment	596,000	5,760,000	Sugar - 2% Other crops - 1% Grazing - 87% Forest - 9% Other - 1%	5,164,000	23.3	7.4	99.1	121	3.71	13.3	0.93	0.49	TSS: 0 DIN: 4 PSII Herb: 5	**MEDIUM - HIGH**
	Total Nitrogen	2,652	12,362		9,710										
	Dissolved Inorganic Nitrogen[e]	1,096	4,340	Sugar - 67% Other crops - 1% Grazing - 18% Forest - 12% Other - 2%	3,244										
	Dissolved Organic Nitrogen	1,155	2,100	Sugar - 1% Other crops - 0% Grazing - 87% Forest - 11% Other - 1%	945										
	Particulate Nitrogen	195	10,400	Sugar - 1% Other crops - 0% Grazing - 90% Forest - 8% Other - 1%	10,205										
	Total Phosporus	317	2,424		2,107										
	Dissolved Inorganic Phosphorus	20	218	Sugar -2% Other crops - 0% Grazing - 86% Forest - 10% Other - 1%	198										
	PS II Herbicides	0	0.51		0.51										

	Contaminant Load[1]					Current Inshore Reef Condition[2]									
BASIN	Contaminant	TONNES - pre european	TONNES - current	SOURCE [A,c]	TONNES - Anthropogenic Load	Macroalgal cover (%)		Hard Coral Richness		Secchi depth (water clarity) Target: ≥10m [b] (m)		Chlorophyll Target: ≤0.45µg/L[b] µg/L		Reef Exposure % of Reef area with medium to very high exposure[3]	OVERALL REEF RISK
					Difference btwn Current & pre-European	Coastal *GBR mean = 26.5*	Inner Shelf *GBR mean = 17.1*	Coastal *GBR mean = 104.9*	Inner Shelf *GBR mean = 126.2*	Coastal *GBR mean = 5.7*	Inner Shelf *GBR mean = 11.4*	Coastal *GBR mean = 0.7*	Inner Shelf *GBR mean = 0.4*		
MACKAY WHITSUNDAYS (Proserpine) (O'Connell) (Pioneer) (Plane)	Total Suspended Sediment[f]	248000	540,000	Sugar - 29% Other crops - 1% Grazing - 29% Forest - 39% Other - 4%	292,000	41	26.6	82.5	72.3	4.35	8.7	0.58	0.45	TSS: 2 DIN: 2 PSII Herb: 78	**HIGH**
	Total Nitrogen	913	6,159		5,246										
	Dissolved Inorganic Nitrogen[f]	387	2,000	Sugar - 77% Other crops - 1% Grazing - 12% Forest - 1% Other - 9%	1,613										
	Dissolved Organic Nitrogen	477	730	Sugar - 26% Other crops - 0% Grazing - 46% Forest - 25% Other - 4%	253										
	Particulate Nitrogen[f]	48	1,600	Sugar - 53% Other crops - 1% Grazing - 34% Forest - 6% Other - 6%	1,552										
	Total Phosporus	147	1,621		1,474										
	Dissolved Inorganic Phosphorus[f]	14	250	Sugar - 84% Other crops - 1% Grazing - 5% Forest - 0% Other - 10%	236										
	PS II Herbicides	0	3.55		3.55										

	Contaminant Load[1]					Current Inshore Reef Condition[2]									
BASIN	Contaminant	TONNES - pre european	TONNES - current	SOURCE [A]	TONNES - Anthropogenic Load	Macroalgal cover (%)		Hard Coral Richness		Secchi depth (water clarity) Target: ≥10m [b] (m)		Chlorophyll Target: ≤0.45µg/L[b] µg/L		Reef Exposure % of Reef area with medium to very high exposure[3]	OVERALL REEF RISK
					Difference btwn Current & pre-European	Coastal *GBR mean = 26.5*	Inner Shelf *GBR mean = 17.1*	Coastal *GBR mean = 104.9*	Inner Shelf *GBR mean = 126.2*	Coastal *GBR mean = 5.7*	Inner Shelf *GBR mean = 11.4*	Coastal *GBR mean = 0.7*	Inner Shelf *GBR mean = 0.4*		
FITZROY (Fitzroy) (Calliope) (Boyne) (Styx) (Shoalwater) (Waterpark)	Total Suspended Sediment	393000	4,100,000	Sugar - 0% Other crops - 3% Grazing - 91% Forest - 5% Other - 1%	3,707,000	33.3	31.3	50.5	57.8	5.54	14.3	0.72	0.45	TSS: 6 DIN: 10 PSII Herb: 12	**MEDIUM -HIGH**
	Total Nitrogen	1674	10,223		8,549										
	Dissolved Inorganic Nitrogen	770	1,800	Sugar - 0% Other crops - 3% Grazing - 84% Forest - 12% Other - 1%	1,030										
	Dissolved Organic Nitrogen	800	3,010	Sugar - 0% Other crops - 3% Grazing - 86% Forest - 11% Other - 1%	2,210										
	Particulate Nitrogen	102	9,920	Sugar - 0% Other crops - 2% Grazing - 89% Forest - 9% Other - 1%	9,818										
	Total Phosporus	197	2,735		2,538										
	Dissolved Inorganic Phosphorus	13	370	Sugar - 0% Other crops - 3% Grazing - 86% Forest - 10% Other - 1%	357										
	PS II Herbicides	0	1.20		1.20										

	Contaminant Load[1]					Current Inshore Reef Condition[2]									
BASIN	Contaminant	TONNES - pre european	TONNES - current	SOURCE [a]	TONNES - Anthropogenic Load	Macroalgal cover (%)		Hard Coral Richness		Secchi depth (water clarity) Target: ≥10m [b] (m)		Chlorophyll Target: ≤0.45µg/L[b] µg/L		Reef Exposure % of Reef area with medium to very high exposure[3]	OVERALL REEF RISK
					Difference btwn Current & pre-European	Coastal *GBR mean = 25.5*	Inner Shelf *GBR mean = 17.1*	Coastal *GBR mean = 104.9*	Inner Shelf *GBR mean = 126.2*	Coastal *GBR mean = 5.7*	Inner Shelf *GBR mean = 11.4*	Coastal *GBR mean = 0.7*	Inner Shelf *GBR mean = 0.4*		
BURNETT-MARY (Burnett) (Mary) (Baffle) (Kolan) (Burrum)	Total Suspended Sediment	263000	1,900,000	Sugar - 3% Other crops - 6% Grazing - 61% Forest - 28% Other - 2%	1,637,000	20.3	Not avail.	41	Not avail.	6.42	11.4	1.2	0.83	TSS: 0 DIN: 0 PSII Herb: 0	**MEDIUM**
	Total Nitrogen	1464	5,244		3,780										
	Dissolved Inorganic Nitrogen[g]	660	1,500	Sugar+hort - 55% Grazing - 25% Forest - 18% Other - 2%	840										
	Dissolved Organic Nitrogen	720	1,000	Sugar - 3% Other crops - 4% Grazing - 60% Forest - 31% Other - 3%	280										
	Particulate Nitrogen	83	2,950	Sugar - 2% Other crops - 4% Grazing - 62% Forest - 23% Other - 2%	2,867										
	Total Phosporus	189	913		724										
	Dissolved Inorganic Phosphorus	23	115	Sugar - 2% Other crops - 4% Grazing - 62% Forest - 29% Other - 3%	92										
	PS II Herbicides	0	0.97		0.97										

1 - Brodie, J., Waterhouse, J., Lewis, S., Bainbridge, Z. and Johnson, J. 2009. Current loads of priority pollutants discharged from Great Barrier Reef Catchments to the Great Barrier Reef. ACTFR Report Number 09/02.

a - 'Other crops' includes all crops other than sugar cane and includes horticulture, cotton and grains. Where data is available, 'Hort' refers to horticulture; 'Other' refers to other land uses including dairy and urban.

b - *GBRMPA 2008. Water Quality Guidelines for the Great Barrier Reef Marine Park. Great Barrier Reef Marine Park Authority, Townsville.*

c - Estimated from *Hunter, H.M. and Walton, R.S. 2008. Land-use effects on fluxes of suspended sediment, nitrogen and phosphorus from a river catchment of the Great Barrier Reef, Australia. Journal of Hydrology 356, 131-146.* and *Armour, J.D., Hateley, L.R. and Pitt, G.L. 2007. Improved SedNet and Annex modelling of the Tully-Murray catchment. A report prepared for the Tully Water Quality Improvement Plan. Department of Natural Resources and Water, Mareeba. 27 pp.*

d - The result for DON is negative as a result of working with estimates that have large error margins and therefore should be considered as "no net change" in load rather than an improvement in catchment condition or reduced loads.

e - Estimated from 1; *Brodie, J. and Bainbridge, Z. 2008. Water quality targets for the Burdekin WQIP. Burdekin Solutions Ltd, Townsville. 28 pp.; Bainbridge, Z.T., Lewis, S., Davis, A. and Brodie, J. 2008. Event-based community water quality monitoring in the Burdekin Dry Tropics region: 2007-2008 wet se*

f - *Drewry, J., Higham, W. and Mitchell, C. 2008. Water Quality Improvement Plan. Final report for Mackay Whitsunday Region. Mackay Whitsunday Natural Resource Management Group.*

g - Estimated from *Brodie, J. and Grinter, S. In prep. Water Quality Targets for the Burnett / Baffle WQIP. Prepared for the Burnett/Baffle Water Quality Improvement Plan.*

2 - De'ath, G and Fabricius, K. 2007. Water Quality of the Great Barrier Reef: Distributions, Effects on Reef Biota and Trigger Values for Conservation of Ecosystem Health. Report to the Great Barrier Reef Marine Park Authority from the Australian Institute of Marine Science. GBRMPA Research Publication No. 89, February 2008.

Note: Refer to pages 25-27 for a defintion of the cross shelf boundaries.

3 - Maughan, M., Brodie, J. and Waterhouse, J. 2008. Reef Exposure Model for the Great Barrier Reef Lagoon. ACTFR Report No. 07/19. Australian Centre for Tropical Freshwater Research, James Cook University, Townsville. Note: Based on the number of reefs in each region predicted in the model to be Medium, High or Very High Exposure.

Appendix 2: Simple sensitivity analysis of parameters and criteria used in the Relative Risk Assessment

Appendix 2 presents a simple sensitivity analysis of the criteria to test the importance of each criterion, and the parameters within them, in determining the overall score. A series of alternative combinations of criteria, and ways of defining the criteria in terms of parameters (for Reef Condition and Reef Exposure), were tested. It was found that the pattern of the regional priorities is evident with many combinations of criteria, providing confidence to the final outcome.

The results of different combinations are summarised in Tables 1 to 3, and overall scores can be compared in Figure 1.
The combinations tested were:

Anthropogenic Load, Reef Condition & Reef Exposure
1: Reef Exposure = % area in exposure areas
1A : Reef Exposure = No. reefs in exposure areas
1B : Reef Exposure = No. reefs <50km from coast

Anthropogenic Load & Reef Exposure
2: Reef Exposure = % area in exposure areas
2A : Reef Exposure = No. reefs in exposure areas
2B : Reef Exposure = No. reefs <50km from coast

Anthropogenic Load, Reef Condition (exc Chl and Secchi) & Reef Exposure
3: Reef Exposure = % area in exposure areas
3A : Reef Exposure = No. reefs in exposure areas
3B : Reef Exposure = No. reefs <50km from coast

The results from the individual runs are presented in Tables 4 to 12.

Table 1. Combination 1: Anthropogenic Load, Reef Condition and Reef Exposure

	Scenario	Categories										
		1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
1: Overall Score	Anthropogenic Load, Reef Condition and Reef Exposure (% area in exposure areas)	14 to 20	21 to 27	28 to 34	35 to 41	42 to 48	Max score = 70	43	39	41	37	32
Relative Risk							Min score = 14	5	4	4	4	3
								HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MED
1A: Overall Score	Anthropogenic Load, Reef Condition and Reef Exposure (No. reefs in exposure areas)	14 to 19	20 to 25	26 to 31	32 to 37	38 to 43	Max score = 70	40	33	43	36	31
Relative Risk							Min score = 14	5	4	5	4	3
								HIGH	MED-HIGH	HIGH	MED-HIGH	MED
1B: Overall Score	Anthropogenic Load and Reef Exposure (% area in exposure areas)	12 to 17	18 to 23	24 to 29	30 to 35	36 to 41	Max score = 60	31	31	41	35	29
Relative Risk							Min score = 12	4	4	5	4	3
								MED-HIGH	MED-HIGH	HIGH	MED-HIGH	MED

Table 2. Combination 2: Anthropogenic Load and Reef Exposure

	C	Categories										
		1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
		6 to 9	10 to 13	14 to 17	18 to 21	22 to 25	Max score = 30	23	20	14	13	10
2: Overall Score	Anthropogenic Load and Reef Exposure (% area in exposure areas)						Min score = 6	5	4	3	2	2
Relative Risk								HIGH	MED-HIGH	MED	MED-LOW	MED-LOW
2A: Overall Score	Anthropogenic Load and (No. reefs in exposure areas)	6 to 9	10 to 13	14 to 17	18 to 21	22 to 25	Max score = 30	20	14	16	12	9
							Min score = 6	4	3	3	2	1
Relative Risk								MED-HIGH	MED	MED	MED-LOW	LOW
2B: Overall Score	Anthropogenic Load and Reef Exposure (No. reefs <50km from coast)	5 to 6	7 to 8	9 to 10	11 to 12	13 to 14	Max score = 20	11	12	14	11	7
							Min score = 4	4	4	5	4	2
Relative Risk								MED-HIGH	MED-HIGH	HIGH	MED-HIGH	MED-LOW

Table 3. Combination 3: Anthropogenic Load, Reef Condition (exc Chl and Secchi) and Reef Exposure

	Combination	Categories										
		1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
3: Overall Score	Anthropogenic Load, Reef Condition (exc Chl and Secchi) and Reef Exposure (% area in exposure areas)	10 to 14	15 to 19	20 to 24	25 to 29	30 to 34	Max score = 50	30	27	27	27	17
							Min score = 10	5	4	4	4	2
Relative Risk								HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MED-LOW
3A: Overall Score	Anthropogenic Load, Reef Condition (exc Chl and Secchi) and Reef Exposure (No. reefs in exposure areas)	*10 to 13*	*14 to 17*	*18 to 21*	*22 to 25*	*26 to 29*	Max score = 50	27	21	30	26	16
							Min score = 10	5	3	5	5	2
Relative Risk								HIGH	MED	HIGH	HIGH	MED-LOW
3B: Overall Score	Anthropogenic Load, Reef Condition (exc Chl and Secchi) and Reef Exposure (No. reefs <50km from coast)	8 to 11	12 to 15	16 to 19	20 to 23	24 to 27	Max score = 40	18	19	28	25	14
							Min score = 8	3	3	5	5	2
Relative Risk								MED	MED	HIGH	HIGH	MED-LOW

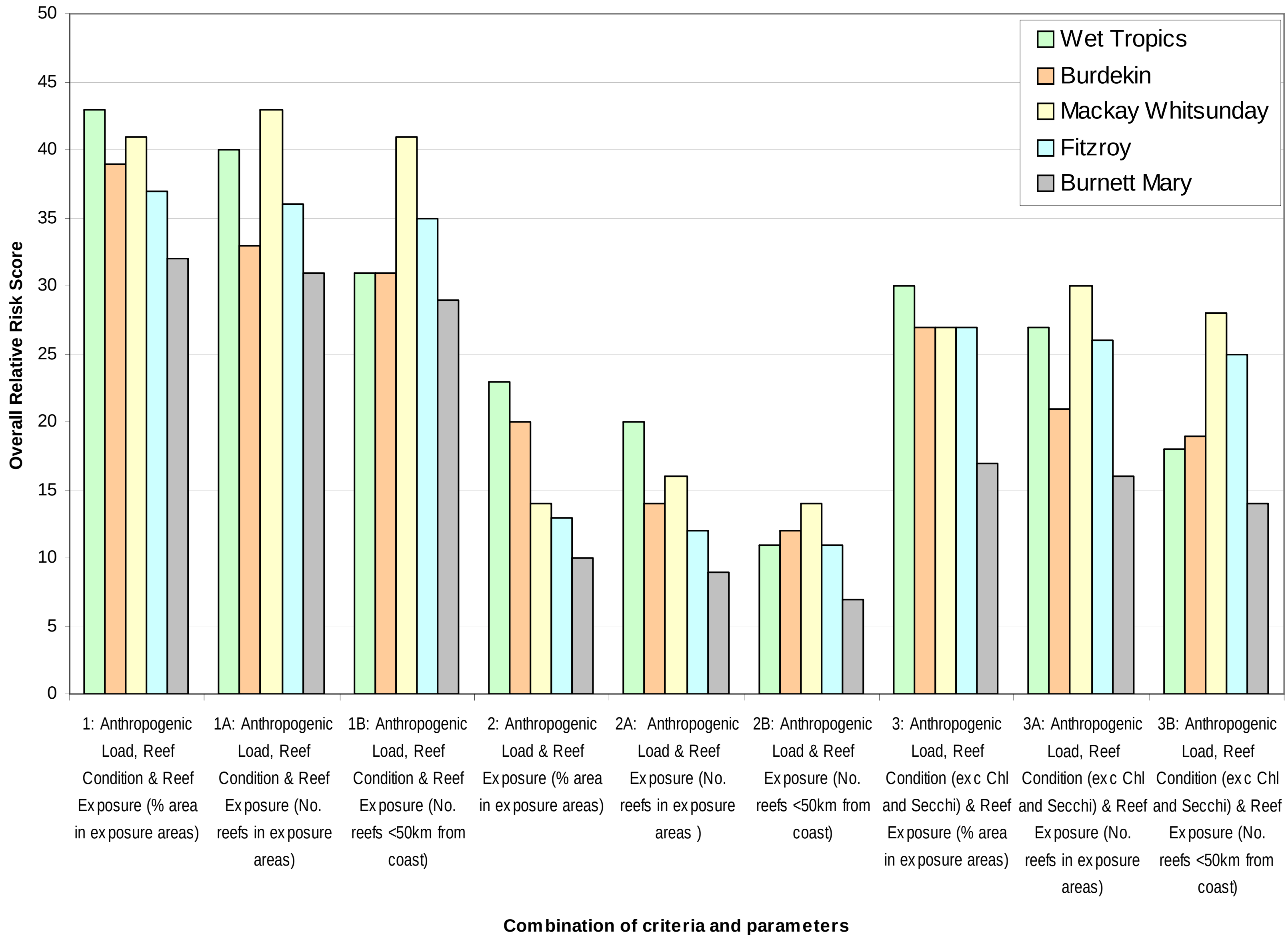

Figure 1. Comparison of the Overall Relative Risk Scores for various combinations of criteria and parameters

Summary Of Comparisons :

Table 4. Relative Risk Assessment for Combination 1: Anthropogenic Load, Reef Condition and Reef Exposure (% area in exposure areas)

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Anthropogenic load													
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M		1,301,000	5,164,000	292,000	3,707,000	1,637,000
TSS Score									2	5	1	4	2
DIN	Range: 840 - 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500		2,791	3,244	1,613	1,030	840
DIN Score									4	5	3	2	2
PSII Herb	Range: 0.51 - 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6		1.84	0.51	3.55	1.20	0.97
PSII Herb Score									3	1	5	2	2
Anthropogenic Load Score									9	11	9	8	6
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Condition													
Macroalgal cover	Range: 7 - 41%	High cover = High impact	0 to 8	8 to 17	17 to 26	26 to 35	35 to 41						
Coastal MAC								GBR mean = 26.8	17.6	23.3	41	33.3	20.3
Coastal MAC Score									3	3	5	4	3
Inner Shelf MAC								GBR mean = 17.1	7.3	7.4	26.6	31.3	Not avail.
Inner Shelf MAC Score									1	1	4	4	
Hard Coral Richness	Range: 121 - 7.3	Low richness = High impact	125 to 100	100 to 75	75 to 50	50 to 25	25 to 0						
Coastal HCR								GBR mean = 104.9	83.5	99.1	82.5	50.5	41
Coastal HCR Score									2	2	2	3	4
Inner Shelf HCR								GBR mean = 126.2	112	121	72.3	57.8	Not avail.
Inner Shelf HCR Score									1	1	3	3	
Secchi Depth	Range: 15 - 4.3m	Low depth = High impact	15 to 12.5	12.5 to 10	10 to 7.5	7.5 to 5	5 to 2.5	Target >10m					
Coastal Secchi								GBR mean = 5.7	4.7	3.71	4.35	5.54	6.42
Coastal Secchi Score									5	5	5	4	4
Inner Shelf Secchi								GBR mean = 11.4	11	13.3	8.7	14.3	11.4
Inner Shelf Score									2	1	3	1	2
Chlorophyll	Range: 0.45 - 1.2ug/L	High Chl = High impact	0 to 0.25	0.25 to 0.5	0.5 to 0.75	0.75 to 1.0	1.0 to 1.25	Target <0.45					
Coastal Chl								GBR mean = 0.7	0.87	0.93	0.58	0.72	1.2
Coastal Chl Score									4	4	3	3	5
Inner Shelf Chl								GBR mean = 0.4	0.45	0.49	0.45	0.45	0.83
Inner Shelf Chl Score									2	2	2	2	4
Reef Condition Score									20	19	27	24	22
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Exposure (% area in exposure areas)		High % exposure = High impact											
TSS Exposure	Range: 1 - 10%		0 to 2	3 to 5	6 to 8	9 to 11	12 to 14		10	10	1	5	5
TSS Exposure Score									4	4	1	2	2
DIN Exposure	Range: 0 - 65%		0 to 13	14 to 27	28 to 41	42 to 55	56 to 69		65	25	1	5	10
DIN Exposure Score									5	2	1	1	1
PSII Herb Exposure	Range: 0 - 40%		0 to 8	9 to 17	18 to 26	26 to 34	34 to 42		40	20	20	10	5
PSII Herb Exposure Score									5	3	3	2	1
Reef Exposure Score									14	9	5	5	4
			1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
1: Overall Score	Anthropogenic Load, Reef Condition and Reef Exposure (% area in exposure areas)								43	39	41	37	32
								Maximum score = 70					
Relative Risk			14 to 20	21 to 27	28 to 34	35 to 41	42 to 48	Minimum score = 14	5	4	4	4	3
									HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MED

Table 5. Relative Risk Assessment for Combination 1A: Anthropogenic Load, Reef Condition and Reef Exposure (No. reefs in exposure areas)

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Anthropogenic load													
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M		1,301,000	5,164,000	292,000	3,707,000	1,637,000
TSS Score									2	5	1	4	2
DIN	Range: 840 - 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500		2,791	3,244	1,613	1,030	840
DIN Score									4	5	3	2	2
PSII Herb	Range: 0.51 - 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6		1.84	0.51	3.55	1.20	0.97
PSII Herb Score									3	1	5	2	2
Anthropogenic Load Score									9	11	9	8	6
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Condition													
Macroalgal cover	Range: 7 - 41%	High cover = High impact	0 to 8	8 to 17	17 to 26	26 to 35	35 to 41						
Coastal MAC								GBR mean = 26.8	17.6	23.3	41	33.3	20.3
Coastal MAC Score									3	3	5	4	3
Inner Shelf MAC								GBR mean = 17.1	7.3	7.4	26.6	31.3	Not avail.
Inner Shelf MAC Score									1	1	4	4	
Hard Coral Richness	Range: 121 - 7.3	Low richness = High impact	125 to 100	100 to 75	75 to 50	50 to 25	25 to 0						
Coastal HCR								GBR mean = 104.9	83.5	99.1	82.5	50.5	41
Coastal HCR Score									2	2	2	3	4
Inner Shelf HCR								GBR mean = 126.2	112	121	72.3	57.8	Not avail.
Inner Shelf HCR Score									1	1	3	3	
Secchi Depth	Range: 15 - 4.3m	Low depth = High impact	15 to 12.5	12.5 to 10	10 to 7.5	7.5 to 5	5 to 2.5	Target >10m					
Coastal Secchi								GBR mean = 5.7	4.7	3.71	4.35	5.54	6.42
Coastal Secchi Score									5	5	5	4	4
Inner Shelf Secchi								GBR mean = 11.4	11	13.3	8.7	14.3	11.4
Inner Shelf Score									2	1	3	1	2
Chlorophyll	Range: 0.45 - 1.2ug/L	High Chl = High impact	0 to 0.25	0.25 to 0.5	0.5 to 0.75	0.75 to 1.0	1.0 to 1.25	Target <0.45					
Coastal Chl								GBR mean = 0.7	0.87	0.93	0.58	0.72	1.2
Coastal Chl Score									4	4	3	3	5
Inner Shelf Chl								GBR mean = 0.4	0.45	0.49	0.45	0.45	0.83
Inner Shelf Chl Score									2	2	2	2	4
Reef Condition Score									20	19	27	24	22
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Exposure (No. reefs in exposure areas)													
No. of Reefs at Risk		High number of reefs in Mod-V High exposure areas = High impact	0 to 10	11 to 20	21 to 30	31 to 50	>50						
TSS Exposure # Reefs	Range: 0 - 9								9	0	2	6	0
% of Reefs in the Region									*5.7*	*0*	*0.4*	*0.8*	*0*
TSS Exposure Score									1	1	1	1	1
DIN Exposure # Reefs	Range: 0 - 123								123	4	2	10	0
% of Reefs in the Region									*78.3*	*2.2*	*0.4*	*1.4*	*0*
DIN Exposure Score									5	1	1	1	1
PSII Herb Exposure # Reefs	Range: 0 - 78								53	5	78	12	0
% of Reefs in the Region									*33.8*	*2.8*	*15.1*	*1.7*	*0*
PSII Herb Exposure Score									5	1	5	2	1
Reef Exposure Score									11	3	7	4	3
			1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
1A: Overall Score	Anthropogenic Load, Reef Condition and Reef Exposure (No. reefs in exposure areas)							Maximum score = 70	40	33	43	36	31
			14 to 19	20 to 25	26 to 31	32 to 37	38 to 43	Minimum score = 14	5	4	5	4	3
Relative Risk									HIGH	MED-HIGH	HIGH	MED-HIGH	MED

Table 6. Relative Risk Assessment for Combination 1B: Anthropogenic Load, Reef Condition and Reef Exposure (No. reefs <50km from coast)

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Anthropogenic load													
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M		1,301,000	5,164,000	292,000	3,707,000	1,637,000
TSS Score									2	5	1	4	2
DIN	Range: 840 - 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500		2,791	3,244	1,613	1,030	840
DIN Score									4	5	3	2	2
PSII Herb	Range: 0.51 - 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6		1.84	0.51	3.55	1.20	0.97
PSII Herb Score									3	1	5	2	2
Anthropogenic Load Score									9	11	9	8	6
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Condition													
Macroalgal cover	Range: 7 - 41%	High cover = High impact	0 to 8	8 to 17	17 to 26	26 to 35	35 to 41						
Coastal MAC								GBR mean = 26.8	17.6	23.3	41	33.3	20.3
Coastal MAC Score									3	3	5	4	3
Inner Shelf MAC								GBR mean = 17.1	7.3	7.4	26.6	31.3	Not avail.
Inner Shelf MAC Score									1	1	4	4	
Hard Coral Richness	Range: 121 - 7.3	Low richness = High impact	125 to 100	100 to 75	75 to 50	50 to 25	25 to 0						
Coastal HCR								GBR mean = 104.9	83.5	99.1	82.5	50.5	41
Coastal HCR Score									2	2	2	3	4
Inner Shelf HCR								GBR mean = 126.2	112	121	72.3	57.8	Not avail.
Inner Shelf HCR Score									1	1	3	3	
Secchi Depth	Range: 15 - 4.3m	Low depth = High impact	15 to 12.5	12.5 to 10	10 to 7.5	7.5 to 5	5 to 2.5	Target >10m					
Coastal Secchi								GBR mean = 5.7	4.7	3.71	4.35	5.54	6.42
Coastal Secchi Score									5	5	5	4	4
Inner Shelf Secchi								GBR mean = 11.4	11	13.3	8.7	14.3	11.4
Inner Shelf Score									2	1	3	1	2
Chlorophyll	Range: 0.45 - 1.2ug/L	High Chl = High impact	0 to 0.25	0.25 to 0.5	0.5 to 0.75	0.75 to 1.0	1.0 to 1.25	Target <0.45					
Coastal Chl								GBR mean = 0.7	0.87	0.93	0.58	0.72	1.2
Coastal Chl Score									4	4	3	3	5
Inner Shelf Chl								GBR mean = 0.4	0.45	0.49	0.45	0.45	0.83
Inner Shelf Chl Score									2	2	2	2	4
Reef Condition Score									20	19	27	24	22
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Exposure (No. reefs <50km from coast)													
Reefs within 50km of coas	Range: 21 - 483	High number = High risk	0 to 100	100 to 200	200 to 300	300 to 400	400 to 500		188	77	483	276	21
Reef Exposure Score									2	1	5	3	1
			1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
1B: Overall Score	Anthropogenic Load, Reef Condition and Reef Exposure (No. reefs <50km from coast)								31	31	41	35	29
			12 to 17	18 to 23	24 to 29	30 to 35	36 to 41	Maximum score = 60	4	4	5	4	3
Relative Risk								Minimum score = 12	MED-HIGH	MED-HIGH	HIGH	MED-HIGH	MED

Table 7. Relative Risk Assessment for Combination 2: Anthropogenic Load, Reef Condition and Reef Exposure (% area in exposure areas)

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Anthropogenic load													
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M		1,301,000	5,164,000	292,000	3,707,000	1,637,000
TSS Score									2	5	1	4	2
DIN	Range: 840 - 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500		2,791	3,244	1,613	1,030	840
DIN Score									4	5	3	2	2
PSII Herb	Range: 0.51 - 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6		1.84	0.51	3.55	1.20	0.97
PSII Herb Score									3	1	5	2	2
Anthropogenic Load Score									9	11	9	8	6
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Exposure		High % exposure = High impact											
TSS Exposure	Range: 1 - 10%		0 to 2	3 to 5	6 to 8	9 to 11	12 to 14		10	10	1	5	5
TSS Exposure Score									4	4	1	2	2
DIN Exposure	Range: 0 - 65%		0 to 13	14 to 27	28 to 41	42 to 55	56 to 69		65	25	1	5	10
DIN Exposure Score									5	2	1	1	1
PSII Herb Exposure	Range: 0 - 40%		0 to 8	9 to 17	18 to 26	26 to 34	34 to 42		40	20	20	10	5
PSII Herb Exposure Score									5	3	3	2	1
Reef Exposure Score									14	9	5	5	4
			1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
2: Overall Score	Anthropogenic Load and Reef Exposure (% area in exposure areas)		6 to 9	10 to 13	14 to 17	18 to 21	22 to 25		23	20	14	13	10
								Maximum score = 30	5	4	3	2	2
Relative Risk			6 to 10	11 to 15	16 to 20	21 to 25	26 to 30	Minimum score = 6	HIGH	MED-HIGH	MED	MED-LOW	MED-LOW

Table 8. Relative Risk Assessment for Combination 2A: Anthropogenic Load, Reef Condition and Reef Exposure (No. reefs in exposure areas)

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Anthropogenic load													
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M		1,301,000	5,164,000	292,000	3,707,000	1,637,000
TSS Score									2	5	1	4	2
DIN	Range: 840 - 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500		2,791	3,244	1,613	1,030	840
DIN Score									4	5	3	2	2
PSII Herb	Range: 0.51 - 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6		1.84	0.51	3.55	1.20	0.97
PSII Herb Score									3	1	5	2	2
Anthropogenic Load Score									9	11	9	8	6
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Exposure (No. reefs in exposure areas)													
No. of Reefs at Risk		High number of reefs in Mod-V High exposure areas = High impact	0 to 10	11 to 20	21 to 30	31 to 50	>50						
TSS Exposure # Reefs	Range: 0 - 9								9	0	2	6	0
% of Reefs in the Region									*5.7*	*0*	*0.4*	*0.8*	*0*
TSS Exposure Score									1	1	1	1	1
DIN Exposure # Reefs	Range: 0 - 123								123	4	2	10	0
% of Reefs in the Region									*78.3*	*2.2*	*0.4*	*1.4*	*0*
DIN Exposure Score									5	1	1	1	1
PSII Herb Exposure # Reefs	Range: 0 - 78								53	5	78	12	0
% of Reefs in the Region									*33.8*	*2.8*	*15.1*	*1.7*	*0*
PSII Herb Exposure Score									5	1	5	2	1
Reef Exposure (No. reefs in exposure areas)									11	3	7	4	3
			1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
2A: Overall Score	Anthropogenic Load and Reef Exposure (No. reefs in exposure areas)		6 to 9	10 to 13	14 to 17	18 to 21	22 to 25		20	14	16	12	9
								Maximum score = 30	4	3	3	2	1
Relative Risk								Minimum score = 6	MED-HIGH	MED	MED	MED-LOW	LOW

Table 9. Relative Risk Assessment for Combination 2B: Anthropogenic Load, Reef Condition and Reef Exposure (No. reefs <50km from coast)

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Anthropogenic load													
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M		1,301,000	5,164,000	292,000	3,707,000	1,637,000
TSS Score									2	5	1	4	2
DIN	Range: 840 - 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500		2,791	3,244	1,613	1,030	840
DIN Score									4	5	3	2	2
PSII Herb	Range: 0.51 - 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6		1.84	0.51	3.55	1.20	0.97
PSII Herb Score									3	1	5	2	2
Anthropogenic Load Score									9	11	9	8	6
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Exposure (No. reefs <50km from coast)													
Reefs within 50km of coas	Range: 21 - 483	High number = High risk	0 to 100	100 to 200	200 to 300	300 to 400	400 to 500		188	77	483	276	21
Reef Exposure Score									2	1	5	3	1
			1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
2B: Overall Score	Anthropogenic Load and Reef Exposure (No. reefs <50km from coast)		5 to 6	7 to 8	9 to 10	11 to 12	13 to 14	Maximum score = 20	11	12	14	11	7
								Minimum score = 4	4	4	5	4	2
Relative Risk									MED-HIGH	MED-HIGH	HIGH	MED-HIGH	MED-LOW

Table 10. Relative Risk Assessment for Combination 3: Anthropogenic Load, Reef Condition and Reef Exposure (% area in exposure areas)

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Anthropogenic load													
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M		1,301,000	5,164,000	292,000	3,707,000	1,637,000
TSS Score									2	5	1	4	2
DIN	Range: 840 - 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500		2,791	3,244	1,613	1,030	840
DIN Score									4	5	3	2	2
PSII Herb	Range: 0.51 - 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6		1.84	0.51	3.55	1.20	0.97
PSII Herb Score									3	1	5	2	2
Anthropogenic Load Score									9	11	9	8	6
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Condition													
Macroalgal cover	Range: 7 - 41%	High cover = High impact	0 to 8	8 to 17	17 to 26	26 to 35	35 to 41						
Coastal MAC								GBR mean = 26.8	17.6	23.3	41	33.3	20.3
Coastal MAC Score									3	3	5	4	3
Inner Shelf MAC								GBR mean = 17.1	7.3	7.4	26.6	31.3	Not avail.
Inner Shelf MAC Score									1	1	4	4	
Hard Coral Richness	Range: 121 - 7.3	Low richness = High impact	125 to 100	100 to 75	75 to 50	50 to 25	25 to 0						
Coastal HCR								GBR mean = 104.9	83.5	99.1	82.5	50.5	41
Coastal HCR Score									2	2	2	3	4
Inner Shelf HCR								GBR mean = 126.2	112	121	72.3	57.8	Not avail.
Inner Shelf HCR Score									1	1	3	3	
Reef Condition Score									7	7	14	14	7
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Exposure		High % exposure = High impact											
TSS Exposure	Range: 1 - 10%		0 to 2	3 to 5	6 to 8	9 to 11	12 to 14		10	10	1	5	5
TSS Exposure Score									4	4	1	2	2
DIN Exposure	Range: 0 - 65%		0 to 13	14 to 27	28 to 41	42 to 55	56 to 69		65	25	1	5	10
DIN Exposure Score									5	2	1	1	1
PSII Herb Exposure	Range: 0 - 40%		0 to 8	9 to 17	18 to 26	26 to 34	34 to 42		40	20	20	10	5
PSII Herb Exposure Score									5	3	3	2	1
Reef Exposure Score									14	9	5	5	4
			1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
3: Overall Score	Anthropogenic Load, Reef Condition (exc Chl and Secchi) and Reef Exposure (% area in exposure areas)								30	27	28	27	17
			10 to 14	15 to 19	20 to 24	25 to 29	30 to 34	Maximum score = 50	5	4	4	4	2
Relative Risk								Minimum score = 10	HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MED-LOW

Table 11. Relative Risk Assessment for Combination 3A: Anthropogenic Load, Reef Condition and Reef Exposure (No. reefs in exposure areas)

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Anthropogenic load													
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M		1,301,000	5,164,000	292,000	3,707,000	1,637,000
TSS Score									2	5	1	4	2
DIN	Range: 840 - 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500		2,791	3,244	1,613	1,030	840
DIN Score									4	5	3	2	2
PSII Herb	Range: 0.51 - 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6		1.84	0.51	3.55	1.20	0.97
PSII Herb Score									3	1	5	2	2
Anthropogenic Load Score									9	11	9	8	6
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Condition													
Macroalgal cover	Range: 7 - 41%	High cover = High impact	0 to 8	8 to 17	17 to 26	26 to 35	35 to 41						
Coastal MAC								GBR mean = 26.8	17.6	23.3	41	33.3	20.3
Coastal MAC Score									3	3	5	4	3
Inner Shelf MAC								GBR mean = 17.1	7.3	7.4	26.6	31.3	Not avail.
Inner Shelf MAC Score									1	1	4	4	
Hard Coral Richness	Range: 121 - 7.3	Low richness = High impact	125 to 100	100 to 75	75 to 50	50 to 25	25 to 0						
Coastal HCR								GBR mean = 104.9	83.5	99.1	82.5	50.5	41
Coastal HCR Score									2	2	2	3	4
Inner Shelf HCR								GBR mean = 126.2	112	121	72.3	57.8	Not avail.
Inner Shelf HCR Score									1	1	3	3	
Reef Condition Score									7	7	14	14	7
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Exposure (No. reefs in exposure areas)													
No. of Reefs at Risk		High number of reefs in Mod-V High exposure areas = High impact	0 to 10	11 to 20	21 to 30	31 to 50	>50						
TSS Exposure # Reefs	Range: 0 - 9								9	0	2	6	0
% of Reefs in the Region									*5.7*	*0*	*0.4*	*0.8*	*0*
TSS Exposure Score									1	1	1	1	1
DIN Exposure # Reefs	Range: 0 - 123								123	4	2	10	0
% of Reefs in the Region									*78.3*	*2.2*	*0.4*	*1.4*	*0*
DIN Exposure Score									5	1	1	1	1
PSII Herb Exposure # Reef	Range: 0 - 78								53	5	78	12	0
% of Reefs in the Region									*33.8*	*2.8*	*15.1*	*1.7*	*0*
PSII Herb Exposure Score									5	1	5	2	1
Reef Exposure Score									11	3	7	4	3
			1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
3A: Overall Score	Anthropogenic Load, Reef Condition (exc Chl and Secchi) and (No. reefs in exposure areas)								27	21	30	26	16
								Maximum score = 50	5	3	5	5	2
Relative Risk			10 to 13	14 to 17	18 to 21	22 to 25	26 to 29	Minimum score = 10	HIGH	MED	HIGH	HIGH	MED-LOW

Table 12. Relative Risk Assessment for Combination 3B: Anthropogenic Load, Reef Condition and Reef Exposure (No. reefs <50km from coast)

Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Anthropogenic load													
TSS	Range: 292,000 - 5,164,000t	High load = High risk	0 to 1M	1M to 2M	2M to 3M	3M to 4M	4M to 5M		1,301,000	5,164,000	292,000	3,707,000	1,637,000
TSS Score									2	5	1	4	2
DIN	Range: 840 - 3244t	High load = High risk	0 to 700	701 to 1400	1401 to 2100	2101 to 2800	2801 to 3500		2,791	3,244	1,613	1,030	840
DIN Score									4	5	3	2	2
PSII Herb	Range: 0.51 - 3.55t	High load = High risk	0 to 0.7	0.7 to 1.4	1.4 to 2.1	2.1 to 2.8	2.8 to 3.6		1.84	0.51	3.55	1.20	0.97
PSII Herb Score									3	1	5	2	2
Anthropogenic Load Score									9	11	9	8	6
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Condition													
Macroalgal cover	Range: 7 - 41%	High cover = High impact	0 to 8	8 to 17	17 to 26	26 to 35	35 to 41						
Coastal MAC								GBR mean = 26.8	17.6	23.3	41	33.3	20.3
Coastal MAC Score									3	3	5	4	3
Inner Shelf MAC								GBR mean = 17.1	7.3	7.4	26.6	31.3	Not avail.
Inner Shelf MAC Score									1	1	4	4	
Hard Coral Richness	Range: 121 - 7.3	Low richness = High impact	125 to 100	100 to 75	75 to 50	50 to 25	25 to 0						
Coastal HCR								GBR mean = 104.9	83.5	99.1	82.5	50.5	41
Coastal HCR Score									2	2	2	3	4
Inner Shelf HCR								GBR mean = 126.2	112	121	72.3	57.8	Not avail.
Inner Shelf HCR Score									1	1	3	3	
Reef Condition Score									7	7	14	14	7
Parameter		Relationship	1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
Reef Exposure (No. reefs <50km from coast)													
Reefs within 50km of coast	Range: 21 - 483	High number = High risk	0 to 100	100 to 200	200 to 300	300 to 400	400 to 500		188	77	483	276	21
Reef Exposure Score									2	1	5	3	1
			1	2	3	4	5	Reference value	Wet Tropics	Burdekin	Mackay Whitsunday	Fitzroy	Burnett Mary
3B: Overall Score	Anthropogenic Load, Reef Condition (exc Chl and Secchi) and Reef Exposure (No. reefs <50km from coast)								18	19	28	25	14
			8 to 11	12 to 15	16 to 19	20 to 23	24 to 28	Maximum score = 40	3	3	5	5	2
Relative Risk								Minimum score = 8	MED	MED	HIGH	HIGH	MED-LOW

Regional assessment of the relative risk of the impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under the Reef Protection Package

Stage 2 Report
July 2009

ACTFR REPORT NUMBER 09/30

Prepared by Jon Brodie [1], Alan Mitchell[1] and Jane Waterhouse [1, 2]

Australian Centre for Tropical Freshwater Research

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Important message from the Director-General

The Queensland Government's Department of Environment and Resource Management (DERM) commissioned the Australian Centre for Tropical Freshwater Research (ACTFR) to assess the relative risk from agricultural activities which may contribute diffuse pollution to deteriorating water quality in the Great Barrier Reef.

This work is only one aspect of the ongoing science program, which is informing and providing the platform for the implementation of Reef Plan and the roll-out of Queensland Government's Reef Protection Package.

This report is the second of two reports that present the outcomes of the project: *Assessment of relative risk of impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under Reef Protection Package*:

1. Assessment of relative risk of the impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under the Reef Protection Package, Stage 1 Report April 2009; and
2. Regional assessment of the relative risk of the impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under the Reef Protection Package, Stage 2 Report July 2009.

The reports are based on the best available science, with clearly stated parameters and reasonable assumptions. They also acknowledge any limitations in data and uncertainties.

The reports represent the best available science at the time of publication. They provide the Queensland Government with a relative risk assessment of the impacts of agriculture on the Great Barrier Reef in order to make policy decisions in terms of investment in extension, research, regulation and other efforts to improve reef water quality. The Queensland Government is committed to ongoing investment in Reef Protection science and as new information becomes available government policy will be adapted to take account of it.

It is important to understand the information in these reports in context and that reference to and excerpts from these reports are presented in an appropriate manner. Should you have any further enquiries, please do not hesitate to contact [redacted] Project Manager from the department on telephone [redacted].

[redacted]

John Bradley
Director-General
Department of Environment and Resources

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Document Version: *Last edited 22 December 2009, J. Waterhouse*

Acknowledgements

Funding for this project came from the Queensland Department of Environment and Resource Management (DERM, formerly the Environmental Protection Agency) and forms the second stage of the GBR wide assessment completed in April 2009 (Brodie and Waterhouse, 2009). The authors would like to acknowledge the project team and funding agencies associated with the report, *Current loads of priority pollutants discharged from Great Barrier Reef Catchments to the Great Barrier Reef* (Brodie *et al*. 2009) and the regional Water Quality Improvement Plans which formed the foundation for many of the figures provided in this report. This project and the current contract was carried out in conjunction with parallel projects funded by the CSIRO Great Barrier Reef Water Quality Options project under Water for a Healthy Country, and the Marine and Tropical Sciences Research Facility administered through the Reef and Rainforest Research Centre. The manuscript was improved after review by the client (DERM), and Zoe Bainbridge and Stephen Lewis of ACTFR.

Executive Summary

In consideration of the risks from anthropogenic loading of runoff into Great Barrier Reef (GBR) waters, various measures of current and anthropogenic exports of suspended sediments (SS), dissolved inorganic nitrogen (DIN) and PSII Herbicides are compared for the river-creek basins from the Daintree basin south to the Calliope basin. The three key categories of SS, DIN and PSII Herbicides are considered to be the most important pollutants derived from anthropogenic land uses, mainly cropping, grazing and urban use, that may pose threats to the quality of runoff water entering the GBR ecosystem. The purpose of this report is to help direct management activities to basins and pollutants of most concern.

The rivers to be considered in this report include those in the Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy NRM regions as requested by DERM. Rivers in the Cape York and Burnett Mary NRM regions are excluded at this stage. The basins that are included represent most of the coast adjacent to the GBR and most of the land use that has been greatly disturbed by anthropogenic activities. This includes basins which cover the range of climatic regimes along the coast, from the Wet Tropics region (Daintree to Herbert), Dry Tropics (Black to Don), a second wet region (Proserpine to Plane) and a second dry region (Styx to Calliope). They also include basins of considerably variable size, from the sub-basins of the Burdekin and the Fitzroy (not yet partitioned) of very large area to the short coastal rivers of the Wet Tropics and the Mackay-Whitsunday regions with much smaller basin areas.

The sources of data for this report have mainly relied on Brodie *et al*. (2009) and Brodie *et al*. (2003), though a number of recent Water Quality Improvement Plan (WQIP) reports have also been used. In an ideal comparison, identically-derived, consistent data would be used for each of the 27 basins. The reality is that data across these many basins are inconsistent in terms of different model runs, better modeling in more recent runs and very different time periods of monitoring as the observational baseline. To emphasise the latter point, the data sets range from one year to around 20 years. Hence, data consistency between the basins is low. Also, since a number of parameters (e.g. anthropogenic loads) are estimated by differences, this introduces a much larger error. Thus, because we use anthropogenic loads as a basis for comparison between basins, there is an inherent, high degree of inconsistency and uncertainty. However, these are the only data we have available. Despite all these caveats, we consider that confidence in these estimates should be considered fair or better.

It should be noted that data are included for major land uses in this report which potentially contribute to GBR water quality. The land use categories are the same as those used in the Stage 1 Report, ie. Forest, Grazing, Sugar cane, Other Crops and Other. The fact that specific land uses such as dairy or grains and its incorporation into categories such as Other or Other crops respectively are absent as a specific discussion point under any section does not mean that it does not have a contributory effect, but does mean that the contribution is known to be small at a GBR scale as is the case for dairy, or only important in one region such as grains in the Fitzroy.

The key findings in the report are summarised below.

In the Burdekin Region:

- The overall suspended sediment load to the GBR from the Bowen-Bogie basin is the highest in the region, followed by the Upper Burdekin basin and the Don basin.
- The key land use requiring management of suspended sediment is grazing.
- Hillslope erosion across the region contributes the most suspended sediments in comparison to other erosion types like bank or gully erosion.
- The overall DIN load to the GBR from the Lower Burdekin basin is the highest in the region. The other coastal basins in the Burdekin Region also contribute minor anthropogenic DIN loadings but in total are substantially less than that of the Lower Burdekin basin.
- The key contributing land use to DIN delivery to the GBR is sugar cane and associated fertiliser application.
- The Lower Burdekin basin delivers most PSII Herbicides to the GBR from the Burdekin Region.
- The PSII Herbicides delivered from basins in the region are believed to be from two land uses:
    - Sugar cane is the primary source of PSII Herbicides other than tebuthiuron (mainly diuron but also atrazine, ametryn, hexazinone). The sources of simazine are not widely known but it is known to be used in plantation forestry.
    - Grazing lands are the primary source of tebuthiuron.
- The overall load of tebuthiuron to the GBR is highest from the Belyando, Cape and Suttor basins, whilst the largest contribution of Other PSII Herbicides is in the Lower Burdekin basin. The confidence in the load estimates for the Cape, Belyando and Bowen Bogie basins, where tebuthiuron has only been detected in a limited number of samples, is considered low. As tebuthiuron has never been detected in the Upper, East Burdekin, Don, Black and Ross basins the load has been given as 0.

In the Wet Tropics Region:

- The Herbert basin generates the most current and anthropogenic suspended sediment load on an annual basis, followed by the Johnstone, Daintree and Russell Mulgrave basins. However, the Mossman basin generates the most suspended sediment per basin area on an annual basis, followed by the Russell Mulgrave, Daintree and Johnstone basins.
- The greatest anthropogenic load of suspended sediment to the GBR per unit area of land use is from sugar cane in most Wet Tropics basins (except Murray where ‘Other crops’ are higher). Grazing is also an important source in the Herbert, Daintree and Mossman basins.
- Loading reductions of suspended sediment could be achieved through managing hillslope erosion across the region.
- The Russell Mulgrave basin generates the most DIN on an annual basis, followed by the Johnstone, Herbert and Tully basins.
- The key contributing land use to DIN loads is sugar cane and associated fertiliser application.
- The largest proportion of total anthropogenic DIN load from sugar cane is from the Johnstone basin, with high contributions also from the Russell Mulgrave, Herbert, Tully and Murray basins.
- In terms of DIN load from sugar cane per unit area of sugar cane cultivation, the highest loads per unit area are from the Russell Mulgrave, Tully, Murray and Johnstone basins.
- The Herbert basin delivers the greatest load of PSII Herbicide delivery followed by the Johnstone, Russell Mulgrave and Tully basins. The loads from remaining basins are comparatively lower.
- The greatest proportion of PSII Herbicides is generated from sugar cane areas, then grazing for all Wet Tropics basins.
- The greatest proportion of PSII Herbicides in the Herbert basin is generated from sugar cane areas. This is also true for all Wet Tropics basins.
- Diuron is the PSII Herbicide discharged in the highest amounts from the region, followed by atrazine and hexazinone.
- The Herbert, Mulgrave-Russell, Johnstone and Tully basins deliver substantial exports of diuron.
- It is believed that tebuthiuron is derived from grazing but there is little monitoring data for tebuthiuron in the Wet Tropics and all tebuthiuron conclusions need to be treated with caution. The other PSII Herbicides are known to be derived from sugar cane with high certainty (with the exception of simazine). The sources of simazine are not widely known but it is known to be used in plantation forestry.

In the Mackay Whitsunday Region:

- The Pioneer basin delivers the most current and anthropogenic suspended sediment load on an annual basis, followed by the O’Connell basin. The Pioneer basin also delivers the most suspended sediment per basin area on an annual basis in the Mackay Whitsunday Region, followed by the O’Connell basin.
- The land use that generates the most anthropogenic suspended sediment load to the GBR is sugar cane in the Pioneer basin and grazing in the Pioneer and O’Connell basins.
- The greatest anthropogenic load of suspended sediment to the GBR per unit area of land use is from sugar cane in the Pioneer, O’Connell and Proserpine basins. Grazing is also an important source in the Pioneer and O’Connell basins.
- Hillslope erosion across the region contributes the most suspended sediments in comparison to other erosion types like bank or gully erosion.
- The O’Connell basin generates the most DIN load on an annual basis, followed by the Pioneer basin.
- The greatest proportion of anthropogenic DIN load is derived from sugar cane areas, particularly in the Pioneer basin.
- The largest proportion of total anthropogenic DIN load from sugar cane is from the Pioneer basin, followed by the O’Connell basin.
- In terms of DIN load from sugar cane per unit area of sugar cane cultivation, the highest loads per unit area are from the Pioneer and O’Connell basins.
- The Plane basin has the greatest load of PSII Herbicide delivery followed by the Pioneer and O’Connell basins.
- The greatest proportion of PSII Herbicides in the Plane basin is generated from sugar cane areas, accounting for 88% of the total PSII Herbicide load.
- Diuron is the PSII Herbicide discharged in the highest amounts and is discharged in high amounts from all basins. The use of diuron in the region is associated with sugar cane cultivation.
- It is believed that tebuthiuron is derived from grazing, while the other PSII Herbicides are known to be derived from sugar cane. Simazine detection in the region is minor and the sources of simazine are not widely known.

In the Fitzroy Region:

- The overall suspended sediment load to the GBR from the Fitzroy basin is by far the highest in the Fitzroy Region, linked to the large size of this basin.
- The key land use requiring management of suspended sediment in the Fitzroy Region is grazing.

- Loading reductions of suspended sediment could be achieved through managing hillslope erosion across the region.
- Highest erosion inputs are seen from hillslope erosion in the Connors, Lower Fitzroy, Comet and Nogoa sub-basins of the Fitzroy basin (see Figure 22, Dougall *et al*., 2008).
- The overall DIN load to the GBR from the Fitzroy basin is the highest in the Fitzroy Region (Table 4.8), in part a reflection of the large size of this basin.
- The other coastal basins in the Fitzroy Region also contribute minor anthropogenic DIN loadings, but in total this is substantially less than that of the Fitzroy basin (Figure 4.8).
- The key contributing land use to DIN delivery to the GBR is 'Other crops' (Figures 4.10, 4.11), mainly grains and cotton. While the fertilizer application rates for grains crops are relatively low compared to sugar cane activity in other GBR catchments, cotton has comparable fertilizer rates to sugar cane.
- The Fitzroy basin delivers more tebuthiuron (herbicide) than any of the basins considered here in the four regions, largely due to its very large size and area of grazing. An approximately equal amount of Other PSII Herbicides, mostly atrazine, derives from the large cropping area in the Fitzroy basin.
- All of the basins in the region deliver low PSII Herbicide loads per basin area.
- The PSII Herbicides delivered from basins in the region are from two land uses:
    - Other crops, specifically grains are the primary source of PSII Herbicides (primarily atrazine and diuron) other than tebuthiuron.
    - Grazing lands are the primary source of tebuthiuron.
- The largest loads of tebuthiuron (associated with grazing land management) are from the Fitzroy basin. The largest loads of other PSII Herbicides (associated with Other crops cultivation) are also from the Fitzroy basin.

Overall, this study has shown that it is possible with current data to identify 'hot-spots' of pollutant delivery to the GBR with a reasonable degree of certainty. This then allows management prioritisation. However, the results also show that in some areas data are scarce and that quantitative uncertainty estimates are still beyond our current methods to measure.

Introduction

In April 2009, the Australian Centre for Tropical Freshwater Research (ACTFR) completed Stage 1 of the project *Assessment of relative risk of the impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under the Reef Protection Package* for the Department of Environment and Resource Management (DERM). The report and accompanying tables provide a relative risk assessment of suspended sediment, nutrients and PSII Herbicides for the natural resource management regions in the Great Barrier Reef (GBR) catchments (called basins here) (Brodie and Waterhouse, 2009).

The Stage 1 assessment indicates that the Wet Tropics and Mackay Whitsunday regions rank the highest priority (ranked High), with Burdekin and Fitzroy catchments relatively high priority (ranked Medium-High) and the Burnett Mary catchments of moderate priority in terms of the contribution and influence of land based contaminants. This is conducive with several principles of the current understanding of priority contaminants and land uses in the GBR:

1. Sugar cane and horticultural land uses that generate large quantities of Dissolved Inorganic Nitrogen (DIN) and PSII Herbicides runoff per unit area are dominant in the coastal areas of the Wet Tropics, Burdekin, Mackay-Whitsunday and Burnett Mary regions.
2. The predominantly coastal location of intensive agricultural land uses in the GBR catchment results in efficient delivery of contaminants to the GBR.
3. A high number of reefs are located close to the coast in the northern parts of the GBR, particularly in the Wet Tropics, and the southern reefs tend to be located further offshore.

The Stage 1 assessment reflected the importance of dry tropics grazing activities and the contribution of sediment by erosion to receiving waters. A large proportion of the reefs in the dominant grazing areas of the Fitzroy and particularly the Burdekin regions are located further offshore and thus may present a lower risk to reef habitats. However, suspended sediment risk to other important GBR ecosystems such as seagrass beds was not included in the assessment and if this was done the importance of the Burdekin and Fitzroy regions could be enhanced.

The next step of that project is to complete an assessment of management priorities within the basins of the priority regions in terms of water quality improvement outcomes.

Scope

This report forms Stage 2 of the project, *Assessment of the relative risk of the impacts of broad-scale agriculture on the Great Barrier Reef and priorities for investment under the Reef Protection Package.* It addresses the following tasks:

1. Where possible define regional hot-spots for management based on basin/sub-basins for each NRM region Describe the process for defining relative risk/regional hot-spots.
2. Utilise modelled data from relevant WQIPs and other sources across basin/sub-basins to complete the assessment.

A preliminary assessment of data availability for the regions was undertaken and provided to DERM early in the Stage 2 project. DERM requested that the project focus on the Burdekin and Wet Tropics Regions initially, then the Mackay Whitsunday and Fitzroy Regions as second priority. It was decided that given the limitations with data availability in the Burnett Mary Region, that regional assessment could be completed at a later date when the appropriate information is more accessible.

Table A *Data availability for different GBR coastal regions.*

Region	Data availability
Cape York	Poor – no WQIP and limited modelling and monitoring data.
Wet Tropics	Variable across the region - due to WQIPs only available for Douglas, Barron and Tully-Murray catchments.
Burdekin	Good – WQIP complete including Ross Black WQIP but misses the Don Basin. Sub catchment SedNet and Annex data available.
Mackay Whitsunday	Good – WQIP complete and covers entire Region. Sub catchment data available.
Fitzroy	Good – regional water quality plan is complete. Reported modelled data is not at sub catchment scale.
Burnett Mary	Poor – Although a WQIP was recently completed (April 2009), data availability is still poor due to lack of monitoring.

Approach

Within each region, an assessment has been completed to address the following questions:

Suspended sediment

- Which basin of the region delivers the most suspended sediment (current) on an annual basis to the GBR?
- Which basin of the region delivers the most anthropogenic suspended sediment on an annual basis to the GBR?
- Within the basins, which land use contributes the majority of the suspended sediment?
- Within all of the basins what is the erosion type that generates the most suspended sediment?

Dissolved Inorganic Nitrogen

- Which basin of the region delivers the most DIN on an annual basis to the GBR?
- Within the basins, which land use contributes the majority of the DIN?
- Within the primary source land use, which basins deliver the most DIN per hectare?

PSII Herbicides

- Which basins of the region deliver the most herbicides on an annual basis to the GBR?
- What kind of herbicide is delivered from which basins?

Hence, within each region, these measures and major contributing factors are estimated for each basin, as in Table B.

Table B *Measures and major contributing factors for the risk assessment.*

Pollutant	Measure	Most relevant land use	Dominant erosion
TSS	Current load Anthropogenic load Current load per area Anthropogenic load per area	**Grazing**	**Hillslope** **Gully** Bank
DIN	Current load Anthropogenic load Current load per area Anthropogenic load per area	**Sugar cane**	
Herbicides	Current load Current load per area	**Sugar cane and/or Grazing and Other Crops**	

There are some differences in the assessment processes used for each region due to differences in data availability and catchment geographic characteristics. In particular, the assessment approach in the Wet Tropics and Mackay Whitsunday is not the same as the Burdekin and Fitzroy assessments, since the latter regions are mostly one large catchment with large basins all dominated by grazing. In the Wet Tropics and Mackay Whitsunday, there are individual major basins and the dominant land use for water quality purposes is sugar cane. In some cases, the basin consists of one catchment or sub catchment, while in other cases the basin is an aggregation of several catchments or sub catchments.

Whilst the same general approach was used for defining anthropogenic load for suspended sediment and DIN, different datasets were used by judgment of the best available information, but due to different levels of uncertainty in the datasets some anomalous results were obtained. These are discussed below, and within each regional assessment.

The definitions used in this report are outlined below.
Regions: Reflects the boundaries covered by the Natural Resource Management regions.

Basins: The unit used here to refer to both river catchments and sub-catchments.

Land-Use: The land use categories are the same as those used in Stage 1, ie. five land-use classifications as shown in Table C. Land-use groupings are an amalgam of common land use (LU) categories (e.g. Sugar cane includes dryland sugar cane cropping (LU code = 3.3.5) plus Irrigated sugar cane cropping follow (4.3.5), that follow the ALUM classification (version 6) and are provided by the latest QLUMP (2005; latest available) GIS maps.

Table C *Land use classification groupings used in QLUMP analyses.*

Land Use classification	General description	ALUM codes
Forest	Conservation & Natural Environments Production Forestry from Relatively Natural Environments	1 (all classes) 2.2.0
Grazing	Grazing Natural Vegetation	2.1.0
Sugar cane	Dryland + Irrigated Sugar	3.3.5, 4.3.5
Other crops	Production from Dryland Agriculture and Plantations (except Plantation Forestry & Sugar) Production from Irrigated Agriculture and Plantations (except Sugar) Intensive Horticulture	3 (all classes except Plantation forestry 3.1.0 & Sugar, 3.3.5) 4 (all classes except Sugar, 4.3.5) 5.1.0
Other	Intensive uses (includes Urban, Industrial, Mining Animal Production) Dryland Plantation Forestry Water areas	5 (all classes except Intensive Horticulture, 5.1.0) 3.1.0 6 (all classes)

Erosion-type: Categories as used in SedNet, ie. hillslope, gully and bank.

Load: All loads included in this report are an estimate of average annual loads, generally averaged over the last approximately 20 years. This is complicated by the difference in approaches used in modeling and monitoring; modeled data is generally based on much longer time frames compared to monitoring which is only available for less than 10 years in most cases.

Current Load: Best estimates, mostly derived from Brodie *et al*. (2009), Brodie *et al*. (2003) and latest WQIP reports.

Natural Load: Estimated, mostly from Brodie *et al*. (2003) or specific estimates for DIN as explained below.

Anthropogenic Load: Estimated by difference; Current Load minus Natural Load. The sources and methods of the estimates of anthropogenic load varies for parameter, as follows:

- **Suspended sediment (SS)**: The anthropogenic loads of suspended sediment for major basins are derived from Brodie *et al*. (2009). The natural loads for the sub catchment of the Burdekin referred to here as basins (eg. Lower Burdekin) were calculated using a proportional allocation, i.e. using the same proportion of natural:current (~1:10) for the Burdekin basin as a whole.

- **Dissolved Inorganic Nitrogen (DIN)**: The anthropogenic loads of DIN for major basins are derived from Brodie *et al*. (2009). The anthropogenic load for land uses was based on assumptions about natural dynamics of nutrient generation in natural areas and grazing lands. The assumption is that no anthropogenic DIN is generated in these land uses. For Sugar cane, Other Crops and Other land uses, the natural DIN load is calculated from a natural DIN generation rate, derived from current regional natural DIN generation, multiplied by the land use area. Examples of these calculations are provided in the grey boxes within the report.

  Because different techniques were used to estimate anthropogenic loads in different parts of the report, ie. anthropogenic load by basin (Brodie *et al*. 2009), and then anthropogenic load by land use, the total anthropogenic load for the region by the sum of the basins and the sum of the land use contributions may not match. The differences are partly because in Brodie *et al*. (2009), the natural loads are ultimately derived from Brodie *et al*. (2003) where grazed savannah and natural savannah lands assumed that grazed savannah generated more DIN than ungrazed savannah. The current understanding however is that there is no documented difference in DIN generation rate between grazed and ungrazed savannah, and that is the assumption in the DIN land use contributions in this report.

- **PSII Herbicides**: The natural load is zero, hence the current load is all anthropogenic. There is no comprehensive modelling of herbicide loads and limited monitoring data exist for only a few GBR rivers, thus the herbicide load estimates are derived from a simple model initially developed by

Maughan, Brodie and Waterhouse (Maughan *et al*. 2008) and subsequently extended by Lewis (unpublished).

In the analysis, the total herbicide load is assumed to consist of atrazine, ametryn, hexazinone, simazine, tebuthiuron and diuron, and called "Total PSII Herbicides", as all six herbicides work in a similar way by suppressing photosynthesis. Lewis used available pesticide study data from the Pioneer, Barratta, Haughton, Sandy, O'Connell and Fitzroy Rivers to predict the load and eventual concentration of herbicides in other GBR catchments. For each of the known loads, the land area of sugar cane, dryland cropping and dryland grazing was determined, and the loss per hectare calculated. The herbicide load using land area for other GBR river catchments was then calculated and used to estimate the presumed loss per river basin.

All herbicide loading are related to human activities with:

- Tebuthiuron associated with grazing land management.
- Other PSII Herbicides which include diuron, atrazine, ametryn and hexazinone associated with sugar cane cultivation and to a lesser extent, grains; the sources of simazine are not well known at this stage. Atrazine also comes from dryland cropping but mostly from the headwaters of the Burdekin and Fitzroy Rivers.

Data confidence: The assessment of data confidence in the load estimations in this report are drawn from those included in Brodie *et al*. (2009).

Regional Assessment: Burdekin Region

1.1 Regional Summary Table

Table 1.1 *Summary of load characteristics for the Burdekin Region*.

Parameter	Upper	East Burdekin	Cape	Belyando	Suttor	Bowen-Bogie	Lower Burdekin	Don	Black	Ross	Burdekin Region
Basin Area (ha)	3,589,500	884,600	1,969,600	3,514,100	1,729,800	1,189,100	443,075	323,100	87,100	145,200	13,875,176
Suspended sediment											
Current SS load to the GBR (000 tonnes)	806	119	222	299	232	1,091	300	590	180	190	4028
Current SS load to the GBR per basin area (tonnes/ha)	0.23	0.13	0.11	0.08	0.13	0.92	0.68	1.83	2.07	1.31	0.29
Anthropogenic SS load to the GBR (000 tonnes)	725	107	199	269	209	982	271	551	150	170	3633
Anthropogenic SS load per basin area (tonnes/ha)	0.20	0.12	0.10	0.08	0.12	0.83	0.61	1.71	1.72	1.17	0.26
Dominant losses linked to:											
Land use source	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing	Graz+Sugar	Grazing	Grazing	Grazing	Grazing
Erosion type	Hillslope	Hillslope	Gully	Gully	Gully	Hillslope	Hillslope	Hillslope	Hillslope	Hillslope	Hillslope
Dissolved Inorganic Nitrogen (DIN)											
Current DIN load (tonnes)	510	0	150	99	340	460	4100	60	60	70	5,849
Current DIN load per basin area (kg/ha)	0.14	0	0.08	0.03	0.2	0.39	9.25	0.19	0.69	0.48	0.42
Anthropogenic DIN load (tonnes)[1]	170	0	50	33	113	153	3000	27	32	54	3,632
Anthropogenic DIN load per basin area (kg/ha)	0.05	0.00	0.03	0.01	0.07	0.13	6.77	0.08	0.37	0.37	0.26
Anthrop DIN load per sugar area (kg/ha)							37.2				
Dominant losses linked to:											
Land use source	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing	Sugar	Grazing	Grazing	Grazing	Grazing
PSII Herbicides											
Tebuthiuron (kg)	0	0	171	311	154	105	4	0	0	0	
Other PSII Herbicide (kg)	18	213	11	73	91	5	3,603	106	44	1	
Total PSII Herbicide load (kg)	18	213	182	385	245	110	3,607	106	44	1	4,910
PSII Herbicide load per basin area (g/ha)	0.01	0.24	0.09	0.11	0.14	0.09	8.1	0.33	0.51	0.01	0.35
Dominant losses linked to:											
Land use source	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing	Sugar	Grazing	Grazing	Grazing	Grazing

[1]Note: The anthropogenic DIN loads used in this table are taken from Table 1.4.

Attachment 1 provides supporting detail and references to the above summary information. For current suspended sediment loads, the latest estimates of hillslope, gully and bank erosion inputs for the upper and most of the lower sub-catchments were taken from Kinsey-Henderson *et al*. (2007). Input suspended sediment loads for the Lower Burdekin, Don, Black and Ross utilised the estimates of Fentie *et al*. (2006). However, net export suspended sediment loads were cited from two sources. For the sub-basins of the Burdekin, the results of Kinsey-Henderson *et al*. (2007) (Table 2) are used, assuming a 60% trapping rate by the Burdekin Falls Dam. For the whole Burdekin, Lower Burdekin, Don, Black and Ross sub-basins, the current best estimates from Brodie *et al*. (2009) are used.

The nutrient loads were obtained from Bainbridge *et al*. (2007) using Tables 5-11 as the 2002-06 average monitored loads and Table 12 for the whole Burdekin loads. A recent best estimate of DIN loads (Brodie and Bainbridge, 2008) is used for the Lower Burdekin area. The current best estimates of Brodie *et al*. (2009) are used for the remaining forms in the Lower Burdekin, Don, Black and Ross sub-catchments.

1.2 Regional Assessment Data

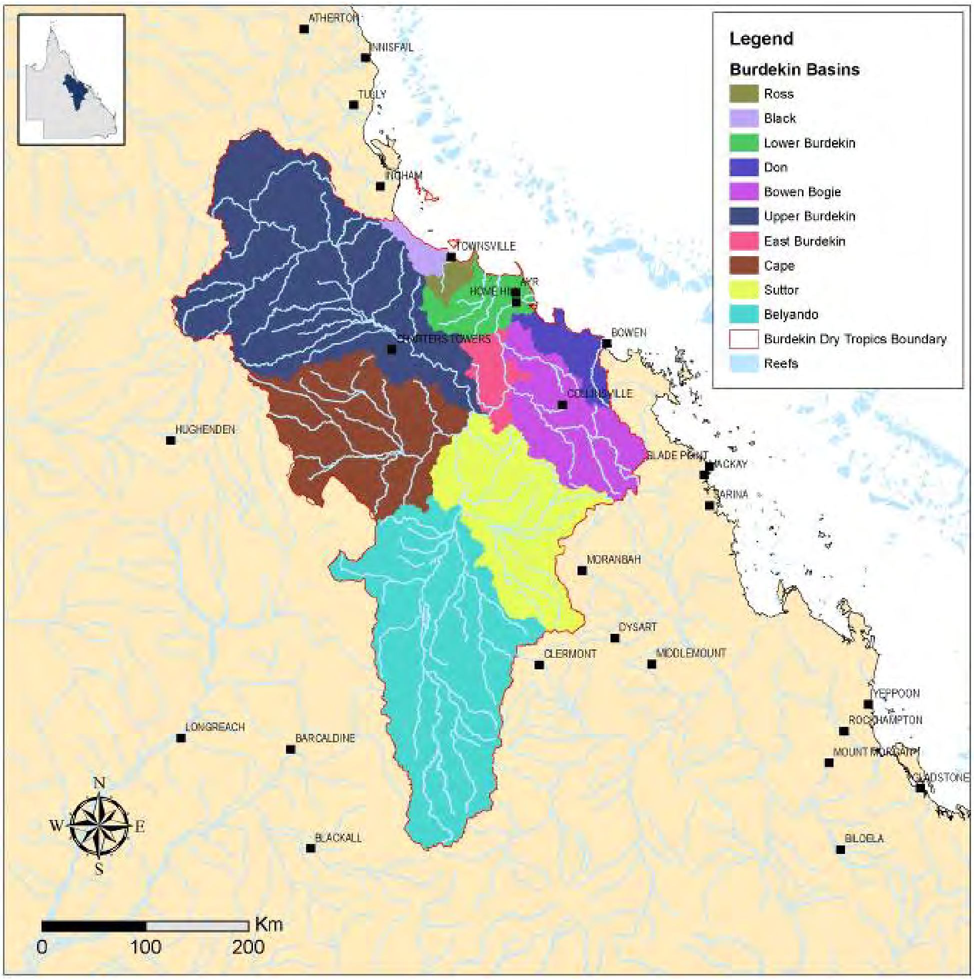
Assessment units in the Burdekin Region

The Burdekin Region consists of one large catchment and 3 smaller coastal basins. The Burdekin catchment is divided into 7 basins.

For the purpose of this risk assessment, the basins of the Burdekin Region are defined as per Table 2 in Bainbridge *et al*. (2007), except for minor changes of boundaries – refer to Figure 1.1, with:

- Basins upstream of the Burdekin Falls Dam include the Upper Burdekin, East Burdekin (partially), Cape, Belyando and Suttor.
- The East Burdekin basin includes the Upper Haughton, Landers Creek and Expedition Creek. The Bowen and Bogie basin lie downstream of the Burdekin Falls Dam.
- A new basin was defined for the Lower Burdekin as the area downstream of the East Burdekin basin, but also including Barratta Creek and the Lower Haughton on the northern side, both banks of the lower Burdekin River and Yellowgin Creek on the southern side. The area is modified from Brodie *et al*. (2003).
- The Don basin is defined as the basin north from the Don River up to Yellowgin Creek.
- The Black and Ross basins are as defined by Bainbridge *et al*. (2008).

Figure 1.1 *Basins in the Burdekin Region.*



1.3 Suspended Sediment in the Burdekin Region

Which basin in the Burdekin Region delivers the most suspended sediment on an annual basis to the GBR?

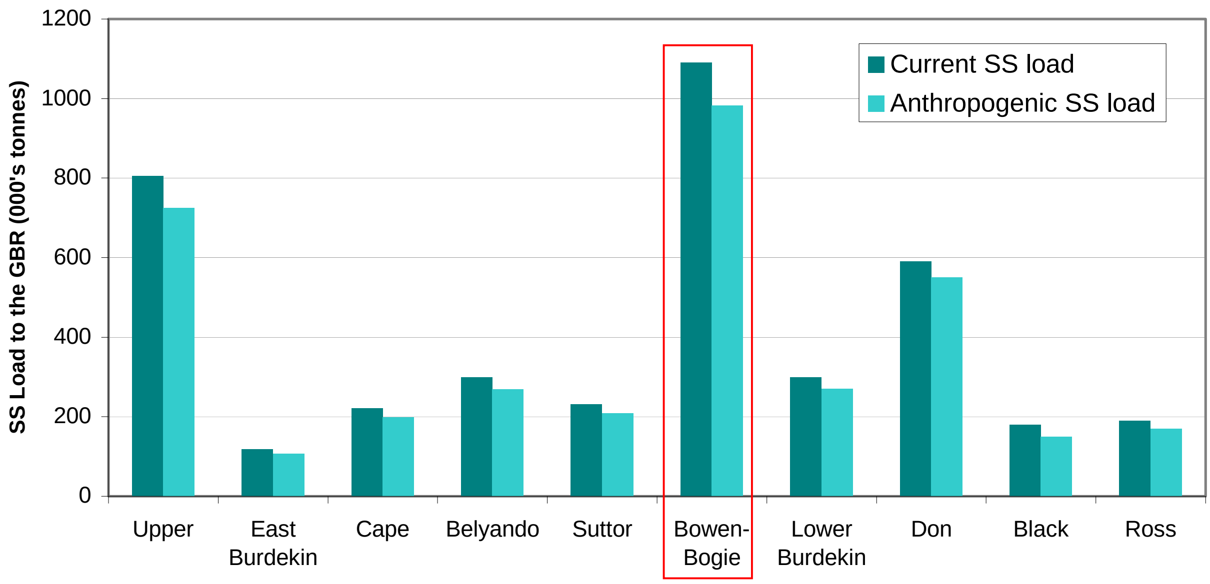
Approach: Rank basins using tonnes of SS based on current and anthropogenic figures. Note that the end of catchment load (delivery to the GBR) is calculated as 40% of the end of sub catchment load for the Belyando, Suttor, Cape and Upper Burdekin basins due to dam trapping. The trapping rate is derived from recent estimates from monitoring results (Lewis *et al*. 2008) and applying it to individual sub basin estimates.

Anthropogenic load is estimated for the Burdekin sub-basins using the same proportion of natural:current (~1:10) for the Burdekin basin as a whole defined in Brodie et al. (2009) (ie. Natural SS load 478,000 / Current SS load 4,600,000 tonnes = 9.62 rounded to ~10) to calculate the natural load, which is then subtracted from the current load. The anthropogenic load for the Lower Burdekin, Don, Black and Ross are derived by subtracting the natural load defined in Brodie *et al*. (2009) from the current load defined in this report.

Table 1.2 *Suspended sediment loads delivered to the GBR from the Burdekin Region*. Source: Brodie *et al*. (2009).

	Upper	East Burdekin	Cape	Belyando	Suttor	Bowen-Bogie	Lower Burdekin	Don	Black	Ross	Burdekin Total
Current SS load to the GBR (000's tonnes)	806	119	222	299	232	1091	300	590	180	190	4028
Anthropogenic SS load to the GBR (000's tonnes)	725	107	199	269	209	982	271	551	150	170	3633
Current SS load to the GBR per basin area (tonnes / ha)	0.23	0.13	0.11	0.08	0.13	0.92	0.68	1.83	2.07	1.31	0.29
Anthropogenic SS load to the GBR per basin area (tonnes / ha)	0.20	0.12	0.10	0.08	0.12	0.83	0.61	1.71	1.72	1.17	0.26

Figure 1.2 *Suspended sediment load (current and anthropogenic) delivered from the Burdekin Region to the GBR.*



Rankings:

Current	Anthropogenic
1. Bowen-Bogie	Bowen-Bogie
2. Upper	Upper
3. Don	Don
4. Lower	Lower
5. Belyando	Belyando
6. Suttor	Suttor
7. Cape	Cape

8. Ross Ross
9. Black Black
10. East Burdekin East Burdekin

Conclusion: The Bowen-Bogie basin currently delivers the most current and anthropogenic suspended sediment load on an annual basis to the GBR.

Data confidence: The data is sourced from a combination of monitored and modeled data and is considered to be moderate reliability. Further assessment of data confidence is included in Brodie *et al*. (2009).

Within the basins, which land use contributes the majority of the suspended sediment?

Approach: Rank land use contributions for SS load. Land use contributions to SS load are not yet determined for all of the Burdekin basins, however, land use can be shown at the catchment scale for some of the basins that have been individually assessed in the past. Given the dominance of grazing land use in the Region, anthropogenic load by land use contributions has not been calculated as the difference is assumed to be around 10%, as indicated in Table 1.2 and Figure 1.2.

Figure 1.3 *Current suspended sediment loads by land use in the Burdekin basins.* Source: Brodie *et al*. (2009).

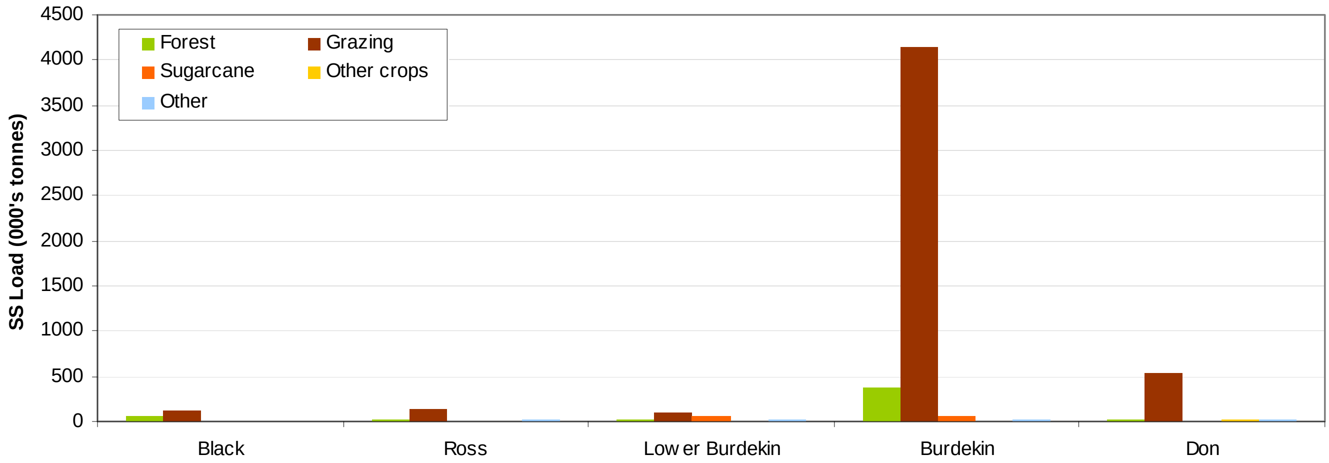
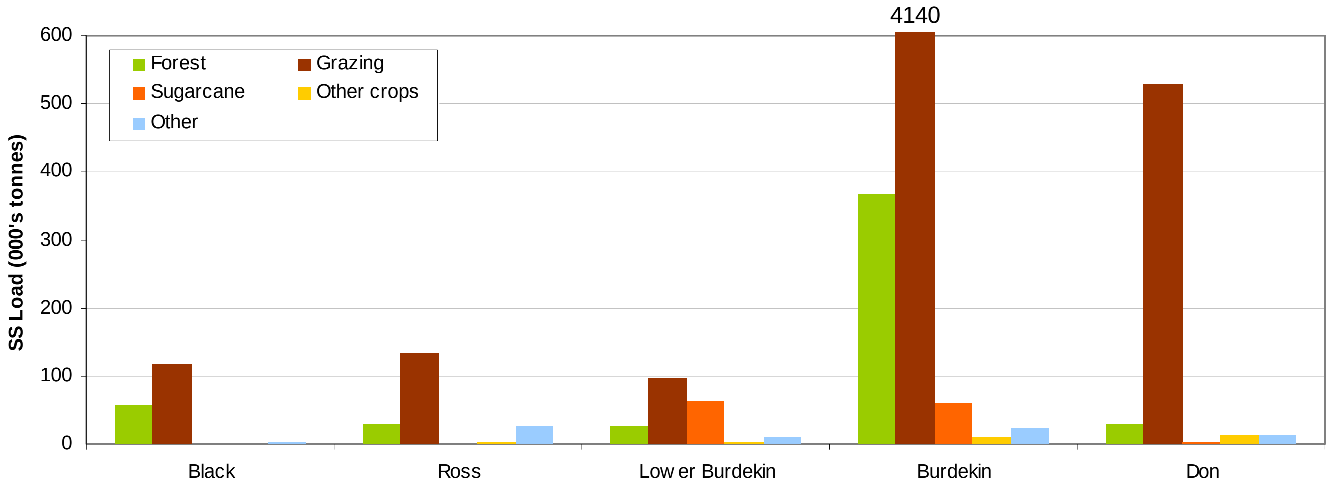


Figure 1.4 *Current suspended sediment loads by land use in the Burdekin basins, with expanded y-axis.*



Rankings:
1. Grazing
2. Forest
3. Sugar cane
4. Other cropping
5. Other

Conclusion: Grazing land use is currently contributing most suspended sediment across the Burdekin region.
Data confidence: High level of confidence.

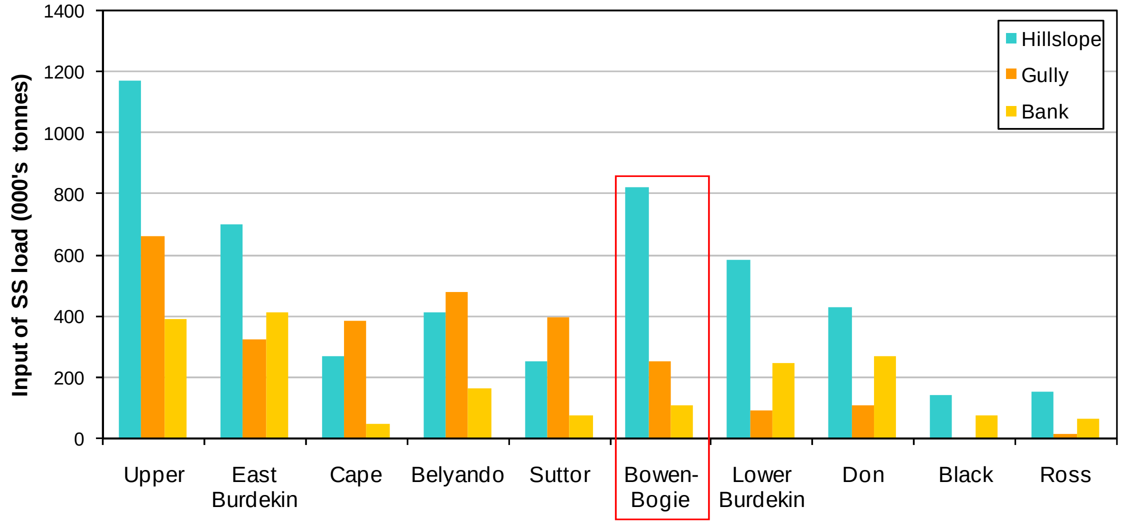
Within all of the basins what is the erosion type that generates the most suspended sediment?

Approach: Rank the input loads of SS from hillslope, gully and bank erosion for each basin from modeled data. There is difficulty in separating natural erosion versus anthropogenic or historic erosion in relation to erosion type, and only current rates are presented here. Note that this analysis is being done within each basin, not to the GBR, hence some differences will appear in the totals compared to Table 1.2.

Table 1.3 *Total suspended sediment loads by erosion type in the Burdekin basins based on current load*. Source: Kinsey Henderson *et al*. (2007).

Source (000's tonnes)	Upper	East Burdekin	Cape	Belyando	Suttor	Bowen-Bogie	Lower Burdekin	Don	Black	Ross	Whole Burdekin
Hillslope	1174	705	269	415	257	823	584	432	146	157	3643
Gully	666	325	388	480	397	256	93	108	6	19	2512
Bank	393	417	48	168	77	112	249	271	77	67	1215
Total Inputs	2233	1447	705	1063	731	1191	926	811	229	243	7370

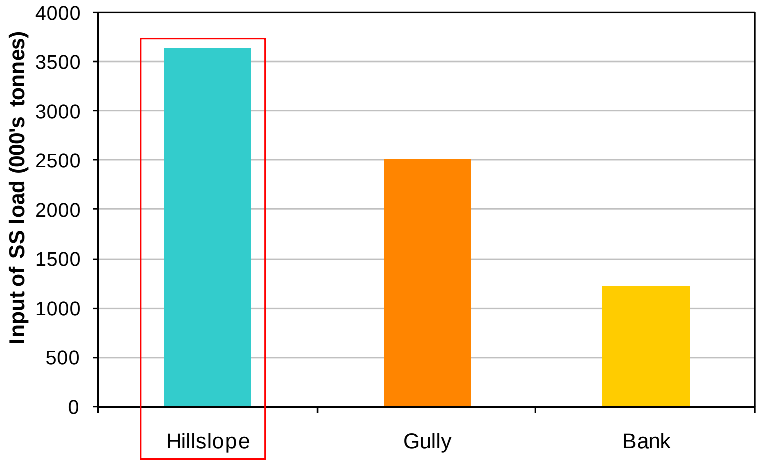
Figure 1.5 *Total suspended sediment loads by erosion type within the Burdekin basins based on current load.*



Rankings:

Bowen-Bogie	Upper	Don	Lower Burdekin
1. Hillslope	1. Hillslope	1. Hillslope	1. Hillslope
2. Gully	2. Gully	2. Bank	2. Bank
3. Bank	3. Bank	3. Gully	3. Gully

Figure 1.6 *Total suspended sediment load by type of erosion within the Burdekin Region (based on current).*



Rankings:

1. Hillslope
2. Gully
3. Bank

Conclusion: Across all of the Burdekin Region, hillslope erosion is the dominant source of suspended sediment generation.

Data confidence: There are limitations with knowledge regarding erosion types as the existing SedNet modeling does not model gully erosion well. New studies will improve this with the incorporation of more detailed gully mapping into SedNet. Therefore the results may present an under estimate of gully erosion. There is also difficulty in separating natural erosion versus anthropogenic or historic erosion in relation to erosion type, and only current rates are presented here.

Key findings for suspended sediment in the Burdekin Region

- **The overall suspended sediment load to the GBR from the Bowen-Bogie basin is the highest in the Burdekin Region, followed by the Upper Burdekin basin and the Don basin.**
- **The key land use requiring management of suspended sediment in the Burdekin Region is grazing.**
- **Hillslope erosion across the region contributes the most suspended sediments in comparison to other erosion types like bank or gully erosion.**

Data confidence: Relatively high with the exception of erosion types and attribution to natural, current or anthropogenic loads.

1.4 Dissolved Inorganic Nitrogen in the Burdekin Region

Which basin of the region delivers the most DIN on an annual basis to the GBR?

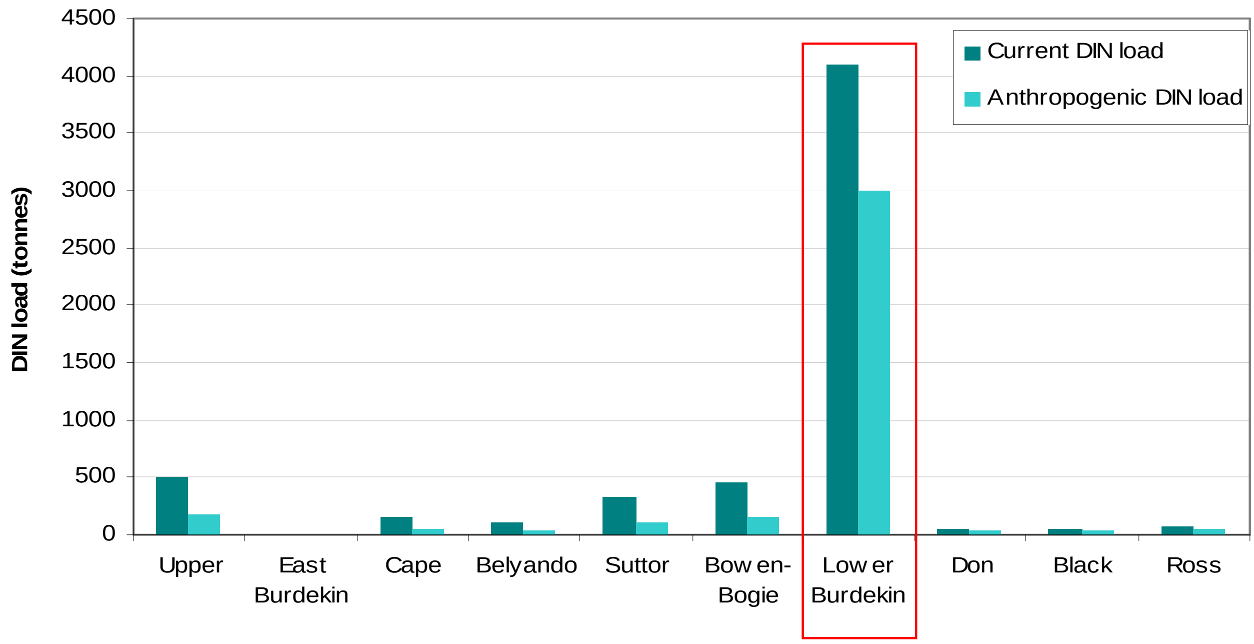
Approach: Rank the current and anthropogenic DIN loads by basin, and the DIN load per basin area (kg/ha). The anthropogenic load is calculated as the difference between the current and natural loads.

Table 1.4 *Current and anthropogenic DIN load to the GBR in the Burdekin basins*.

Load (tonnes)	Upper	East Burdekin	Cape	Belyando	Suttor	Bowen-Bogie	Lower Burdekin	Don	Black	Ross
Current DIN load	510	0	150	99	340	460	4,100	60	60	70
Anthropogenic DIN load	170	0	50	33	113	153	3,000	27	32	54

Note: The DIN loads for the East Burdekin are based on a subtraction of monitored data for each of the other basins, from the monitored data for the whole of Burdekin. Inconsistencies in this monitoring data at different time periods produces a huge uncertainty in the estimates for the East Burdekin and our conclusion is that these estimates should not be used for comparison or decision making at this stage.

Figure 1.7 *Current and anthropogenic DIN loads in the Burdekin Region.*



Ranking:

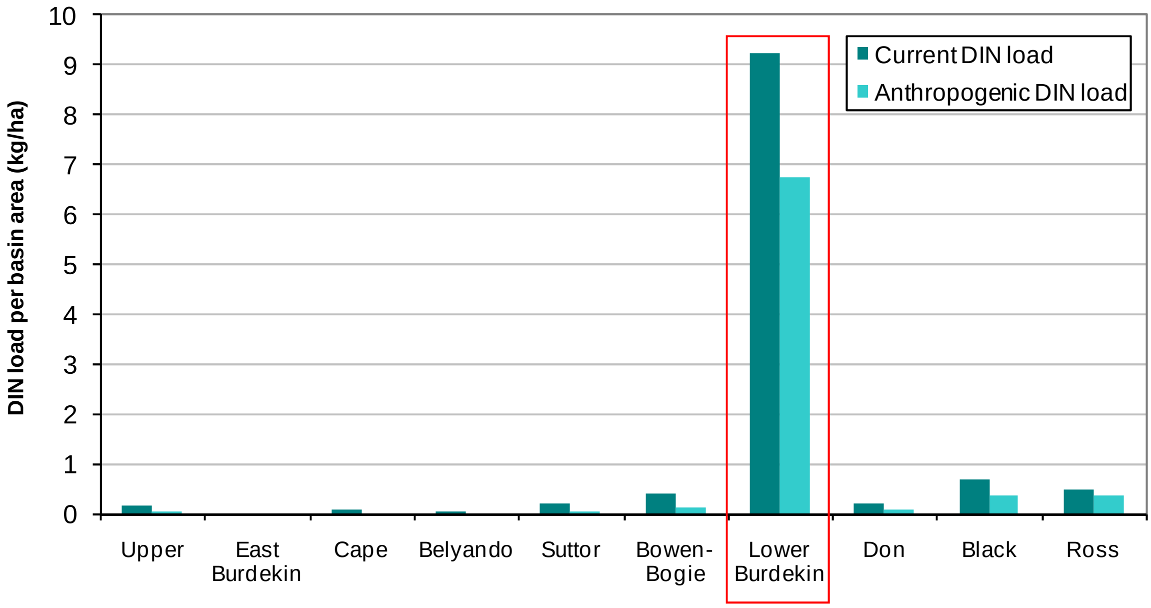
	Current	Anthropogenic
1.	Lower Burdekin	Lower Burdekin
2.	Upper Burdekin	Upper Burdekin
3.	Bowen-Bogie	Bowen-Bogie
4.	Suttor	Suttor
5.	Cape	Ross
6.	Belyando	Cape
7.	Ross	Belyando
8.	Don	Black
9.	Black	Don
10.	East Burdekin	East Burdekin

Conclusion: The Lower Burdekin basin generates the most DIN load in the region and it is almost entirely anthropogenic.

Table 1.5 *Current and anthropogenic DIN load per basin area to the GBR in the Burdekin basins.*

DIN load (kg/ha)	Upper	East Burdekin	Cape	Belyando	Suttor	Bowen-Bogie	Lower Burdekin	Don	Black	Ross
Current DIN load per basin area (kg/ha)	0.14	0.00	0.08	0.03	0.20	0.39	9.25	0.19	0.69	0.48
Anthropogenic DIN load per basin area (kg/ha)	0.05	0.00	0.03	0.01	0.07	0.13	6.77	0.08	0.37	0.37

Figure 1.8 *Current and anthropogenic DIN load per basin area in the Burdekin basins.*



Rankings:

	Current	Anthropogenic
1.	Lower Burdekin	Lower Burdekin
2.	Black	Black
3.	Ross	Ross
4.	Bowen-Bogie	Bowen-Bogie
5.	Suttor	Suttor
6.	Don	Don
7.	Upper Burdekin	Upper Burdekin
8.	Cape	Cape
9.	Belyando	Belyando
10.	East Burdekin	East Burdekin

Conclusion: The Lower Burdekin basin delivers the most DIN per basin area in the Burdekin Region, almost entirely from anthropogenic sources (Table 1.5). Further analyses of DIN in the Burdekin Region will concentrate only on the Lower Burdekin basin.

Within the basin delivering the highest load (overall and per unit area), which landuse contributes the majority of the DIN?

Approach: Rank the anthropogenic DIN load by land use type in the Lower Burdekin basin (Figure 1.9) and by unit area of land use in the basin (Figure 1.10). The calculated loads are in Table 1.6.

Given the limitations in knowledge of land use contributions by the basins defined in this report, the figures reported in the Stage 1 Report (Brodie and Waterhouse, 2009) for the Haughton River are used which excludes some of the coastal areas of the Lower Burdekin boundary. The anthropogenic load is calculated assuming that the anthropogenic DIN load from forest and grazing is zero, and from Sugar cane, Other Crops and Other is estimated to be 80% of the current load.

Table 1.6 *Current and anthropogenic DIN load by land-use type in the Lower Burdekin basin.*

	Forest	Grazing	Sugar cane	Other crops	Other	Total
Area (ha) (modified from Brodie ***et al***. 2003)	25,066	312,360	80,650	5,000	20,000	443,075
Current DIN load (tonnes)	272	759	3100	28	128	4,287
Anthropogenic DIN load (tonnes)	0	0	3000	22	102	3,124
Anthropogenic DIN per land-use area (kg/ha)	0	0	37.2	4.4	5.1	7.0

Figure 1.9 *Anthropogenic DIN load by land use type in the Lower Burdekin basin.*

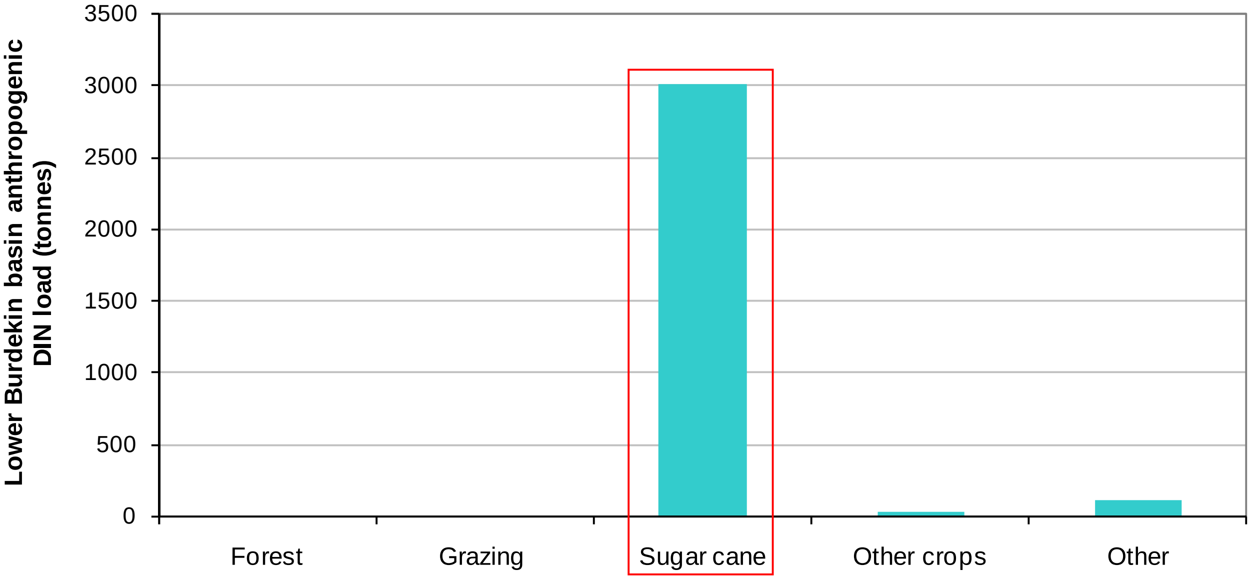
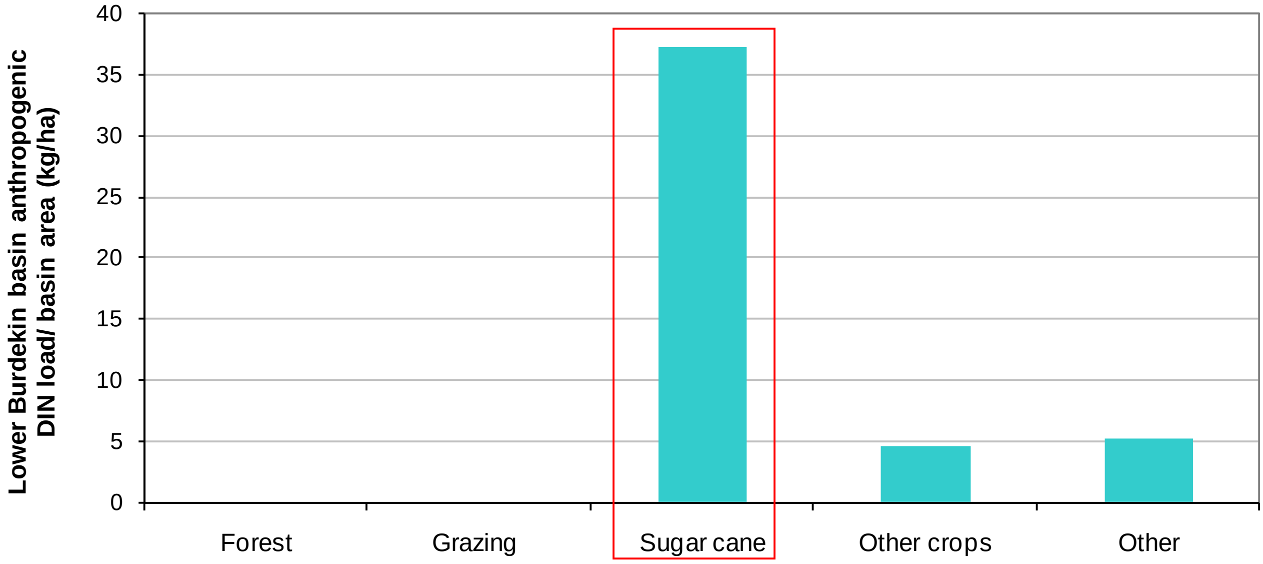


Figure 1.10 *Anthropogenic DIN load per basin area (kg/ha) by land-use type in the Lower Burdekin basin.*



Rankings:

1. Sugar cane
2. Other (mostly Urban + Water)
3. Other crops

Conclusion: From Figure 1.8, the basin with the highest DIN load in the Burdekin Region is the Lower Burdekin basin and from Figures 1.9 and 1.10 the land use with the highest anthropogenic DIN load is sugar cane.

Within the land use contributing the largest proportion of the DIN, which process generates the most DIN?

Based on extensive research, fertiliser application in sugar cane cultivation generates the large loads of DIN discharged from sugar cane areas in the GBR (e.g. Rayment, 2003; Brodie and Mitchell, 2005; Hunter and Walton, 2008; Brodie *et al*. 2008) and similarly in fertilized cropping areas throughout the world (e.g. Tilman *et al*. 2002).

Key findings for DIN in the Burdekin Region

- **The overall DIN load to the GBR from the Lower Burdekin basin is the highest in the region (Table 1.4).**
- **The key contributing land use to DIN delivery to the GBR is sugar cane (Figure 1.9, 1.11) and associated fertiliser application.**
- **The other coastal basins in the Burdekin Region also contribute minor anthropogenic DIN loadings but in total is substantially less than that of the Lower Burdekin basin (Figure 1.8).**

1.5 PSII Herbicides within the Burdekin Region

Which basins of the Burdekin Region deliver the most herbicides on an annual basis to the GBR?

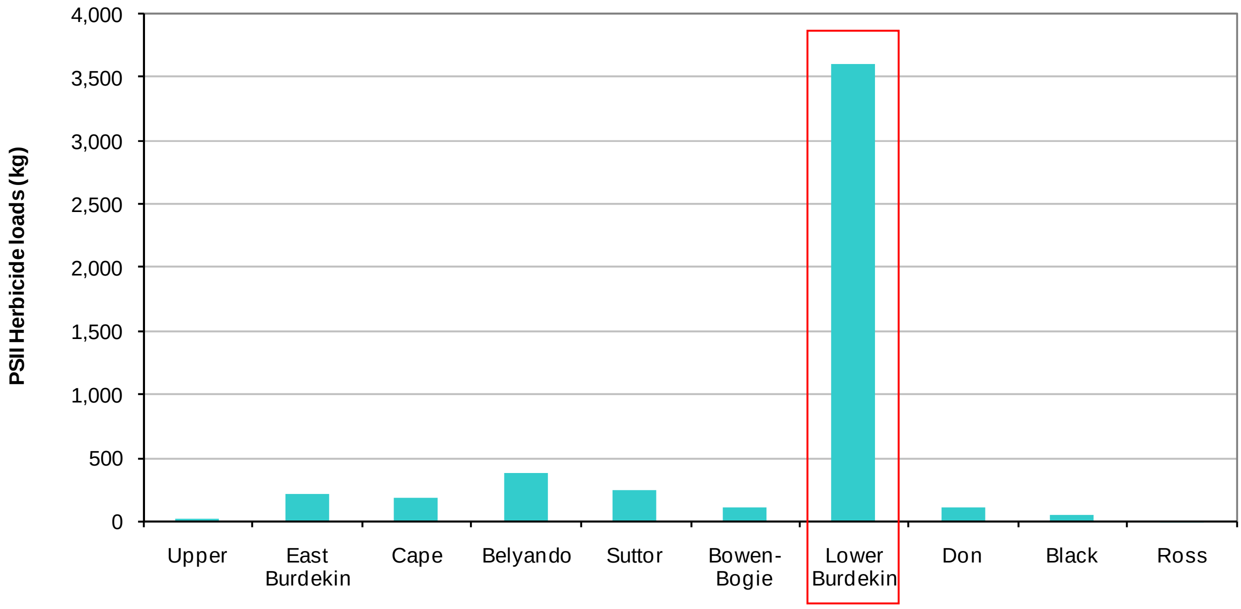
Approach: Rank the PSII Herbicide loads by basin using the herbicide assessment used in Brodie *et al*. (2009) (based on Lewis, unpublished and Lewis *et al*. 2009) which uses area of land use (sugar cane, grazing, dryland cropping) to predict loads of herbicides (refer to the method described in the Approach). Note that the model assumes that herbicide delivery is not affected by dam trapping.

Important note: The assessment for PSII Herbicide loads for the Upper, East Burdekin, Cape, Belyando, Suttor and Bowen-Bogie have been estimated by using proportions based on the land use areas and applying that to the Burdekin River figures reported in Lewis (unpublished). The tebuthiuron loads for the Cape, Belyando, Suttor and Bowen Bogie basins were based on the kg/ha runoff coefficient for the Fitzroy River. Limited monitoring data from these basins have detected tebuthiuron, although this herbicide has only been detected with greater regularity in the Suttor Basin. Therefore the confidence in the load estimates for the Cape, Belyando and Bowen Bogie basins, where tebuthiuron has only been detected in a limited number of samples, is considered low. As tebuthiuron has never been detected in the Upper, East Burdekin, Don, Black and Ross basins the load has been given as 0. For the lower Burdekin basin, the tebuthiuron load has been calculated using the runoff coefficient developed for the Haughton River.

Table 1.7 *PSII Herbicide loads to the GBR from the Burdekin Region*.

Load	Upper	East Burdekin	Cape	Belyando	Suttor	Bowen-Bogie	Lower Burdekin	Don	Black	Ross
PSII Herbicides (kg)	18	213	182	385	245	110	3,607	106	44	1
PSII Herbicide (g/ha)	0.01	0.24	0.09	0.11	0.14	0.09	8.1	0.33	0.51	0.01
Tebuthiuron (kg)	0	0	171	311	154	105	4	0	0	0
Other PSII Herbicides (kg)	18	213	11	73	91	5	3,603	106	44	1

Figure 1.11 *PSII Herbicides load from the Burdekin Region to the GBR.*



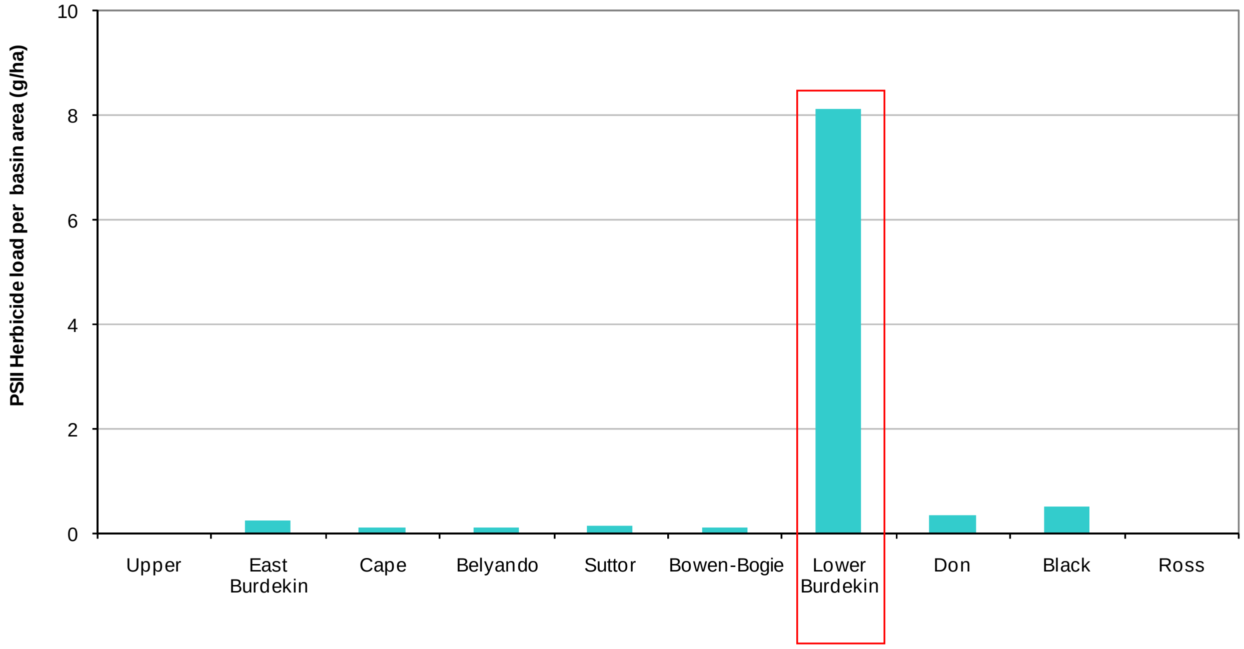
Rankings:

1. Lower Burdekin
2. Belyando
3. Suttor
4. East Burdekin
5. Cape
6. Bowen-Bogie
7. Don
8. Black
9. Upper
10. Ross

Conclusion: The Lower Burdekin basin delivers more PSII Herbicides to the GBR than the other basins in the Burdekin Region.

Data confidence: Moderate confidence as for comparison purposes, the relationship between land use area and PSII Herbicide delivery is robust. However, the tebuthiuron loads for the Cape, Belyando, Suttor and Bowen Bogie basins were based on the kg/ha runoff coefficient for the Fitzroy River. Limited monitoring data from these basins have detected tebuthiuron, although this herbicide has only been detected with greater regularity in the Suttor basin. Therefore the confidence in the load estimates for the Cape, Belyando and Bowen Bogie basins, where tebuthiuron has only been detected in a limited number of samples, is considered low. As tebuthiuron has never been detected in the Upper, East Burdekin, Don, Black and Ross basins the load has been given as 0. For the Lower Burdekin basin, the tebuthiuron load has been calculated using the runoff coefficient developed for the Haughton River.

Figure 1.12 *PSII Herbicide load to the GBR in the Burdekin Region (g/ha) per basin area.*



Rankings:

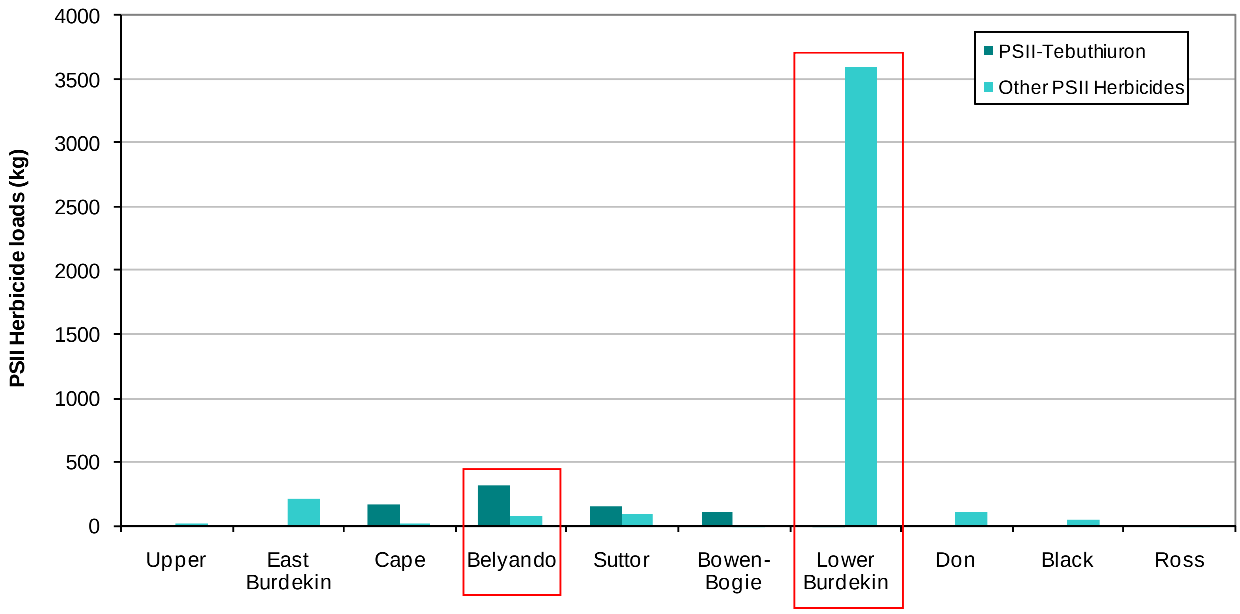
1. Lower Burdekin
2. Black
3. Don
4. East Burdekin

Conclusion: The Lower Burdekin basin delivers the most PSII Herbicide load per basin area to the GBR in the Burdekin Region.

What kind of herbicide is delivered from which basins in the Burdekin Region?

Approach: Rank loads of tebuthiuron and Other PSII Herbicides (diuron, atrazine, ametryn, hexazinone and simazine) by basin. The analysis of herbicide type has not been completed at the basin scale that is defined in this report, that is for Upper, East, Cape, Belyando, Suttor and Bowen Bogie. Therefore, the types can only be assessed by tebuthiuron and Other PSII Herbicides as shown in Figure 1.13.

Figure 1.13 *Tebuthiuron and Other PSII Herbicide loads to the GBR from individual basins in the Burdekin Region.*



Rankings:

	Tebuthiuron	Other PSII Herbicides
1.	Belyando	Lower Burdekin
2.	Cape	East Burdekin
3.	Suttor	Don
4.	Bowen-Bogie	Suttor
5.		Belyando
6.		Black

Conclusion: The largest loads of tebuthiuron (associated with grazing land management) in the Burdekin Region are from the Belyando, Cape and Suttor basins. The largest loads of Other PSII Herbicides (associated with sugar cane cultivation, but not simazine) are from the Lower Burdekin and East Burdekin basins.

Data confidence: The tebuthiuron loads for the Cape, Belyando, Suttor and Bowen Bogie basins were based on the kg/ha runoff coefficient for the Fitzroy River. Limited monitoring data from these basins have detected tebuthiuron, although this herbicide has only been detected with greater regularity in the Suttor basin. Therefore the confidence in the load estimates for the Cape, Belyando and Bowen Bogie basins, where tebuthiuron has only been detected in a limited number of samples, is considered low. As tebuthiuron has never been detected in the Upper, East Burdekin, Don, Black and Ross basins the load has been given as 0. For the Lower Burdekin basin, the tebuthiuron load has been calculated using the runoff coefficient developed for the Haughton River.

Key findings for PSII Herbicides in the Burdekin Region

- **The Lower Burdekin basin delivers most PSII Herbicides to the GBR in the Burdekin Region.**
- **The PSII Herbicides delivered from basins in the Burdekin Region are from two land uses:**
  - **Sugar cane is the primary source of PSII Herbicides other than tebuthiuron (mainly diuron but also atrazine, ametryn, hexazinone). The sources of simazine are not widely known but it is known to be used in plantation forestry.**
  - **Grazing lands are the primary source of tebuthiuron.**
- **The largest loads of tebuthiuron (associated with grazing land management) in the Burdekin Region are from the Belyando, Cape and Suttor basins. The largest loads of Other PSII Herbicides (associated with sugar cane cultivation, but not simazine) are from the Lower Burdekin and East Burdekin basins.**

1.6 Sources of information

Refer also to spreadsheet in Attachment 1.

Information	Catchments	Source
Current loads		
Suspended Sediment	Upper, East, Cape, Belyando, Suttor, Bowen-Bogie	Kinsey-Henderson *et al.* (2007)
	Lower Burdekin, Don, Black Ross	Brodie *et al.* (2009)
DIN	Upper, East, Cape, Belyando, Suttor, Bowen-Bogie	Bainbridge *et al*. (2007)
	Lower Burdekin	Brodie and Bainbridge, (2008)
	Don, Black Ross	Brodie *et al*. (2009), Bainbridge *et al*. (2008)
PSII Herbicides	All	Lewis *et al*. (2009); unpublished
Natural loads	All	Brodie *et al*. (2009)
Erosion type	Upper, East, Cape, Belyando, Suttor, Bowen-Bogie	Kinsey-Henderson *et al*. (2007)
	Lower Burdekin, Don, Black Ross	Fentie *et al*. (2006)
Land use area	All	Derived from Brodie *et al*. (2003)
Land use loads by pollutant		
Suspended Sediment	All	Brodie *et al*. (2009)
DIN	All	Brodie and Waterhouse, (2009) (Stage 1 Report)

Regional Assessment: Wet Tropics Region

2.1 Regional Summary Table

Table 2.1 *Summary of load characteristics for the Wet Tropics Region*.

Parameter	Daintree	Mossman	Barron	Mulgrave-Russell	Johnstone	Tully	Murray	Herbert	Wet Tropics Total
Basin Area (ha)	199,650	31,770	225,600	166,400	223,990	174,240	88,290	980,600	2,090,540
Suspended sediment (SS)									
Current SS load (000 tonnes)	240	80	100	210	260	120	50	540	1,600
Current SS load per basin area (tonnes/ha)	1.20	2.52	0.44	1.26	1.16	0.69	0.57	0.55	0.77
Anthropogenic SS load (000 tonnes)	195	73	75	169	219	96	41	433	1,301
Anthropogenic SS load per basin area (tonnes/ha)	0.98	2.30	0.33	1.02	0.98	0.55	0.46	0.44	0.62
Dominant losses linked to:									
Land use source	Forest	Forest	Grazing	Forest	Forest	Forest	Forest	Grazing	Grazing
Land use per area	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar
Erosion type source	Hillslope	Hillslope	Hillslope	Hillslope	Hillslope	Hillslope	Hillslope	Hillslope	Hillslope
Dissolved Inorganic Nitrogen (DIN)									
Current DIN load (tonnes)	200	50	200	1,000	850	600	300	700	3,900
Anthropogenic DIN load (tonnes) [1]	77	33	141	834	607	428	228	443	2,791
Anthropogenic DIN load per basin area (kg/ha) [1]	0.39	1.04	0.63	5.01	2.71	2.46	2.58	0.45	1.34
Anthropogenic DIN load per sugar area (kg/ha)	1.1	3.4	0.1	8.3	6.8	7.5	6.9	1.5	5.0
Dominant losses linked to:									
Land use source	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar
PSII Herbicides									
Tebuthiuron (kg)	0	0	0	0	193	0	0	0	193
Diuron (kg)	51	110	21	1079	1445	704	253	2296	5,960
Atrazine (kg)	24	52	25	513	687	335	120	1099	2,855
Hexazinone (kg)	8	17	3	164	219	107	39	348	904
Ametryn (kg)	1	3	0	25	34	17	6	54	140
Simazine (kg)	0	0	2	0	0	0	0	1	3
Total PSII Herbicide load (kg)	84	181	52	1,780	2,578	1,162	418	3,799	10,055
Total PSII Herbicide load per basin area (g/ha)	0.42	5.7	0.23	10.7	11.5	6.7	4.7	3.9	4.8
Dominant delivery linked to:									
Land use source	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar	Sugar

[1]Note: The anthropogenic DIN loads used in this table are taken from Table 2.5. Calculated loads are also in Table 2.7.

2.2 Regional Assessment Data

Assessment units in the Wet Tropics Region

For the purpose of this assessment, the basins for the Wet Tropics Region are shown in Figure 2.1 with:

- The basin boundaries for the Wet Tropics are as defined in Brodie *et al*. (2003).
- It is important to note that Trinity Inlet drainage area is included in the Russell Mulgrave basin and not the Barron basin. This area contains large areas of sugar cane. This differs from the Barron WQIP boundary but is consistent with the Australian Water Resource Commission basin boundaries (utilised by NRW for river gauging).

Figure 2.1 *Basins in the Wet Tropics Region.*

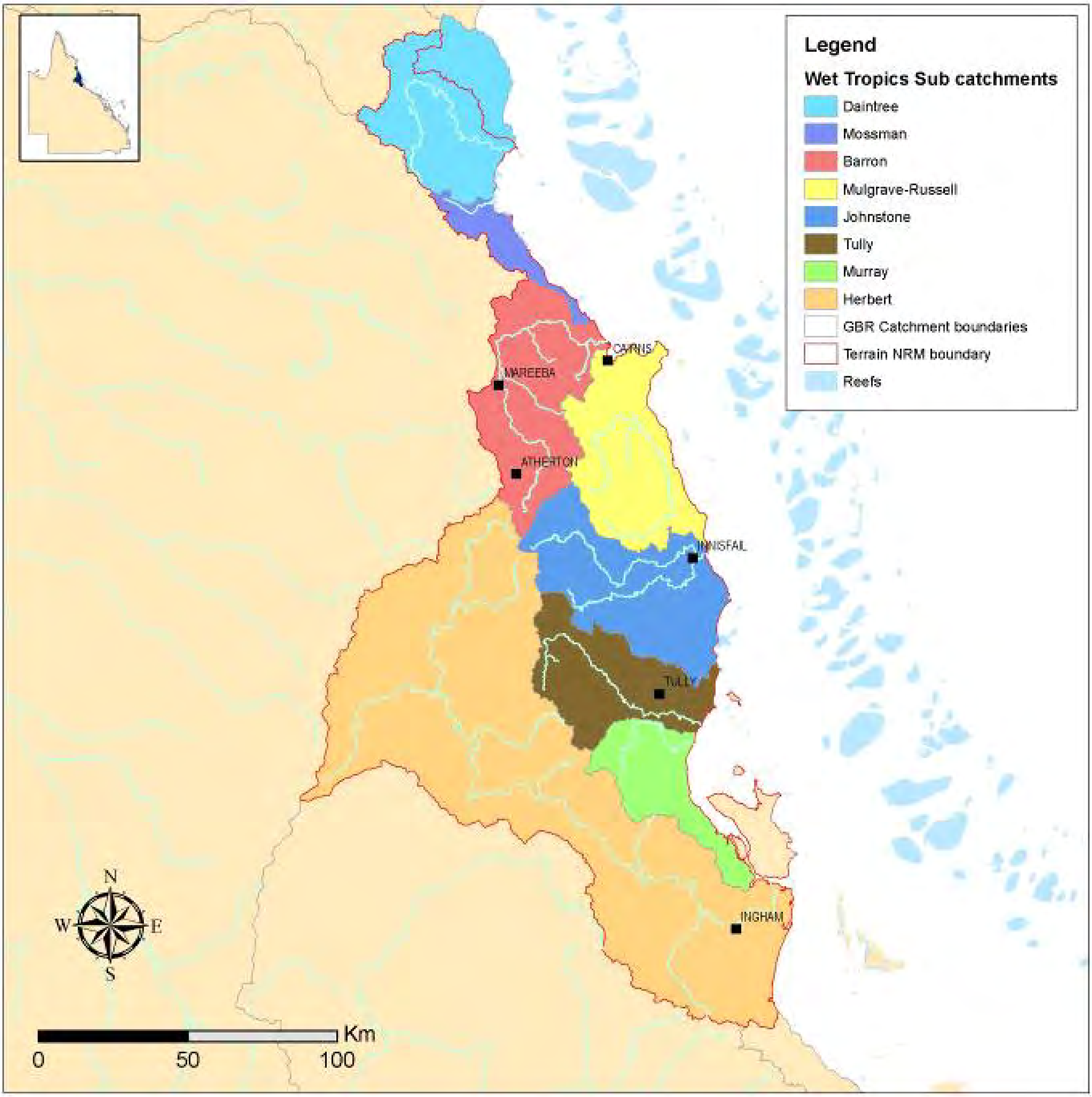


Table 2.1 summarises Current, Natural and Anthropogenic loads of suspended sediments (SS) and nutrient forms of N and P including dissolved inorganic (DIN, DIP), dissolved organic (DON, DOP) and particulate (PN, PP), as well as herbicides (PSII herbicides). **Attachment 2** presents the detailed spreadsheet.

2.3 Suspended Sediment in the Wet Tropics Region

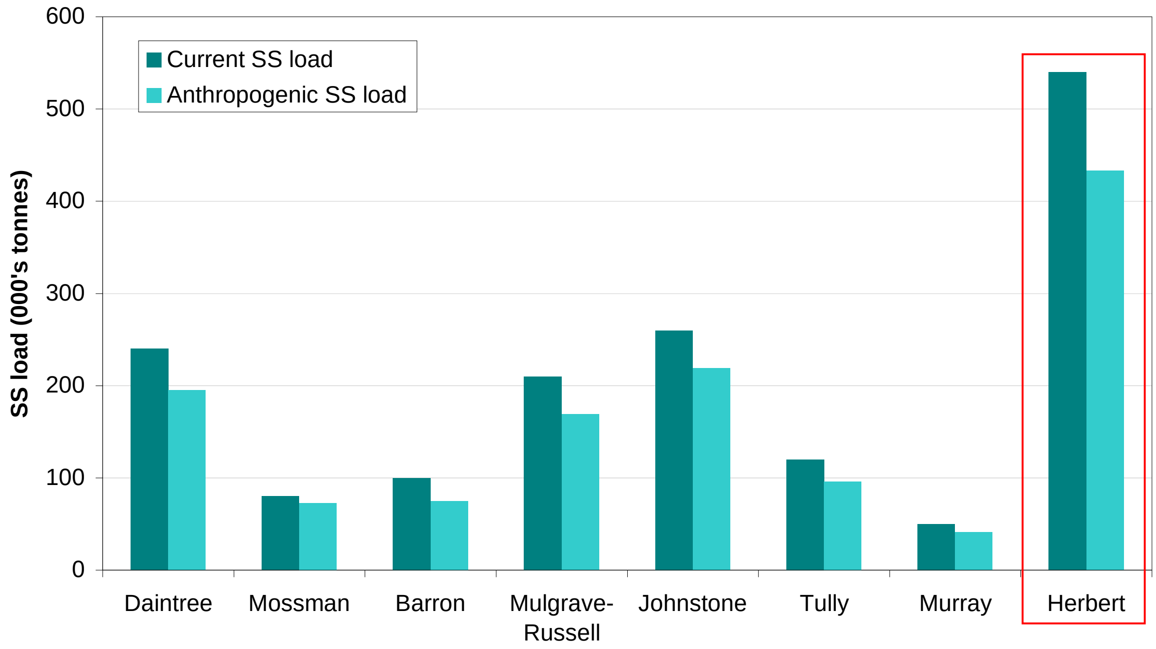
Which basin in the Wet Tropics Region delivers the most suspended sediment on an annual basis to the GBR?

Approach: Rank basins using tonnes of SS and load per basin area (hectares) based on current and anthropogenic figures.

Table 2.2 *Suspended sediment loads delivered to the GBR from the Wet Tropics Region*.

	Daintree	Mossman	Barron	Mulgrave-Russell	Johnstone	Tully	Murray	Herbert	Wet Tropics Total
Current SS load (000's tonnes)	240	80	100	210	260	120	50	540	1,600
Anthropogenic SS load (000's tonnes)	195	73	75	169	219	96	41	433	1,301
Current SS load per basin area (tonnes / ha)	1.20	2.52	0.44	1.26	1.16	0.69	0.57	0.55	0.77
Anthropogenic SS load per basin area (tonnes / ha)	0.98	2.30	0.33	1.02	0.98	0.55	0.46	0.44	0.62

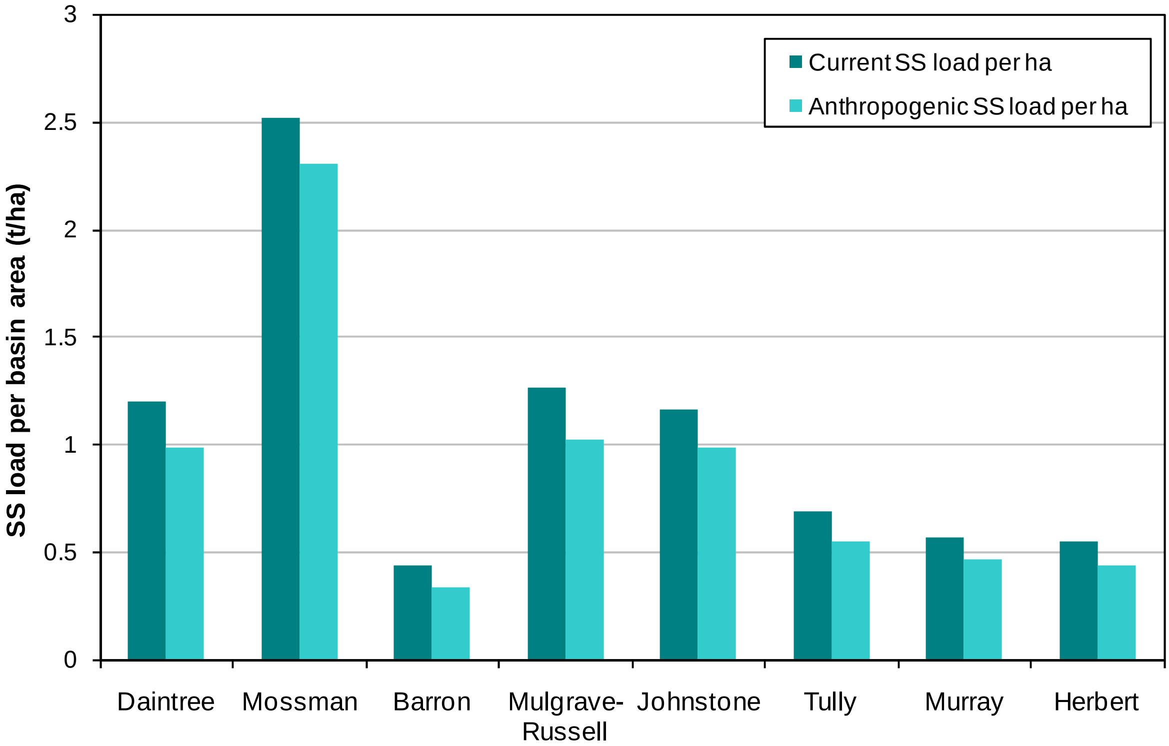
Figure 2.2 *Loads of suspended sediment delivered to the GBR from the Wet Tropics Region.*



Rankings:

Current		**Anthropogenic**
1.	Herbert	Herbert
2.	Johnstone	Johnstone
3.	Daintree	Daintree
4.	Russell Mulgrave	Russell Mulgrave
5.	Tully	Tully
6.	Barron	Barron
7.	Mossman	Mossman
8.	Murray	Murray

Figure 2.3 *Loads of suspended sediment per basin area delivered to the GBR from the Wet Tropics Region.*



Rankings:

Current	Anthropogenic
1. Mossman	Mossman
2. Russell Mulgrave	Russell Mulgrave
3. Daintree	Daintree
4. Johnstone	Johnstone
5. Tully	Tully
6. Murray	Murray
7. Herbert	Herbert
8. Barron	Barron

Conclusion: The Herbert basin generates the most current and anthropogenic suspended sediment load on an annual basis in the Wet Tropics Region (Figure 2.2), followed by the Johnstone, Daintree and Russell Mulgrave basins. However, the Mossman basin generates the most suspended sediment per basin area on an annual basis in the Wet Tropics Region, followed by the Russell Mulgrave, Daintree and Johnstone basins (Figure 2.3).

Data confidence: Confidence in the results for the Mossman, Russell Mulgrave and Daintree is low due to reliance on modeling with limited monitoring data. Where monitoring data gives greater confidence in the results such as in the Johnstone and Tully basins, the Johnstone basin may be a priority area for suspended sediment management.

Within the basins in the Wet Tropics Region, which land use contributes the majority of the suspended sediment?

Approach: Current estimates of land use contributions of SS in the Wet Tropics Region are mostly based on dated SedNet modeled data where erosion in forest areas was substantially overestimated. Calculation of the anthropogenic load is therefore necessary, using a generation factor for suspended sediment calculated from the total estimated natural suspended sediment load for the region (derived from Brodie *et al*. 2003) divided by the total area of the region. The method is described in the box below and the results are in Table 2.3. The anthropogenic suspended sediment load per hectare of land use in each basin can then be calculated (Table 2.4) to guide potential management focus areas.

'Natural' generation rate for suspended sediment =
Wet Tropics 'Natural' SS load = 299,000 tonnes
Wet Tropics area = 2,090,540 ha
= 0.143 tonnes/ha

1. Assume Natural SS load for forest is the same as the current load, and that Anthropogenic SS load for forest is zero.
2. Assume that all other areas were forest prior to anthropogenic influence and apply the generation factor to each of the land use areas to determine the Natural load. Subtract the Natural load from the Current load to give Anthropogenic load.

For example, for the Daintree basin
For forest:
Current forest area = 179,950 ha
Natural forest SS load = 179,950 ha x 0.143 tonnes/ha
= 25,737 tonnes
Current forest SS load = 25,737 tonnes
Anthropogenic forest SS load = 25,737 – 25,737 tonnes
= 0 tonnes

For sugar cane:
Current sugar cane area = 1580 ha
Natural sugar cane SS load = 1580 ha x 0.143 tonnes / ha
= 226 tonnes
Current sugar cane SS load = 4,000 tonnes
Anthropogenic sugar cane SS load = 4,000 – 226 tonnes
= 3,774 tonnes

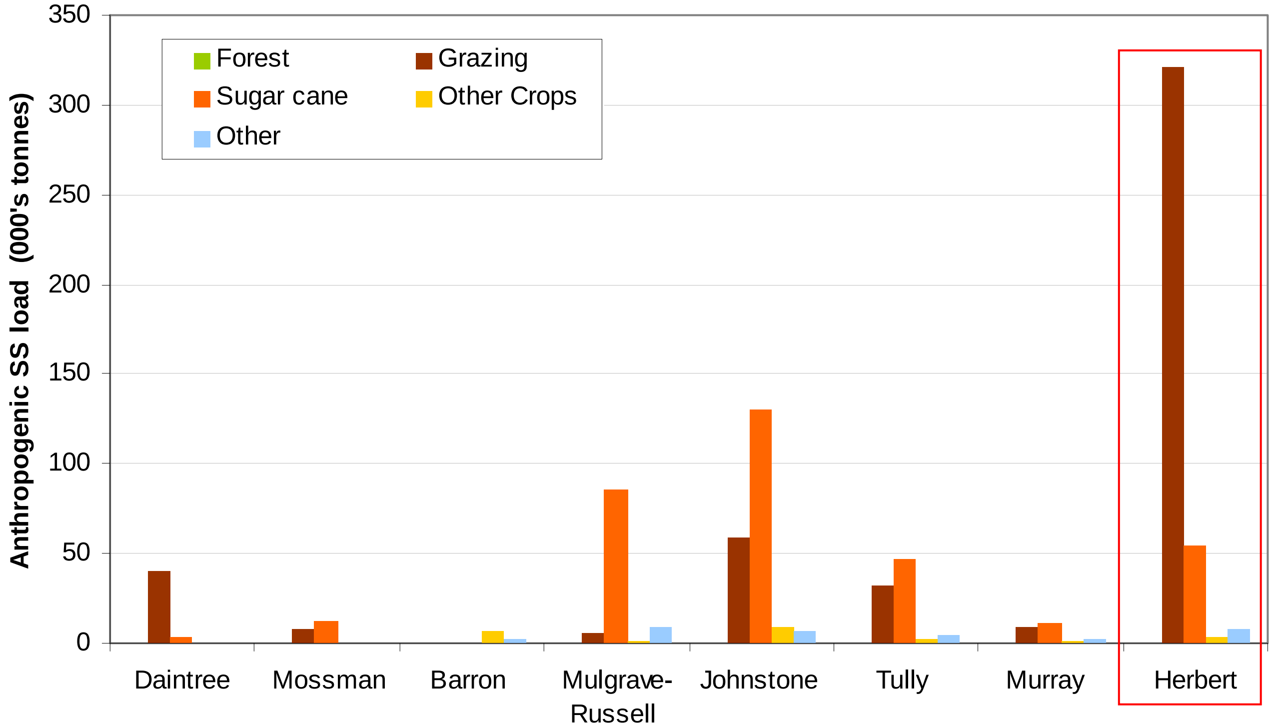
and similarly for each land use and each basin.

Note that the areas and current suspended sediment loads used in this exercise are from Brodie *et al*. (2003).

Table 2.3 *Anthropogenic suspended sediment load delivered to the GBR by land use type in the Wet Tropics Region*. Source: Current SS load from Brodie *et al*. (2009); Natural SS load and basin area from Brodie *et al*. (2003).

	Total suspended sediment load (tonnes)				Total SS load contributions by land use (tonnes)				
Basin	Best estimate Current SS load	Anthropogenic SS load	Natural SS load	Basin Area (ha)	Forest	Grazing	Sugar cane	Other Crops	Other
Daintree	240,000	195,000	45,000	199,650	0	40,426	3,774	0	0
Mossman	80,000	73,000	7,000	31,770	0	7,539	12,511	0	0
Barron	100,000	75,000	25,000	225,600	0	0	0	6,938	2,318
Mulgrave-Russell	210,000	169,000	41,000	166,400	0	5,079	86,199	947	8,829
Johnstone	260,000	219,000	41,000	223,990	0	59,518	130,567	8,484	7,042
Tully	120,000	96,000	24,000	174,240	0	31,889	46,865	2,637	4,133
Murray	50,000	41,000	9,000	88,290	0	9,265	10,872	924	1,798
Herbert	540,000	433,000	107,000	980,600	0	320,773	54,787	2,863	7,800
Wet Tropics Total	1,600,000	1,301,000	299,000	2,090,540	0	460,032	345,492	22,792	31,903

Figure 2.4 *Anthropogenic suspended sediment load delivered to the GBR by land use type in the Wet Tropics Region.*



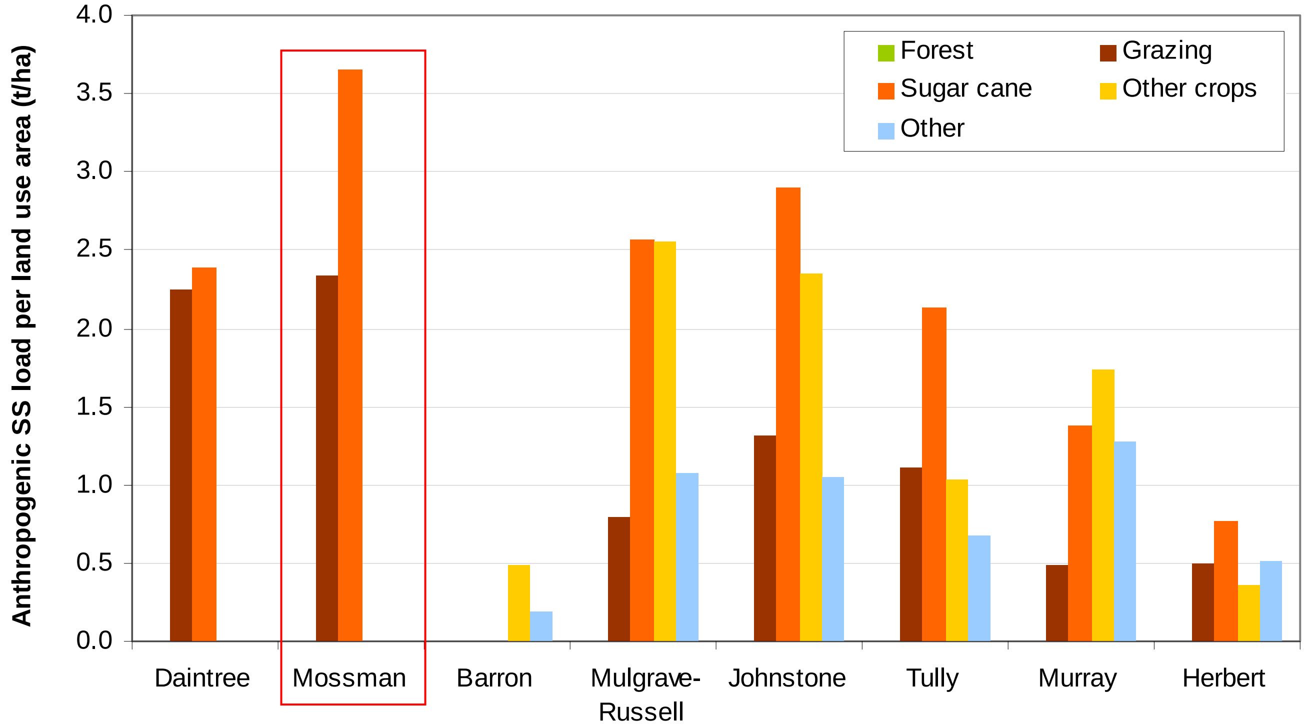
Rankings:

	Herbert	**Johnstone**	**Russell Mulgrave**	**Tully**
1.	Grazing	Sugar cane	Sugar cane	Sugar cane
2.	Sugar cane	Grazing	Other crops	Grazing
3.	Other	Other crops	Grazing	Other
4.	Other crops	Other	Other	Other crops

Table 2.4 *Anthropogenic suspended sediment load delivered to the GBR per unit area of land use in the Wet Tropics Region.*

Basin	Anthropogenic SS load per land use area (tonnes/ha)				
	Forest	Grazing	Sugar cane	Other crops	Other
Daintree	0.0	2.2	2.4	0.0	0.0
Mossman	0.0	2.3	3.7	0.0	0.0
Barron	0.0	0.0	0.0	0.5	0.2
Mulgrave-Russell	0.0	0.8	2.6	2.6	1.1
Johnstone	0.0	1.3	2.9	2.4	1.1
Tully	0.0	1.1	2.1	1.0	0.7
Murray	0.0	0.5	1.4	1.7	1.3
Herbert	0.0	0.5	0.8	0.4	0.5

Figure 2.5 *Anthropogenic suspended sediment load delivered to the GBR per unit area of land use in the Wet Tropics Region.*



Rankings:

Herbert	Mossman	Johnstone	Russell Mulgrave
1. Sugar cane	Sugar cane	Sugar v	Sugar cane
2. Grazing	Grazing	Other crops	Other crops
3. Other		Grazing	Other
4. Other crops		Other	Grazing

Conclusion: The land use that generates the most anthropogenic suspended sediment load from the Wet Tropics Region to the GBR is grazing in the Herbert basin and sugar cane in the Johnstone and Mulgrave-Russell basins (Table 2.3, Figure 2.4). The greatest anthropogenic load of suspended sediment to the GBR per unit area of land use is from sugar cane in most Wet Tropics basins (except the Murray basin where 'Other crops' are higher) (Table 2.4, Figure 2.5). Grazing is also an important source in the Herbert, Daintree and Mossman basins.

Within all of the basins, what is the erosion type that generates the most suspended sediment to the GBR?

This information is not readily available for the Wet Tropics region, however hillslope erosion in this type of landscape is most likely to contribute the most suspended sediment.

Key findings for suspended sediment in the Wet Tropics Region

- **The Herbert basin generates the most current and anthropogenic suspended sediment load on an annual basis in the Wet Tropics Region (Figure 2.2), followed by the Johnstone, Daintree and Russell Mulgrave basins. However, the Mossman basin generates the most suspended sediment per basin area on an annual basis in the Wet Tropics Region, followed by the Russell Mulgrave, Daintree and Johnstone basins (Figure 2.3).**
- **Grazing lands in the Herbert basin and sugar cane in the Johnstone and Russell -Mulgrave basins generate the most anthropogenic suspended sediment load from the Wet Tropics Region to the GBR (Table 2.3, Figure 2.4).**
- **The greatest anthropogenic load of suspended sediment to the GBR per unit area of land use is from sugar cane in most Wet Tropics basins (except the Murray basin where 'Other crops' are higher) (Table 2.4, Figure 2.5. Grazing is also an important source in the Herbert, Daintree and Mossman basins.**
- **Hillslope erosion across the region contributes the most suspended sediments in comparison to other erosion types like bank or gully erosion.**

Data confidence: Modeled data results are uncertain for SS generation by land use, particularly in forest areas, and there is limited supporting monitoring data in some catchments. Therefore, it is concluded that there is insufficient data to make any further assessment of the sources of SS in the Wet Tropics Region, other than to identify areas known to generate higher rates of SS including grazing areas, and areas of high slope.

2.4 Dissolved Inorganic Nitrogen within the Wet Tropics Region

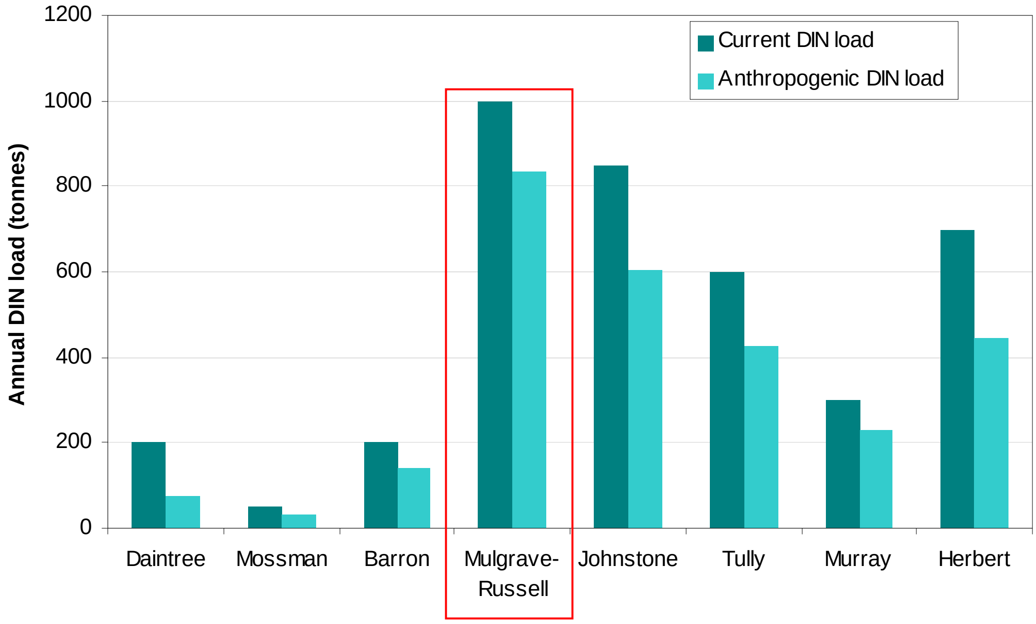
Which basins of the Wet Tropics Region deliver the most DIN on an annual basis to the GBR?

Approach: Rank the current and anthropogenic DIN loads by basin. The anthropogenic load is calculated as the difference between the current and natural loads.

Table 2.5 *Current and anthropogenic DIN load delivered to the GBR from the Wet Tropics Region*. Source: Brodie *et al*. (2009).

Load (tonnes)	Daintree	Mossman	Barron	Mulgrave-Russell	Johnstone	Tully	Murray	Herbert	Wet Tropics
Current DIN load	200	50	200	1,000	850	600	300	700	3,900
Anthropogenic DIN load	77	33	141	834	607	428	228	443	2,791

Figure 2.6 *Current and anthropogenic DIN load delivered to the GBR in the Wet Tropics Region.*



Rankings:

Current	**Anthropogenic**
1. Russell Mulgrave	1. Russell Mulgrave
2. Johnstone	2. Johnstone
3. Herbert	3. Herbert
4. Tully	4. Tully
5. Murray	5. Murray
6. Daintree	6. Barron
7. Barron	7. Daintree
8. Mossman	8. Mossman

Conclusion: The Russell Mulgrave basin generates the most DIN load on an annual basis in the Wet Tropics Region, followed by the Johnstone, Herbert and Tully basins (Figure 2.6).

Data confidence: Confidence in the results for the Russell Mulgrave basin is lower than that for the Johnstone, Herbert and Tully basins due to limited monitoring data being available for the Russell Mulgrave basins. A combined monitoring and modeling approach, as applied for the Johnstone, Herbert and Tully basins, provides greater confidence in the results. However the confidence in the Russell Mulgrave basin estimate is still high enough to consider it as a high priority basin along with the Johnstone, Tully and Herbert basins.

Within all basins, which land use contributes the majority of the DIN load in the Wet Tropics Region?

Approach: Calculate anthropogenic load for each land use using the method described below. Rank land uses based on the Anthropogenic DIN load estimated for each land use.

'Natural' load has been calculated using proportional estimates based on the forest DIN generation figures, and the following assumptions:

'Natural' generation rate for DIN =
Wet Tropics 'Natural' DIN load for forest = 1,592 tonnes
Wet Tropics forest area = 952,120 ha
= 1,592 tonnes / 952,120 ha
= 1.67kg/ha
For each basin, perform the following calculations

For example, for Daintree:

1. Assume sugar cane area was forest prior to anthropogenic influence.
   Natural sugar cane load = Current area of sugar cane x Generation factor
   = 1,580ha x 1.67 kg/ha
   = 2,641 kg
   Anthropogenic sugar cane load = Current load – Natural load
   = 4,400 – 2,641
   = 1,758 kg

2. Assume no change in the DIN load for grazing areas.
   Anthropogenic grazing load = Current load – Natural load
   = 30,600 – 30,600 kg
   = 0 kg

3. Assume area of Other crops area was forest prior to anthropogenic influence.
   Natural Other crops load = Current area of Other Crops x Generation factor
   = 0 ha x 1.67 kg/ha
   = 0 kg
   Anthropogenic Other crops load = Current load – Natural load
   = 0 – 0kg
   = 0 kg

4. Assume area of Other land uses was forest prior to anthropogenic influence.
   Natural Other load = Current area of Other x Generation factor
   = 120 ha x 1.67 kg/ha
   = 206 kg
   Anthropogenic Other load = Current load – Natural load
   = 0 – 206 kg
   = 0 kg

Land use areas are sourced from Brodie *et al*. (2003) and Current DIN load is sourced from Brodie et al. (2009).

Note that with the application of this simple method, the Natural load may be calculated as being higher than the Current load which is due the broad assumptions about conversion of land uses from forest in calculating the Natural loads. In these instances, the Anthropogenic load is considered to be zero.

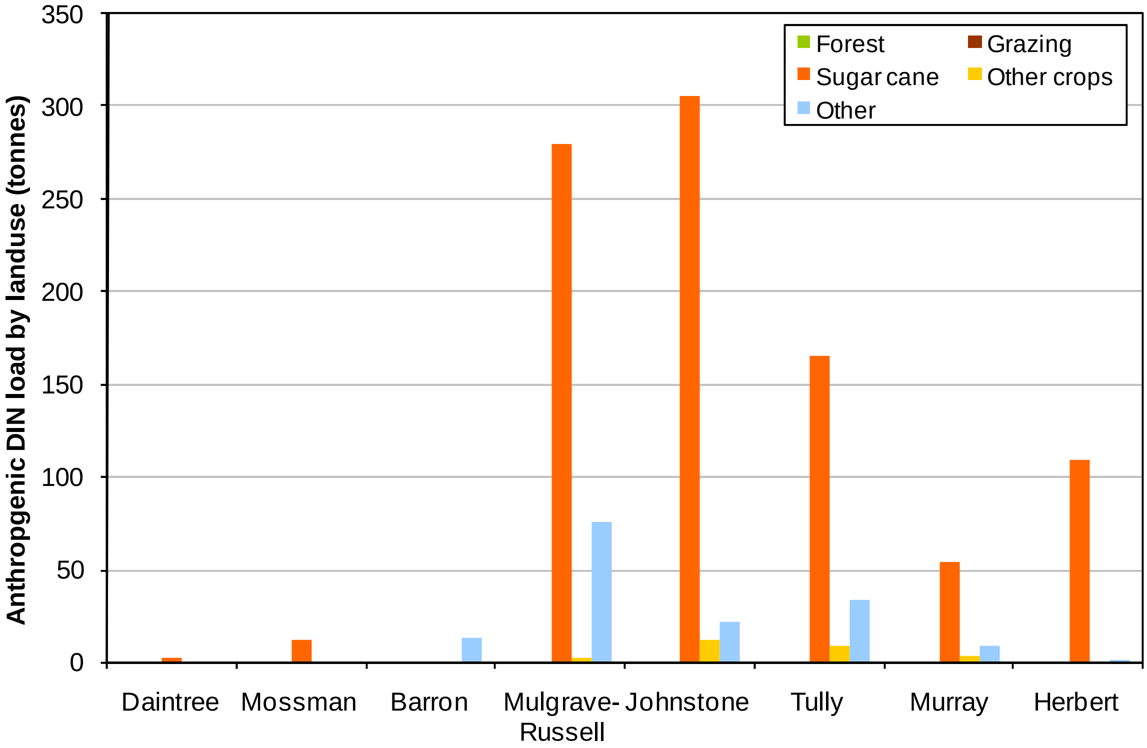
Table 2.6 *Current DIN load delivered to the GBR by land use types in the Wet Tropics region.* Source: Brodie *et al*. (2009).

		Current DIN load by land use (tonnes) (rounded)					
Basin	Best estimate: Current DIN load	Forest	Grazing	Sugar cane	Other crops	Other	% Current DIN from sugar cane
Daintree	200	165	31	4	0	0	2%
Mossman	50	26	7	17	0	0	35%
Barron	200	66	89	1	12	32	1%
Mulgrave-Russell	1,000	549	23	336	3	89	34%
Johnstone	850	303	116	381	18	32	45%
Tully	600	205	131	202	13	43	34%
Murray	300	120	98	67	4	11	23%
Herbert	700	158	280	229	6	27	33%
Wet Tropics Total (rounded)	3,900	1,592	775	1,237	54	235	32%
Percentage of Total		41%	20%	32%	1%	6%	

Table 2.7 *Estimated anthropogenic DIN load delivered to the GBR by land use types in the Wet Tropics Region.*

		Anthropogenic DIN load by land use (tonnes) Rounded figures					
Name	Best Estimate Anthropogenic Load	Forest	Grazing	Sugar cane	Other crops	Other	% Anthropogenic DIN from sugar cane
Daintree	2	0	0	2	0	0	100%
Mossman	12	0	0	12	0	0	100%
Barron	13	0	0	0	0	13	0%
Mulgrave-Russell	358	0	0	280	2	75	78%
Johnstone	339	0	0	306	12	21	90%
Tully	206	0	0	165	8	33	80%
Murray	66	0	0	54	3	9	83%
Herbert	111	0	0	110	0	2	99%
Wet Tropics Total	1,105	0	0	928	25	153	84%
Percentage of Total		0%	0%	84%	2%	14%	

Figure 2.7 *Anthropogenic DIN load delivered to the GBR by land use types in the Wet Tropics Region.*



Rankings:

1. Sugar cane
2. Other
3. Other crops

Forest and grazing are not considered to contribute to the anthropogenic load.

Conclusion: The greatest proportion of anthropogenic DIN load in the Wet Tropics Region is derived from sugar cane areas, particularly in the Johnstone, Russell Mulgrave, Tully and Herbert basins.

Data confidence: The method for calculating anthropogenic DIN load is based on a number of assumptions about current land use DIN generation and pre-European DIN generation. However, the results could be qualified using monitoring data for each land use in the sub catchments, eg. Hunter and Walton, (2008).

Within the land use contributing the largest proportion of the DIN, which basins deliver the most DIN per hectare?

Approach: The land use contributing the largest proportion of DIN in the Wet Tropics Region is sugar cane as shown in Figure 2.7. Rank basins based on anthropogenic load by land use, and kg/ha within the primary source land use, sugar cane.

Referring back to Figure 2.7, the loads of DIN from sugar cane from the basins can be ranked as follows.

Rankings:

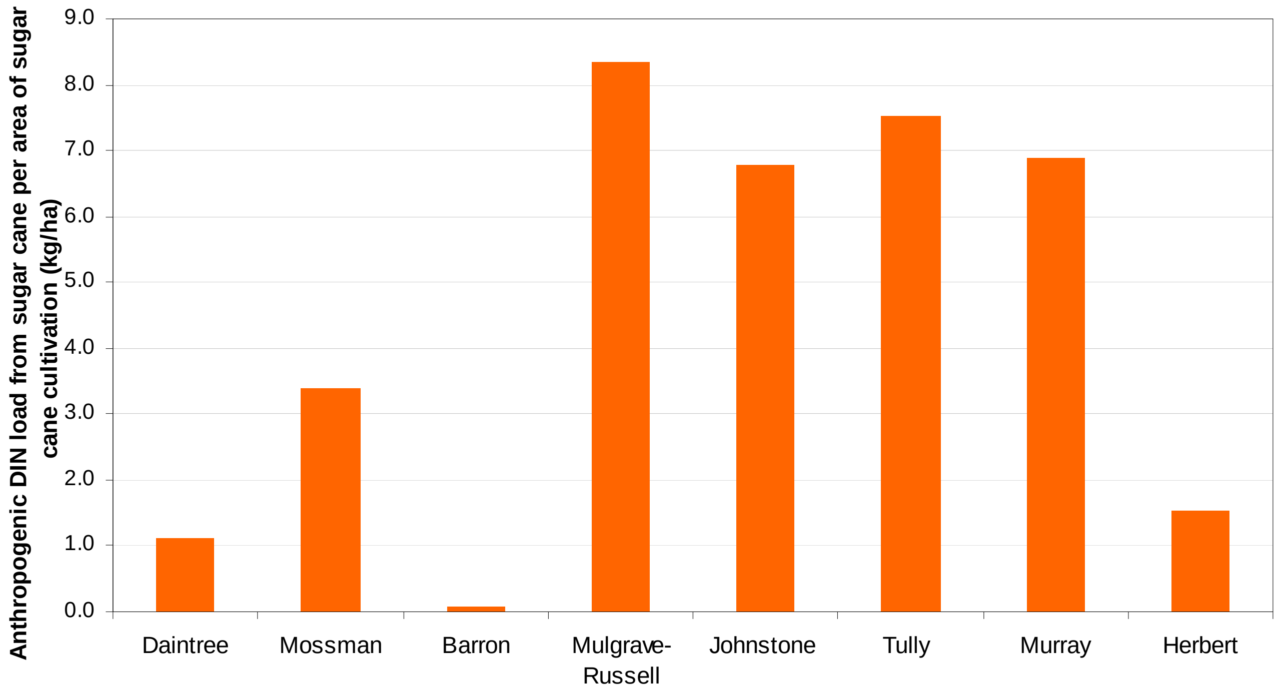
1. Johnstone
2. Russell Mulgrave
3. Tully
4. Herbert
5. Murray
6. Mossman
7. Daintree
8. Barron

Table 2.8 *Anthropogenic load of DIN delivered to the GBR per unit area of land use in the Wet Tropics Region.*

Basin	Anthropogenic DIN load per unit area of land use (kg/ha)					Total
	Forest	Grazing	Sugar cane	Other crops	Other	
Daintree	0	0	1.1	0	0	0.0
Mossman	0	0	3.4	0	0	0.4
Barron	0	0	0.1	0	1.1	0.1
Mulgrave-Russell	0	0	8.3	6.4	9.2	2.1
Johnstone	0	0	6.8	3.3	3.1	1.5
Tully	0	0	7.5	3.3	5.5	1.2
Murray	0	0	6.9	5.1	6.2	0.7
Herbert	0	0	1.5	0	0.1	0.1
Wet Tropics Total	0	0	5.0	0.9	3.1	0.5

The anthropogenic load per unit area of sugar cane is shown in Figure 2.8.

Figure 2.8 *Anthropogenic DIN load from sugar cane per area of sugar cane cultivation in the Wet Tropics Region.*



Rankings:

1. Russell Mulgrave
2. Tully
3. Murray
4. Johnstone
5. Mossman
6. Herbert
7. Daintree
8. Barron

Conclusion: The results show that the largest proportion of total anthropogenic DIN load from sugar cane in the Wet Tropics Region is from the Johnstone basin, followed by the Russell Mulgrave, Herbert, Tully and Murray basins. In terms of DIN load from sugar cane per unit area of sugar cane cultivation, the highest loads per unit area are from the Russell Mulgrave, Tully, Murray and Johnstone basins.

Key findings for DIN in the Wet Tropics Region

- **The Russell Mulgrave basin generates the most DIN on an annual basis in the Wet Tropics Region, followed by the Johnstone, Herbert and Tully basins (Figure 2.6).**

- **The key contributing land use to DIN loads in the Wet Tropics Region is sugar cane (Figure 2.7) and associated fertiliser application.**
- **The largest proportion of total anthropogenic DIN load from sugar cane in the Wet Tropics Region is from the Johnstone basin, with high contributions also from the Russell Mulgrave, Herbert, Tully and Murray basins (Figure 2.7).**
- **In terms of DIN load from sugar cane per unit area of sugar cane cultivation, the highest loads per unit area are from the Russell Mulgrave, Tully, Murray and Johnstone basins (Figure 2.8).**

Data confidence: As with suspended sediment loads, the DIN load data is mostly derived from ANNEX modeling in the Daintree, Russell Mulgrave and Mossman catchments, so the results may be highly uncertain in these catchments due to insufficient monitoring data being available to validate the models. Greater confidence in the Tully, Johnstone, Barron and Herbert results is provided through the monitoring data used to support the models and the ranked order between these catchments is probably likely. However, there are limitations in the load estimations at the end of catchments across the GBR catchments. The gauging stations and monitoring sites are in most cases located upstream of the coastal strip, and often exclude a large drainage area, often characterised by sugar cane. Furthermore, a proportion of the drainage in each basin discharges via small waterways that discharge directly in the coastal waters and not via the main river system. Accordingly, the load is not accurately reflected by unit area of sugar cane land use, and in most cases is most likely to be underestimated. This partly explains the differences between the DIN load per area of land use in the Wet Tropics basins, which otherwise may be expected to be relatively similar.

2.5 PSII Herbicides within the Wet Tropics Region

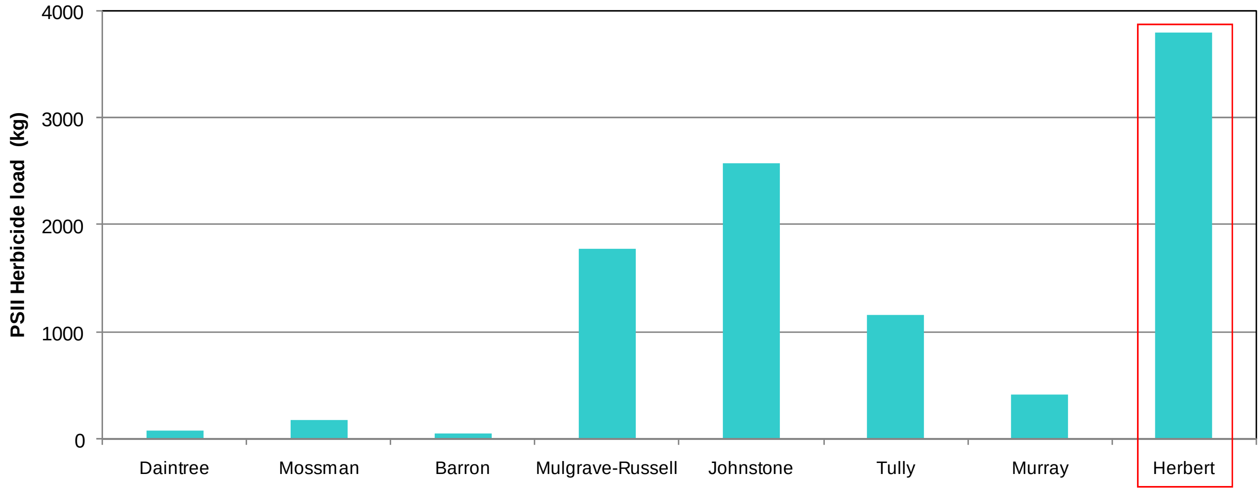
Which basins in the Wet Tropics Region deliver the most herbicides on an annual basis to the GBR?

Approach: Rank the PSII Herbicide loads by basin using the herbicide assessment used in Brodie *et al*. (2009) (based on Lewis, unpublished and Lewis *et al*. 2009) uses area of land use (sugar cane, grazing, dryland cropping) to predict loads of herbicides (refer to the method described in the Approach). Note that the model assumes that herbicide delivery is not affected by dam trapping. Monitoring programs have only detected tebuthiuron in the Johnstone basin and as such the tebuthiuron-grazing area coefficient has only been applied to the Johnstone basin with the other basins of the Wet Tropics Region given a 0 load.

Table 2.9 *PSII Herbicide loads to the GBR from the Wet Tropics Region*.

Basin	PSII Herbicide load (kg)						
	Diuron	Atrazine	Hexazinone	Ametryn	Tebuthiuron	Simazine	Total
Daintree	51	24	8	1	0	0	84
Mossman	110	52	17	3	0	0	181
Barron	21	25	3	0	0	2	52
Russell Mulgrave	1,079	513	164	25	0	0	1,780
Johnstone	1,445	687	219	34	193	0	2,578
Tully	704	335	107	17	0	0	1,162
Murray	253	120	39	6	0	0	418
Herbert	2,296	1,099	348	54	0	1	3,799
Total	5,960	2,855	904	140	193	3	10,055

Figure 2.9 *Total PSII Herbicide loads delivered to the GBR from the Wet Tropics Region*.



Rankings:

1. Herbert
2. Johnstone
3. Russell Mulgrave
4. Tully
5. Murray
6. Mossmon
7. Daintree
8. Barron

Conclusion: The Herbert basin has the greatest load of PSII Herbicide delivery in the Wet Tropics region followed by the Johnstone, Russell Mulgrave and Tully basins. The remaining basins are comparatively lower.

Data confidence: High confidence as for comparison purposes, the relationship between land use area and PSII Herbicide delivery is robust.

Within the basin delivering the highest PSII Herbicide load (Herbert), which land use contributes the majority of the PSII Herbicides?

Approach: Tabulate areas of different land use and PSII Herbicide exports from the Herbert basin.

Table 2.11 *Land use areas and PSII Herbicide loads in the Herbert basin*.

Land use	Forest	Grazing	Sugar cane	Other crops*	Other
Area (ha)	234,040	651,820	71,410	7,950	15,380
PSII Herbicide load (kg)	0	0	3,799	0	0
PSII Herbicide load/ area (g/ha)	0	0	53.2	0	0

* Note – There is insufficient knowledge about other crops, so assume zero PSII Herbicide delivery.

Ranking:

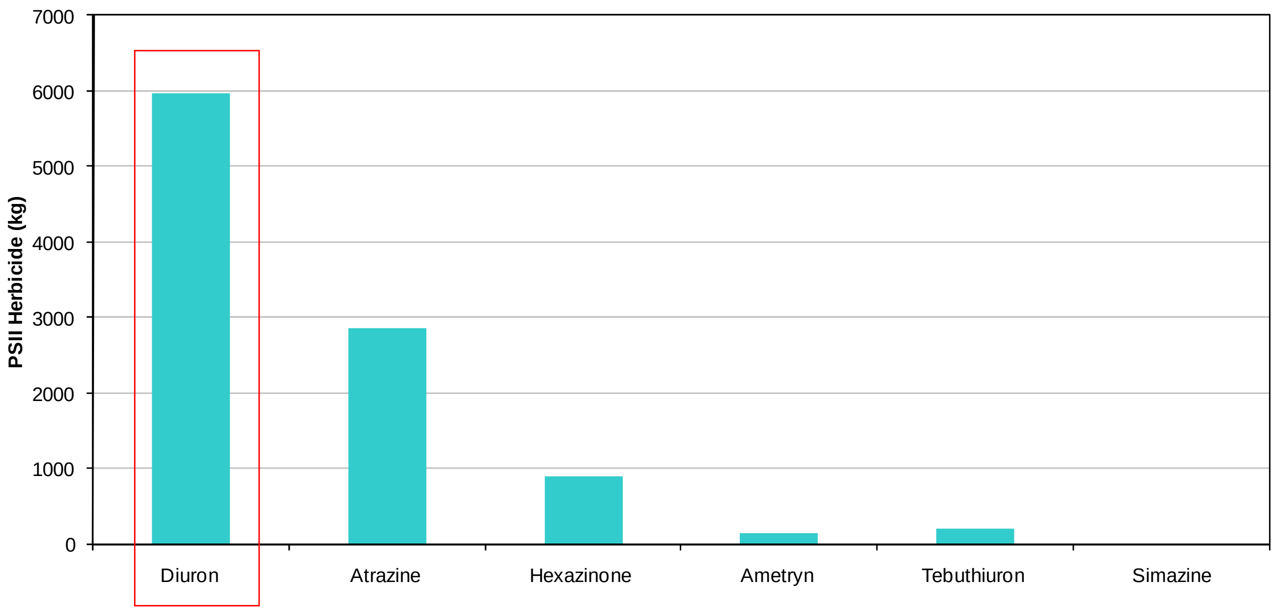
1. Sugar cane

Conclusion: The greatest proportion of PSII Herbicides in the Herbert basin is generated from sugar cane cultivation areas. This is also true for all Wet Tropics basins.

Which PSII Herbicide is discharged in the highest amounts for the Wet Tropics Region?

Approach: Rank loads of PSII Herbicides by type across the region.

Figure 2.10 *PSII herbicide loads in the Wet Tropics Region by herbicide type.*



Ranking:

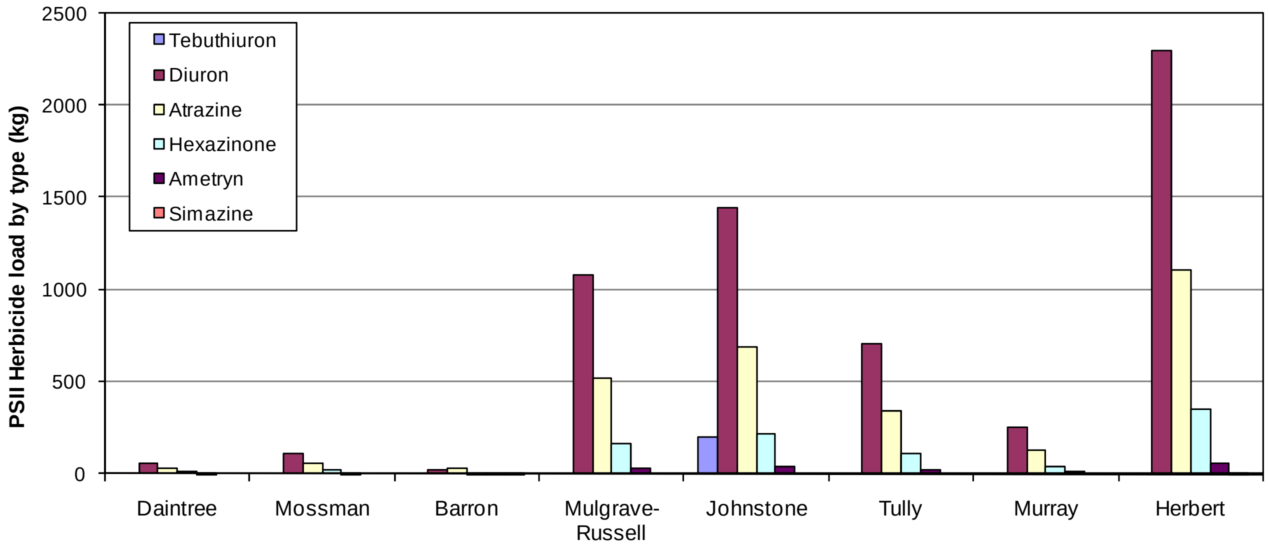
1. Diuron
2. Atrazine
3. Hexazinone

Conclusion: Diuron is the PSII Herbicide discharged in the highest amounts from the Wet Tropics Region, followed by atrazine and hexazinone.

Which PSII Herbicides are associated with which basins in Wet Tropics Region?

Approach: Rank loads of PSII Herbicides within each basin in the Wet Tropics Region.

Figure 2.11 *PSII Herbicide loads in the Wet Tropics Region by herbicide type.*



Conclusion: Figure 2.11 reflects the proportion of sugar cane:grazing in the basins. It is believed that tebuthiuron is derived from grazing but there is little monitoring data for tebuthiuron in the Wet Tropics and all tebuthiuron conclusions need to be treated with caution. The other PSII Herbicides are known to be derived from sugar cane with high certainty (with the exception of simazine). The sources of simazine are not widely known but it is known to be used in plantation forestry.

Key findings for PSII Herbicides in the Wet Tropics Region

- **The Herbert basin delivers the greatest load of PSII Herbicide delivery in the Wet Tropics Region followed by the Johnstone, Russell Mulgrave and Tully basins. The loads from remaining basins are comparatively lower.**
- **The greatest proportion of PSII Herbicides is generated from sugar cane areas, then grazing for all Wet Tropics basins.**
- **The greatest proportion of PSII Herbicides in the Herbert basin is generated from sugar cane areas. This is also true for all Wet Tropics basins.**
- **Diuron is the PSII Herbicide discharged in the highest amounts from the Wet Tropics Region, followed by atrazine and hexazinone.**
- **The Herbert, Mulgrave-Russell, Johnstone and Tully basins deliver substantial exports of diuron.**
- **In the Wet Tropics Region, it is believed that tebuthiuron is derived from grazing but there is little monitoring data for tebuthiuron in the Wet Tropics and all tebuthiuron conclusions need to be treated with caution. The other PSII Herbicides are known to be derived from sugar cane with high certainty (with the exception of simazine). The sources of simazine are not widely known but it is known to be used in plantation forestry.**

Data confidence: High confidence as for comparison purposes, the relationship between land use area and PSII Herbicide delivery is robust. Low confidence in tebuthiuron data.

2.6 Sources of Information

Refer also to spreadsheet in Attachment 2.

Information	Catchments	Source
Current loads		
Suspended Sediment	All	Brodie *et al*. (2009)
DIN	All	Brodie *et al*. (2009)
PSII Herbicides	All	Lewis, unpublished
Natural loads	All	Brodie *et al*. (2009)
Erosion type	All	Hateley *et a.l* (2006)
Land use area	All	Brodie *et al*. (2009) (from Brodie *et al*. 2003)
Land use loads by pollutant		
Suspended Sediment	All	Brodie *et al*. (2009)
DIN	All	Derived from Brodie and Waterhouse, (2009) (Stage 1 Report)

Regional Assessment: Mackay Whitsunday Region

3.1 Regional Summary Table

Table 3.1 *Summary of load characteristics for the Mackay Whitsunday Region*.

Parameter	Proserpine	O'Connell	Pioneer	Plane	Mackay-Whitsunday Total
Basin Area (ha) [1]	227,470	221,020	159,020	234,700	842,210
Basin Area (ha) [2]	202,090	208,430	168,720	175,470	754,710
Suspended Sediment (SS)					
Current SS load (000 tonnes)	50	150	280	60	540
Current SS load per basin area (tonnes/ha)	0.22	0.68	1.76	0.26	0.64
Anthropogenic SS load (000 tonnes)	5	51	230	6	292
Anthropogenic SS load per basin area (tonnes/ha)	0.02	0.23	1.45	0.03	0.35
Dominant losses linked to:					
Land use source	Sugar	Sugar	Sugar	Grazing	Sugar
Land use per area	Sugar	Sugar	Sugar	Grazing	Sugar
Erosion type source	Hillslope	Hillslope	Hillslope	Hillslope	Hillslope
Dissolved Inorganic Nitrogen (DIN)					
Current DIN load (tonnes)	450	700	600	430	2,180
Current DIN load per basin area (kg/ha)					
Anthropogenic DIN load (tonnes) [1]	367	575	516	335	1,793
Anthropogenic DIN load per basin area (kg/ha)	1.61	2.60	3.25	1.43	2.13
Anthropogenic DIN load per sugar area (kg/ha)	1.8	2.3	3.7	0.7	2.1
Dominant losses linked to:					
Land use source	Sugar	Sugar	Sugar	Sugar	Sugar
PSII Herbicides					
Tebuthiuron (kg)	483	439	233	415	1,569
Diuron (kg)	787	1103	1463	1766	5,119
Atrazine (kg)	375	525	695	839	2,434
Hexazinone (kg)	119	168	222	268	777
Ametryn (kg)	19	26	34	42	121
Simazine (kg)	0	0	0	0	0
Total PSII Herbicide load (kg)	1,782	2,260	2,648	3,329	10,020
Total PSII Herbicide load per basin area (g/ha)	7.8	10	17	14	12
Dominant losses linked to:					
Land use source	Sugar	Sugar	Sugar	Sugar	Sugar

[1]Source: Drewry *et al*. (2008).
[2]Source: Brodie *et al*. (2003) – utilised for land use calculations.
[3]Note: The anthropogenic DIN loads used in this table are taken from Table 3.5.

3.2 Regional Assessment Data

Assessment units in the Mackay Whitsunday Region

For the purpose of this assessment, the basins for the Mackay Whitsunday Region are shown in Figure 3.1 and are as defined in Brodie *et al*. (2003).

Figure 3.1 *Basins in the Mackay Whitsunday Region*.

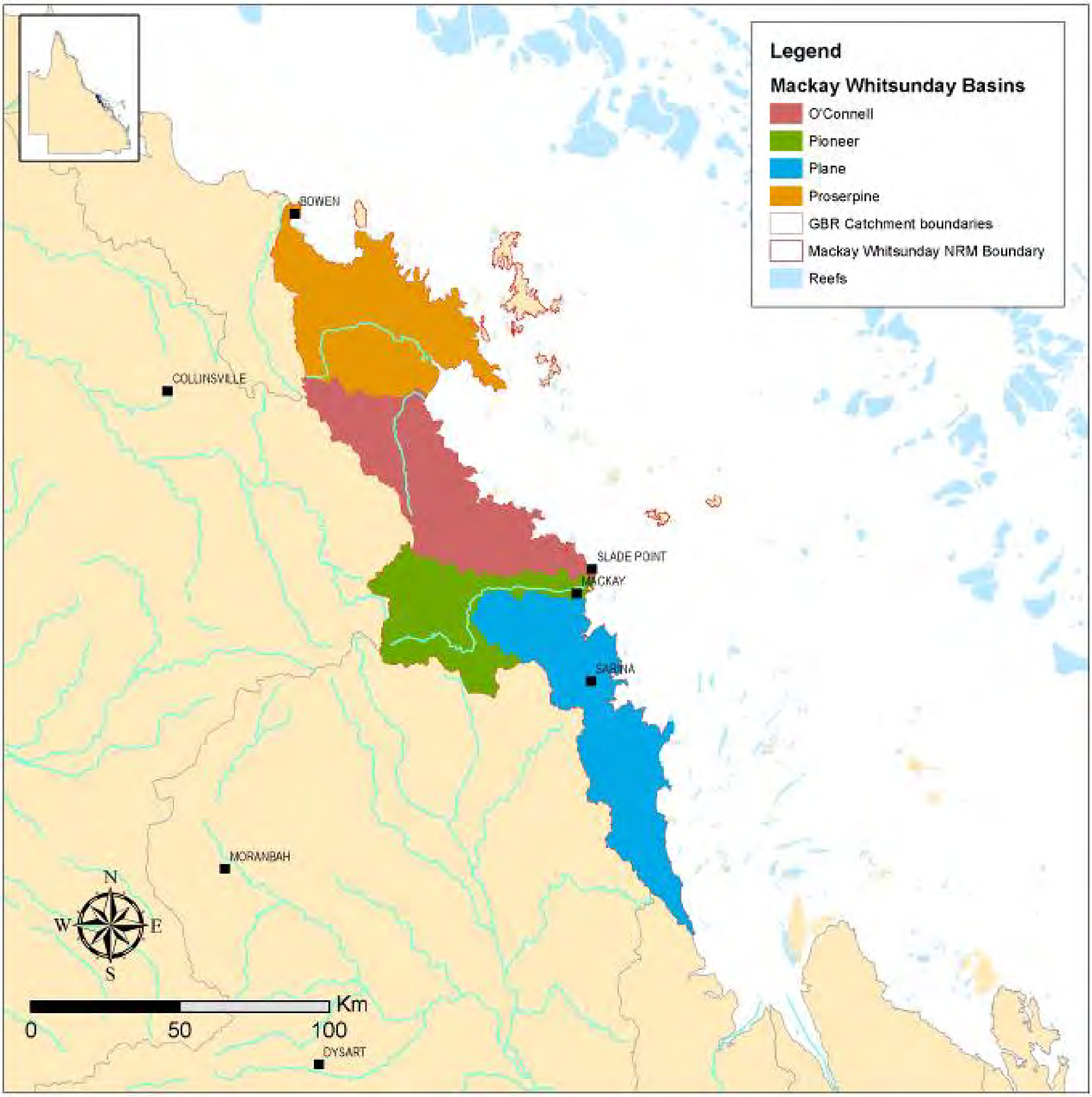


Table 3.1 summarises Current, Natural and Anthropogenic loads of suspended sediments (SS) and nutrient forms of N and P including dissolved inorganic (DIN, DIP), dissolved organic (DON, DOP) and particulate (PN, PP), as well as herbicides (PSII herbicides). **Attachment 3** presents the detailed spreadsheet.

3.3 Suspended Sediment in the Mackay Whitsunday Region

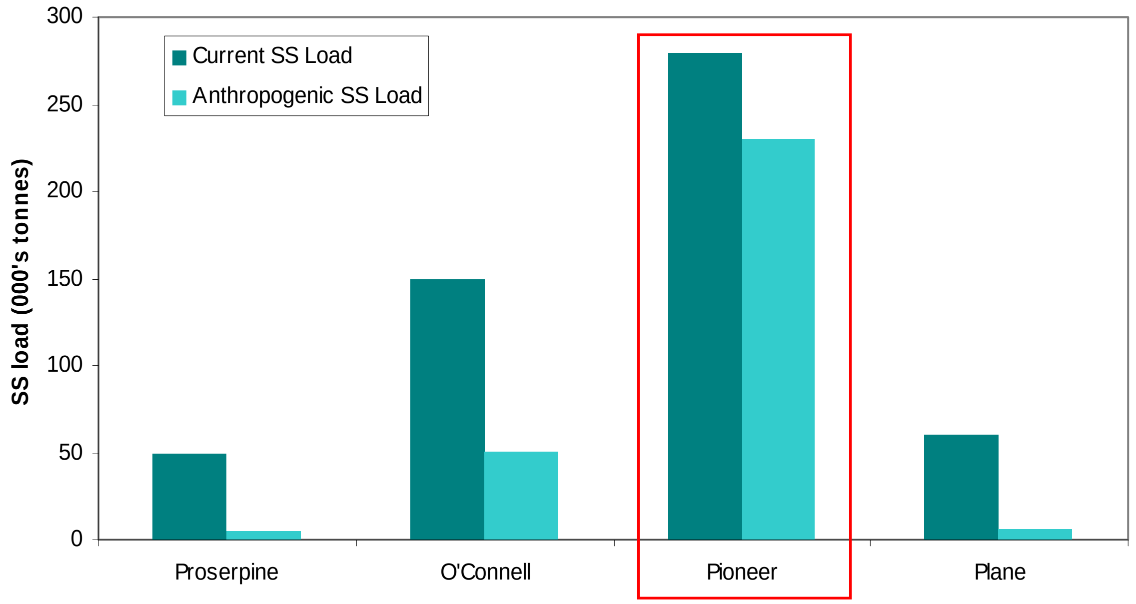
Which basin in the Mackay Whitsunday region delivers the most suspended sediment on an annual basis to the GBR?

Approach: Rank basins using tonnes of SS and load per basin area (hectares) based on current and anthropogenic figures.

Table 3.2 *Suspended sediment loads delivered to the GBR from the Mackay Whitsunday Region*. Source: Areas from Drewry *et al*. (2008), Table 2; Load estimates from Brodie *et al*. (2009).

	Proserpine	O'Connell	Pioneer	Plane
Area (ha)	227,400	221,020	159,020	234,700
Current SS load (thousand tonnes)	50	150	280	60
Current SS load per ha (tonnes/ha)	0.22	0.68	1.76	0.26
Anthropogenic SS load (thousand tonnes)	5	51	230	6
Anthropogenic load per ha (tonnes/ha)	0.02	0.23	1.45	0.03

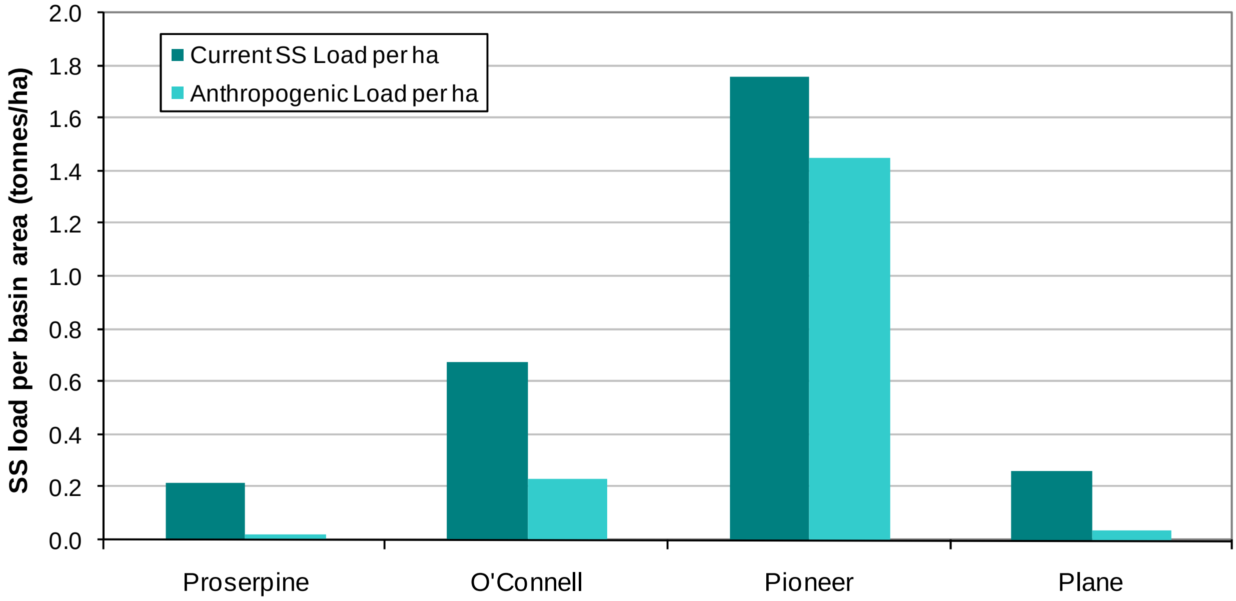
Figure 3.2 *Loads of suspended sediment delivered to the GBR from the Mackay Whitsunday Region.*



Rankings:

Current	**Anthropogenic**
1. Pioneer	Pioneer
2. O'Connell	O'Connell
3. Plane	Plane
4. Proserpine	Proserpine

Figure 3.3 *Loads of suspended sediment per basin area delivered to the GBR from the Mackay Whitsunday Region.*



Rankings:

	Current	**Anthropogenic**
1.	Pioneer	Pioneer
2.	O'Connell	O'Connell
3.	Plane	Plane
4.	Proserpine	Proserpine

Conclusion: The Pioneer basin delivers the most current and anthropogenic suspended sediment load on an annual basis in the Mackay Whitsunday Region (Figure 3.2), followed by the O'Connell basin. The Pioneer basin also delivers the most suspended sediment per basin area on an annual basis in the Mackay Whitsunday Region, followed by the O'Connell basin (Figure 3.3).

Within the basins in the Mackay Whitsunday Region, which land use contributes the majority of the suspended sediment?

Approach: Current estimates of land use contributions of SS in the Mackay Whitsunday Region are mostly based on dated SedNet modeled data where erosion in forest areas was substantially overestimated. Calculation of the anthropogenic load is therefore necessary, using a generation factor for suspended sediment calculated from the total estimated natural suspended sediment load for the region (derived from Brodie *et al*. 2003) divided by the total area of the region. The method is described in the box below and the results are in Table 3.3. The anthropogenic suspended sediment load per hectare of land use in each basin can then be calculated (Table 3.4) to guide potential management focus areas.

The anthropogenic suspended sediment load has been calculated for the Mackay Whitsunday Region using the following approach and assumptions:

1. 'Natural' generation rate =
   Mackay Whitsunday 'Natural' SS load = 248,000 tonnes
   Mackay Whitsunday area = 754,710 ha
   = 0.329 tonnes/ha

2. Assume Natural SS load for forest is the same as the current load, and that Anthropogenic SS load for forest is zero.

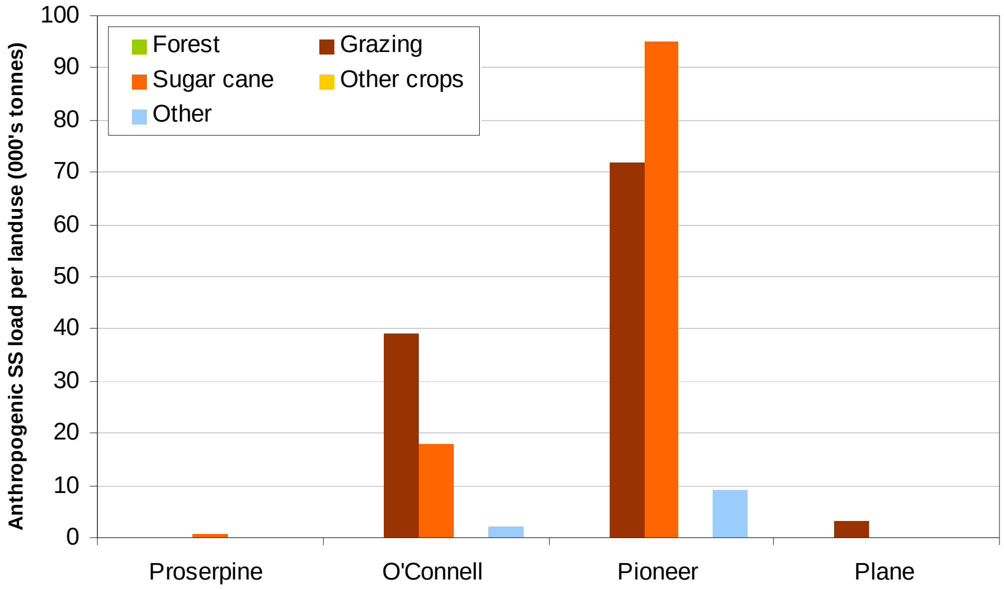
3. Assume that all other areas were forest prior to anthropogenic influence and apply the generation factor to each of the land use areas to determine the Natural load. Subtract the Natural load from the Current load to give Anthropogenic load.

Note that the land use areas are from Brodie *et al*. (2003) and current suspended sediment loads used in this exercise are from Brodie *et al*. (2009).

Table 3.3 *Anthropogenic suspended sediment load delivered to the GBR by land use type in the Mackay Whitsunday Region.*

Basin	Anthropogenic suspended sediment load by land use type					
	Forest	Grazing	Sugar cane	Other crops	Other	Total
Proserpine	0	0	600	0	0	600
O'Connell	0	39,000	18,000	100	2,000	59,100
Pioneer	0	72,000	95,000	0	9,000	176,000
Plane	0	3,000	0	0	0	3,000
Total		114,000	113,600	100	11,000	238,700

Figure 3.4 *Anthropogenic suspended sediment load delivered to the GBR by land use type in the Mackay Whitsunday Region.*



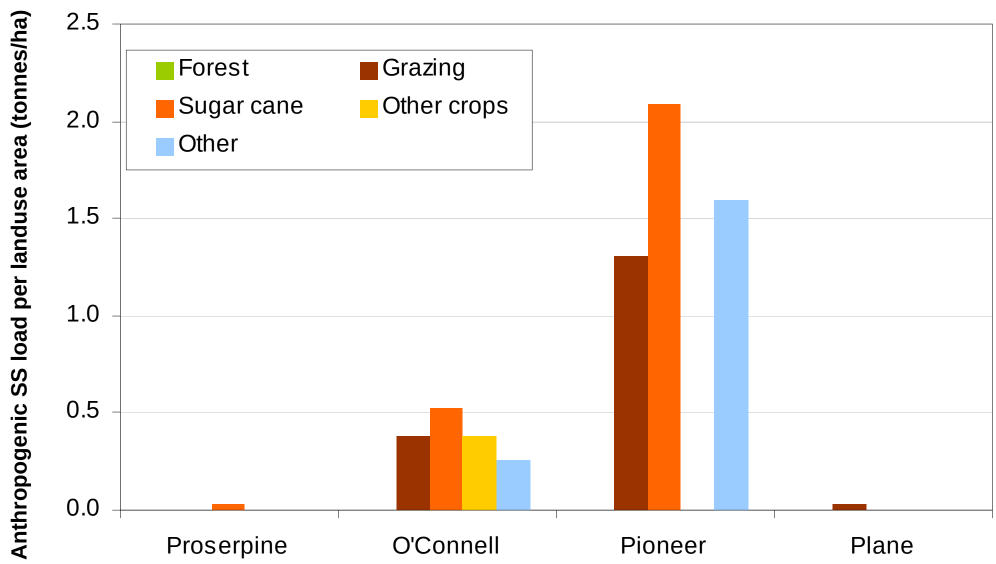
Rankings:

	Proserpine	O'Connell	Pioneer	Plane
1.	Sugar cane	Grazing	Sugar cane	Grazing
2.		Sugar cane	Grazing	
3.		Other	Other	
4.		Other crops	Other crops	

Table 3.4 *Anthropogenic suspended sediment load delivered to the GBR per unit area of land use in the Mackay Whitsunday Region.*

Basin	Anthropogenic SS load per land use area (tonnes/ha)				
	Forest	Grazing	Sugar cane	Other crops	Other
Proserpine	0	0	<0.1	0	0
O'Connell	0	0.4	0.5	0.4	0.3
Pioneer	0	1.3	2.1	0	1.6
Plane	0	<0.1	0	0	0

Figure 3.5 *Anthropogenic suspended sediment load delivered to the GBR per unit area of land use in the Mackay Whitsunday Region.*



Rankings:

	Proserpine	O'Connell	Pioneer	Plane
1.	Sugar cane	Sugar cane	Sugar cane	Grazing
2.		Grazing	Other	
3.		Other crops	Grazing	
4.		Other	Other crops	

Conclusion: The land use that generates the most anthropogenic suspended sediment load from the Mackay Whitsunday Region to the GBR is sugar cane in the Pioneer basin and grazing in the Pioneer and O'Connell basins (Table 3.3, Figure 3.4). The greatest anthropogenic load of suspended sediment to the GBR per unit area of land use is from sugar cane in the Pioneer, O'Connell and Proserpine basins (Table 3.4, Figure 3.5). Grazing is also an important source in the Pioneer and O'Connell basins.

Data confidence: There are considerable uncertainties in calculating anthropogenic suspended sediment load because we are subtracting one number with high uncertainty, from another with high uncertainty.

For example, for Proserpine:

Current 'Other' load	= 2100 tonnes +/- 1000
Natural 'Other' load	= 3500 tonnes +/- 2000
Anthropogenic 'Other' load	= 2100 subtract 3500
	= -1400 tonnes +/- 3000
	i.e. between -4500 tonnes and 1500 tonnes

For Pioneer:

Current 'Other' load	= 11200 tonnes +/- 1000
Natural 'Other' load	= 1912 tonnes +/- 2000
Anthropogenic 'Other' load	= 11200 subtract 1912
	= 9288 tonnes +/- 3000
	i.e. between 6000 tonnes and 12000 tonnes

In the Proserpine it is possible to get a negative value in change from Natural to Anthropogenic load due to the placement of the Peter Faust Dam.

Within all of the basins, what is the erosion type that generates the most suspended sediment to the GBR?

This information is not readily available for the Mackay Whitsunday region, however hillslope erosion in this type of landscape is most likely to contribute the most suspended sediment.

Key findings for suspended sediment in the Mackay Whitsunday region

- **The Pioneer basin delivers the most current and anthropogenic suspended sediment load on an annual basis in the Mackay Whitsunday Region (Figure 3.2), followed by the O'Connell basin. The Pioneer basin also delivers the most suspended sediment per basin area on an annual basis in the Mackay Whitsunday Region, followed by the O'Connell basin (Figure 3.3).**
- **The land use that generates the most anthropogenic suspended sediment load from the Mackay Whitsunday Region to the GBR is sugar cane in the Pioneer basin and grazing in the Pioneer and O'Connell basins (Table 3.3, Figure 3.4).**
- **The greatest anthropogenic load of suspended sediment to the GBR per unit area of land use is from sugar cane in the Pioneer, O'Connell and Proserpine basins (Table 3.4, Figure 3.5). Grazing is also an important source in the Pioneer and O'Connell basins.**
- **Hillslope erosion across the region contributes the most suspended sediments in comparison to other erosion types like bank or gully erosion.**

Data confidence: Modeled data results are uncertain for SS generation by land use, particularly in forest areas, and there is limited supporting monitoring data in some catchments. Therefore, it is concluded that there is insufficient data to make any further assessment of the sources of suspended sediment in the Mackay Whitsunday region, other than to identify areas known to generate higher rates of suspended sediment including grazing areas, and areas of high slope.

3.4 Dissolved Inorganic Nitrogen within the Mackay Whitsunday Region

Which basins of the Mackay Whitsunday Region delivers the most DIN on an annual basis to the GBR?

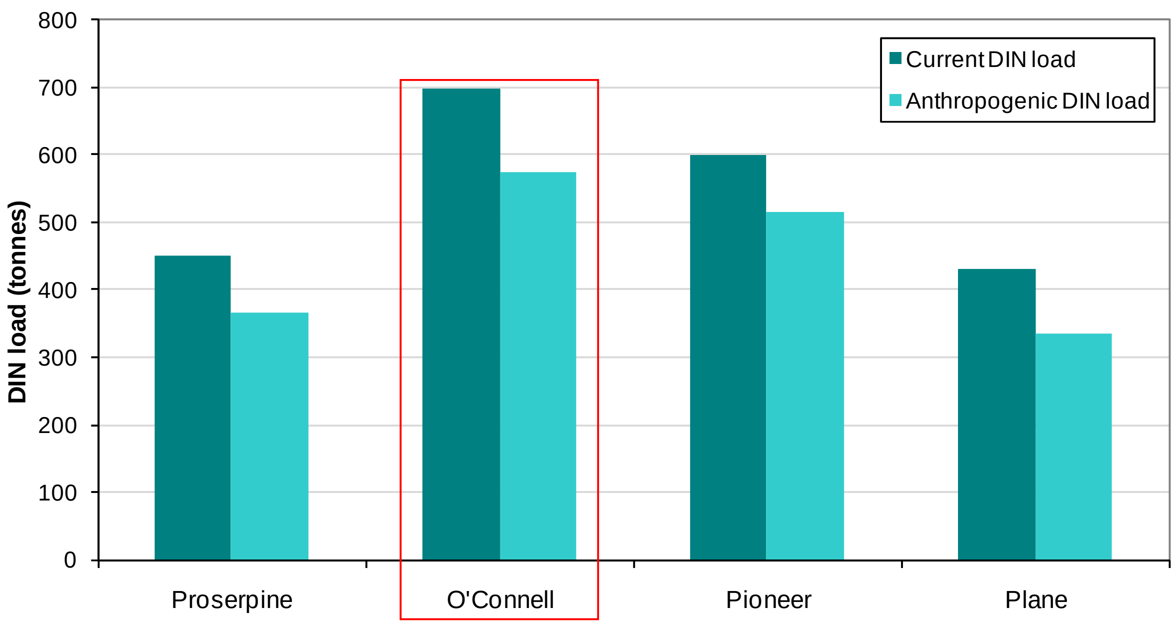
Approach: Rank the current and anthropogenic DIN loads by basin (Brodie *et al*. 2009).

Note: The current DIN load for the Plane basin was taken from Brodie *et al*. (2003), because Drewry *et al*. (2008) appears to have a major error in the estimation of DIN loads from this basin. In particular, lower levels of DIN than expected are reported from Sandy Creek (Drewry *et al*. 2008 Table 22).

Table 3.5 *Current and anthropogenic DIN loads delivered to the GBR from the Mackay-Whitsunday Region.* Source: Brodie *et al*. (2009).

Load (tonnes)	Proserpine	O'Connell	Pioneer	Plane
Current DIN load	450	700	600	430
Anthropogenic DIN load	367	575	516	335

Figure 3.6 *Current and anthropogenic DIN load delivered to the GBR from the Mackay Whitsunday Region.*



Rankings:

Current		Anthropogenic
1.	O'Connell	O'Connell
2.	Pioneer	Pioneer
3.	Proserpine	Plane
4.	Plane	Proserpine

Conclusion: The O'Connell basin generates the most DIN load on an annual basis in the Mackay Whitsunday Region, followed by the Pioneer basin (Figure 3.6).

Within all basins, which land use contributes the majority of the DIN load in the Mackay Whitsunday Region?

Approach: Calculate anthropogenic load for each land use using the method described below. Rank land uses based on the Anthropogenic DIN load estimated for each land use.

'Natural' load has been calculated using proportional estimates based on the forest DIN generation figures, and the following assumptions:

'Natural' generation rate for DIN =
Mackay Whit 'Natural' DIN load for forest = 511 tonnes
Mackay Whit area = 193,370 ha
= 511 tonnes / 193,370 ha (x 1000)
= 2.64 kg/ha

For each basin, perform the following calculations

For example, for Proserpine:

1. Assume sugar cane area was forest prior to anthropogenic influence.
Natural sugar cane load = Current area of sugar cane x Generation factor
= 24,480ha x 2.64 kg/ha
= 64,600 kg
Anthropogenic sugar cane load = Current load – Natural load
= 108,000 – 64,600 kg
= 43,400 kg

2. Assume no change in the DIN load for grazing areas.
Anthropogenic grazing load = Current load – Natural load
= 198,000 – 198,000 kg
= 0 kg

3. Assume area of Other crops area was forest prior to anthropogenic influence.
Natural Other crops load = Current area of Other Crops x Generation factor
= 720 ha x 2.64 kg/ha
= 1,900 kg
Anthropogenic Other crops load = Current load – Natural load
= 1,800 – 1,900 kg
= 0 kg

4. Assume area of Other land uses was forest prior to anthropogenic influence.
Natural Other load = Current area of Other x Generation factor
= 10,650 ha x 2.64 kg/ha
= 28,100 kg
Anthropogenic Other load = Current load – Natural load
= 23,400 – 28,100 kg
= 0 kg

Land use areas are sourced from Brodie *et al*. (2003) and Current DIN load is sourced from Brodie *et al*. (2009).

Note that with the application of this simple method, the Natural load may be calculated as being higher than the Current load which is due the broad assumptions about conversion of land uses from forest in calculating the Natural loads. In these instances, the Anthropogenic load is considered to be zero.

Table 3.6 *Current DIN load delivered to the GBR by land use types in the Mackay Whitsunday Region.* Source: Brodie *et al*. (2009).

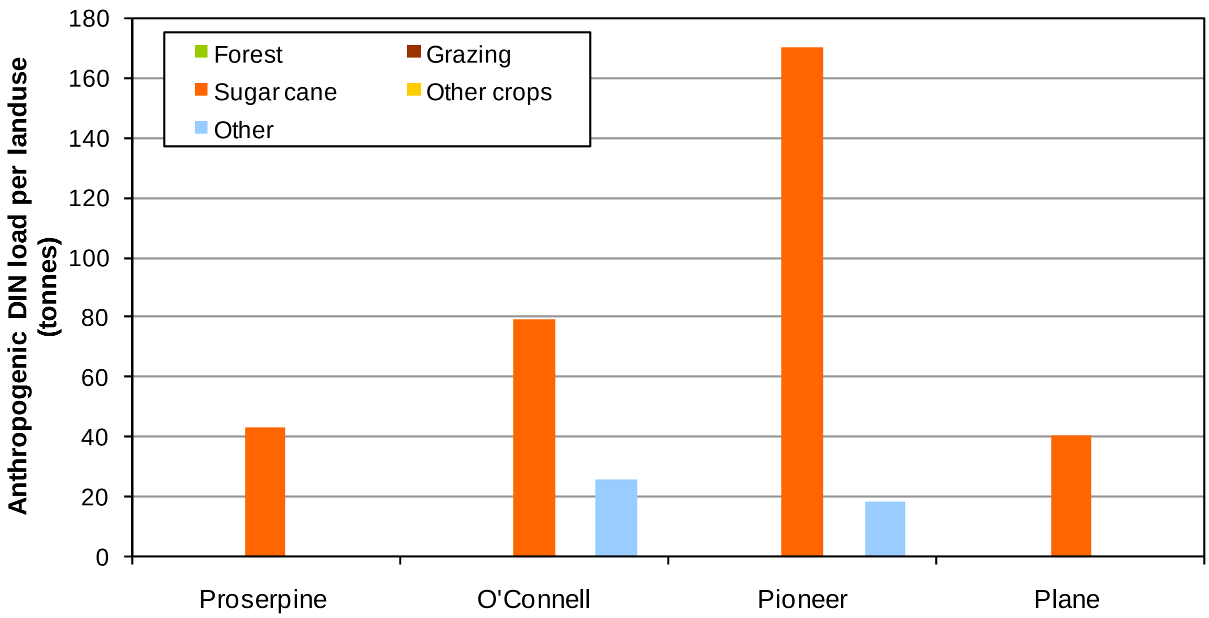
Basin	Best Estimate Current DIN load	Current contribution of DIN from each land use (tonnes)					% Current DIN from sugar cane
		Forest	Grazing	Sugar cane	Other crops	Other	
Proserpine	450	119	198	108	2	23	24%
O'Connell	700	182	302	170	1	45	24%
Pioneer	600	152	124	290	0	34	6%
Plane	430	28	200	185	1	16	4%
Mackay Whitsunday Total	2,180	511	806	737	4	122	34%
Percentage		23%	37%	34%	<1%	6%	

Table 3.7 *Estimated anthropogenic DIN load delivered to the GBR by land use types in the Mackay Whitsunday Region.*

Basin	Best Estimate Anthropogenic DIN load	Sum of calculated Anthropogenic DIN load	Anthropogenic contribution of DIN from each land use (tonnes)					% Anthropogenic DIN from sugar cane
			Forest	Grazing	Sugar cane	Other crops	Other	
Proserpine	367	43	0	0	43.4	0	0	100%
O'Connell	575	106	0	0	79.5	0.7	26.0	75%
Pioneer	516	189	0	0	170.3	0	18.8	90%
Plane	335	40	0	0	40.4	0	0	100%
Mackay Whitsunday Total	1,793	379	0	0	333.6	0.7	44.9	88%
Percentage			0%	0%	88%	0%	12%	

Note: The SedNet approach used by Brodie *et al*. (2003) generates modeled DIN load for natural loads – based on runoff coefficients from rainforest. DIN loads estimate similar to CMCC method based on generation rate from forest / natural areas. Anthropogenic load calculations vary depending on the method of calculating the natural load, which has a large degree of uncertainty. Hence, the estimate of anthropogenic load also has a high degree of uncertainty. This is shown from Table 3.7 where the first column of anthropogenic best estimate from each basin derived from SedNet / ANNEX estimates based on Drewry *et al*. (2008) and Brodie *et al*. (2003); while the estimates by land use give load estimates based on a simple generation rate model (similar to CMSS – Catchment Modelling Support System). The two estimates are widely different, reflecting the high degree of uncertainty in the estimates. However, we believe there is some value in the relative estimates.

Figure 3.7 *Anthropogenic DIN load delivered to the GBR by land use types in the Mackay Whitsunday Region.*



Rankings:

1. Sugar cane
2. Other

Forest and grazing are not considered to contribute to the anthropogenic load. The amounts for Other crops are minor.

Conclusion: The greatest proportion of anthropogenic DIN load in the Mackay Whitsunday Region is derived from sugar cane areas, particularly in the Pioneer basin.

Within the land use contributing the largest proportion of the DIN, which basins deliver the most DIN per hectare?

Approach: The land use contributing the largest proportion of DIN in the Mackay Whitsunday Region is sugar cane as shown in Figure 3.7. Rank basins based on anthropogenic load by land use, and kg/ha within the primary source land use, sugar cane.

Referring back to Figure 3.7, the loads of DIN from sugar cane from the basins can be ranked as follows.

Rankings:

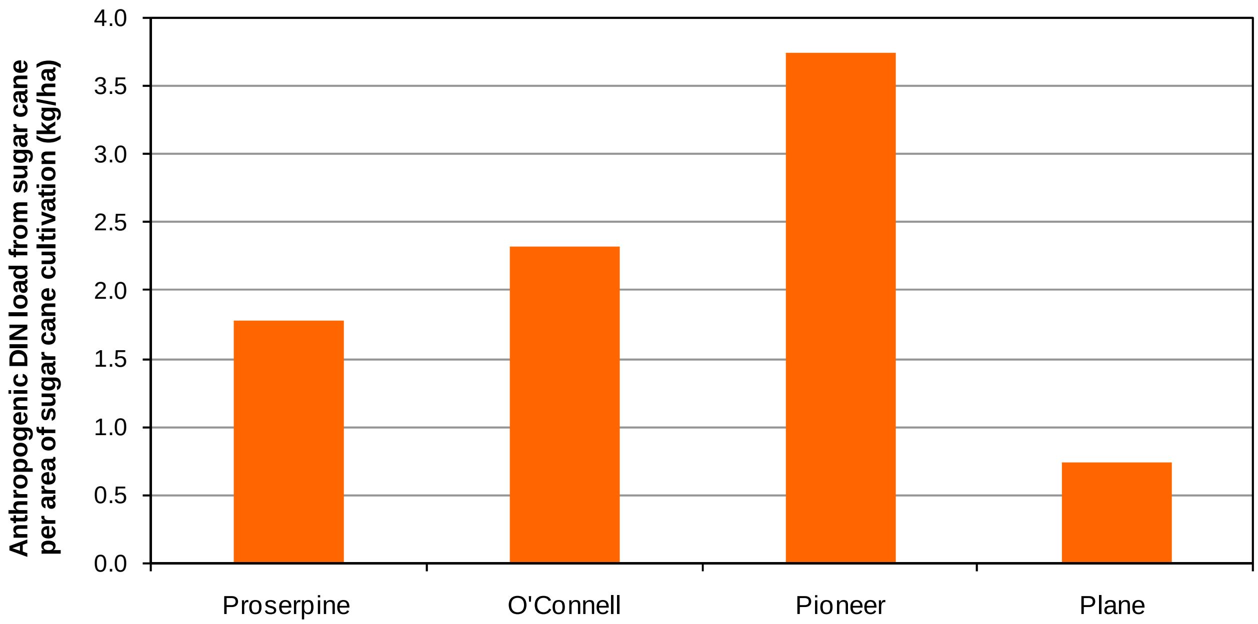
1. Pioneer
2. O'Connell
3. Proserpine
4. Plane

Table 3.8 *Anthropogenic load of DIN delivered to the GBR per unit area of land use in the Mackay Whitsunday Region.*

Basin	Anthropogenic DIN load per unit land use area (kg/ha)					
	Forest	Grazing	Sugar cane	Other crops	Other	Total
Proserpine	0	0	1.8	0	0	0.2
O'Connell	0	0	2.3	2.4	3.7	0.5
Pioneer	0	0	3.7	0	3.2	1.1
Plane	0	0	0.7	0	0	0.2
Mackay Whitsunday Total	0	0	2.1	0.4	1.4	0.5

The anthropogenic load per unit area of sugar cane is shown in Figure 3.8.

Figure 3.8 *Anthropogenic DIN load from sugar cane per area of sugar cane cultivation in the Mackay Whitsunday Region.*



Rankings:

1. Pioneer
2. O'Connell
3. Proserpine
4. Plane

Conclusion: The results show that the largest proportion of total anthropogenic DIN load from sugar cane in the Mackay Whitsunday Region is from the Pioneer basin, followed by the O'Connell basin. In terms of DIN load from sugar cane per unit area of sugar cane cultivation, the highest loads per unit area are from the Pioneer and O'Connell basins.

Key findings for DIN in the Mackay Whitsunday Region

- **The O'Connell basin generates the most DIN load on an annual basis in the Mackay Whitsunday Region, followed by the Pioneer basin (Figure 3.6).**
- **The greatest proportion of anthropogenic DIN load in the Mackay Whitsunday Region is derived from sugar cane areas, particularly in the Pioneer basin (Figure 3.7).**
- **The largest proportion of total anthropogenic DIN load from sugar cane in the Mackay Whitsunday Region is from the Pioneer basin, followed by the O'Connell basin (Figure 3.7).**
- **For DIN load from sugar cane per unit area of sugar cane cultivation, the highest loads per unit area in the Mackay Whitsunday Region are from the Pioneer and O'Connell basins (Figure 3.8).**

Data confidence: Within the accuracy bounds of this assessment, there are limited differences between the O'Connell, Proserpine and Pioneer; the difference between these basins and the Plane basin is unknown but may relate to estimates based on modeling only, and the catchments are small and not well amenable to the current scale of SedNet and ANNEX modeling.

3.5 PSII Herbicides within the Mackay Whitsunday Region

Which basins in the Mackay Whitsunday Region deliver the most herbicides on an annual basis to the GBR?

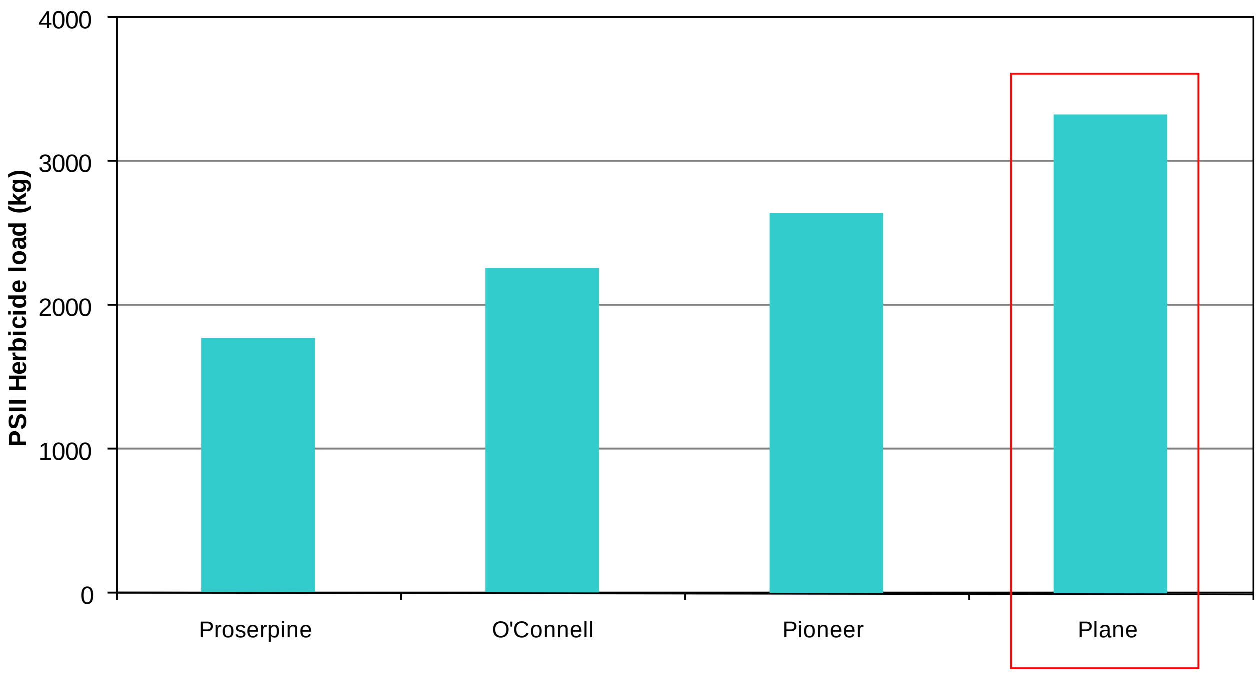
Approach: Rank the PSII Herbicide loads by basin using the herbicide assessment used in Brodie *et al*. (2009) (based on Lewis, unpublished and Lewis *et al*. 2009) which uses area of land use (sugar cane, grazing, dryland cropping) to predict loads of herbicides (described in more detail in the Approach). Note that the model assumes that herbicide delivery is not affected by dam trapping.

Table 3.9 *PSII Herbicide loads to the GBR from the Mackay Whitsunday Region*. Source: Basin areas and land use from Brodie *et al*. (2003).

PSII Herbicide load (kg)	Proserpine	O'Connell	Pioneer	Plane	Total
Tebuthiuron	483	439	233	415	1,569
Diuron	787	1,103	1,463	1,766	5,119
Atrazine	375	525	695	839	2,434
Hexazinone	119	168	222	268	777
Ametryn	19	26	34	42	121
Simazine	0	0	0	0	0
Total	1,782	2,260	2,648	3,329	10,020

Note: Plane basin includes Sandy Creek and Bakers Creek.

Figure 3.9 *Total PSII Herbicide loads delivered to the GBR from the Mackay Whitsunday Region*.



Rankings:
1. Plane
2. Pioneer
3. O'Connell
4. Proserpine

Conclusion: The Plane basin has the greatest load of PSII Herbicide delivery in the Mackay Whitsunday region followed by the Pioneer and O'Connell basins.

Data confidence: High confidence as for comparison purposes, the relationship between land use area and PSII Herbicide delivery is robust.

Within the basin delivering the highest PSII Herbicide load (Plane), which land use contributes the majority of the PSII Herbicides?

Approach: Tabulate areas of different land use and PSII Herbicide exports from the Plane basin.

Table 3.11 *Land use areas and PSII Herbicide loads in the Plane basin*.

	Land use				
	Forest	Grazing	Sugar cane	Other crops*	Other
Area (ha)	15,190	97,580	54,950	340	7,410
PSII Herbicide load (kg)	0	415	2,915	0	0
PSII Herbicide load/ area (g/ha)	0	4.3	53	0	0

* Note – There is insufficient knowledge about Other crops, so assume zero PSII Herbicide delivery.

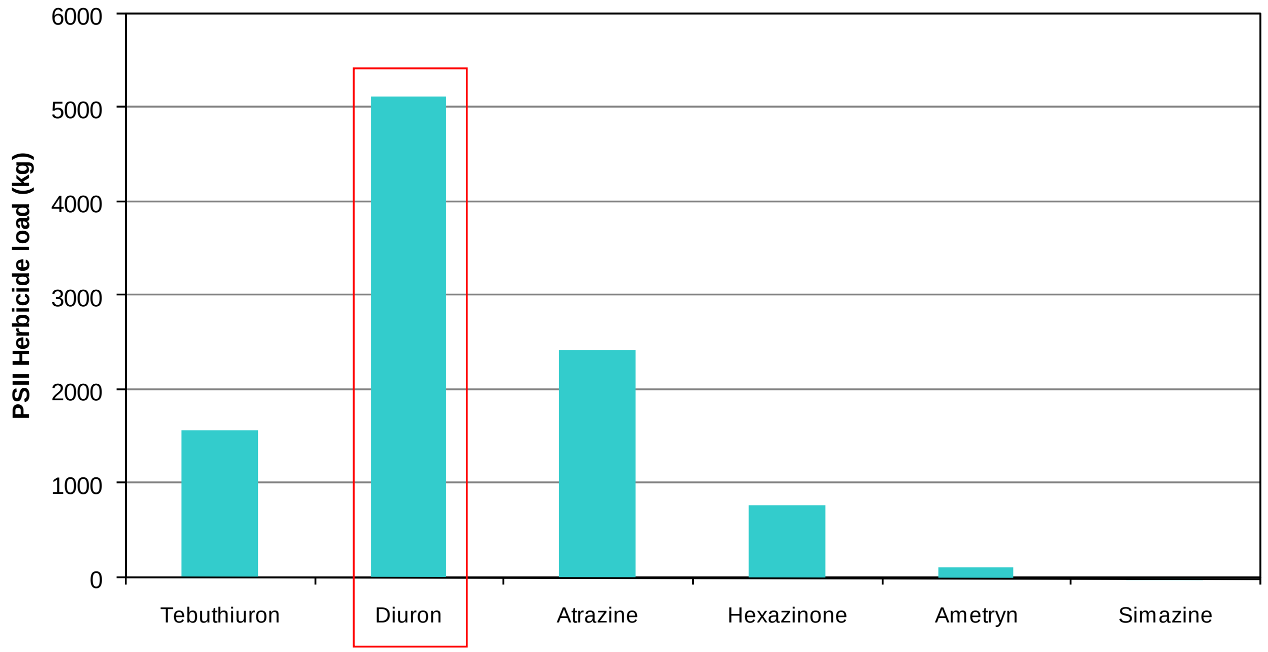
Rankings:
1. Sugar cane
2. Grazing

Conclusion: The greatest proportion of PSII Herbicides in the Plane basin is generated from sugar cane areas, accounting for 88% of the total PSII Herbicide export.

Which PSII Herbicide is discharged in the highest amounts for the Mackay Whitsunday Region?

Approach: Rank loads of PSII Herbicides by type across the region.

Figure 3.10 *PSII Herbicide loads in the Mackay Whitsunday Region by herbicide type.*



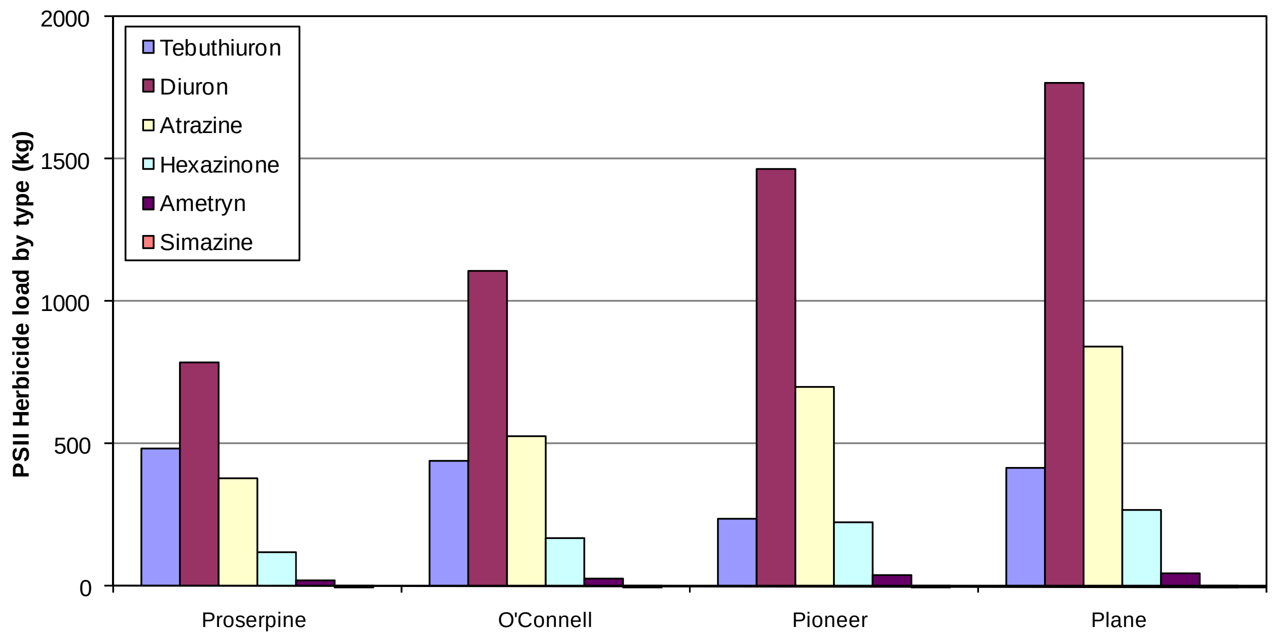
Rankings:
1. Diuron
2. Atrazine
3. Tebuthiuron

Conclusion: Diuron is the PSII Herbicide discharged in the highest amounts from the Mackay Whitsunday Region.

Which PSII Herbicides are associated with which basins in Mackay Whitsunday Region?

Approach: Rank loads of PSII Herbicides within each basin in the Mackay Whitsunday Region.

Figure 3.11 *PSII herbicide loads in the Mackay Whitsunday Region by herbicide type*.



Conclusion: The figure reflects the high proportion of sugar cane in the basins. It is believed that tebuthiuron is derived from grazing, while the other PSII Herbicides are known to be derived from sugar cane. Simazine detection in the region is minor and the sources of simazine are not widely known.

Key findings for PSII Herbicides in the Mackay Whitsunday Region

- **The Plane basin has the greatest load of PSII Herbicide delivery in the Mackay Whitsunday Region followed by the Pioneer and O'Connell basins.**
- **The greatest proportion of PSII Herbicides in the Plane basin is generated from sugar cane areas, accounting for 93-98% of the total PSII Herbicide load.**
- **Diuron is the PSII Herbicide discharged in the highest amounts from the Mackay Whitsunday Region and is discharged in high amounts from all basins. The use of diuron in the region is associated with sugar cane cultivation.**
- **It is believed that tebuthiuron is derived from grazing, while the other PSII Herbicides are known to be derived from sugar cane. Simazine detection in the region is minor and the sources of simazine are not widely known.**

Data confidence: High confidence as for comparison purposes, the relationship between land use area and PSII Herbicide delivery is robust.

3.6 Sources of Information

Refer also to spreadsheet in Attachment 3.

Information	Catchments	Source
Current loads		
Suspended Sediment	All	Brodie *et al*. 2009; Drewry *et al*. 2008
DIN	All	Brodie *et al*. 2009; Drewry *et al*. 2008
PSII Herbicides	All	Lewis, unpublished; Lewis *et al*. 2009
Natural loads	All	Brodie *et al*. 2009
Erosion type	All	
Land use area	All	Brodie *et al*. 2009 (from Brodie *et al*. 2003) for all land use specific calculations; Drewry *et al*. 2008
Land use loads by pollutant		
Suspended Sediment	All	Brodie *et al*. 2009; Drewry *et al*. 2008
DIN	All	Derived from Brodie and Waterhouse, 2009 (Stage 1 Report)

4. Regional Assessment: Fitzroy Region

4.1 Regional Summary Table

Table 4.1 *Summary of load characteristics for the Fitzroy Region*.

Parameter	Styx	Shoalwater	Water Park	Fitzroy	Calliope	Fitzroy Region
Basin Area (ha)	266,260	88,890	299,350	14,275,230	204,310	15,134,040
Suspended sediment						
Current SS load to the GBR (000 tonnes)	250	100	100	3400	200	4050
Anthropogenic SS load to the GBR (000 tonnes)	225	78	90	3,125	180	3,698
Current SS load to the GBR per basin area (tonnes/ha)	0.94	1.12	0.33	0.24	0.98	0.27
Anthropogenic SS load to the GBR per basin area (tonnes/ha)	0.85	0.88	0.30	0.22	0.88	0.24
Dominant losses linked to:						
1) Land use source	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing
2) Erosion type	Hillslope	Hillslope	Hillslope	Hillslope	Hillslope	Hillslope
Dissolved Inorganic Nitrogen (DIN)						
Current DIN load (tonnes)	50	50	80	1,500	50	1,730
Anthropogenic DIN load (tonnes)[1]	27	9	39	893	30	998
Anthropogenic DIN load per basin area (kg/ha)	0.10	0.10	0.13	0.06	0.15	0.07
Anthropogenic DIN load per 'other crops' area (kg/ha)				1.2		
Dominant losses linked to:						
Land use source	Other crops	Other crops	Other crops	Other crops	Other crops	Other crops
PSII Herbicides						
Tebuthiuron (kg)	23	7	12	1098	17	1157
Other PSII (kg)	0	13	0	1098	0	1112
Total PSII load (kg)	23	20	13	2195	18	2269
PSII load per basin area (g/ha)	0.09	0.22	0.04	0.15	0.09	0.15
Dominant delivery linked to:						
Land use source	Other crops	Other crops	Other crops	Other crops	Other crops	Other crops

[1]Note: The anthropogenic DIN loads used in this table are taken from Table 4.4.

Attachment 4 provides supporting detail and references to the above summary information.

4.2 Regional Assessment Data

Assessment units in the Fitzroy Region

For the purpose of this risk assessment, the basins of the Fitzroy Region are defined as including the Styx, Shoalwater, Water Park, Fitzroy and Calliope basins (Figure 4.1a). The area of the Fitzroy River basin is so much larger than the other basins that it dominates the region. It would be appropriate to separately consider the major basins of the Fitzroy basin (Dawson, Comet, Nogoa, Theresa Creek, Isaac, Connors, Mackenzie and Lower Fitzroy – refer to Figure 4.1b), but there has been insufficient effort to date to measure the outputs from these different basins. Comments are made within this report on our limited knowledge of the differences within the Fitzroy basin.

Figure 4.1a. *Basins in the Fitzroy Region.*

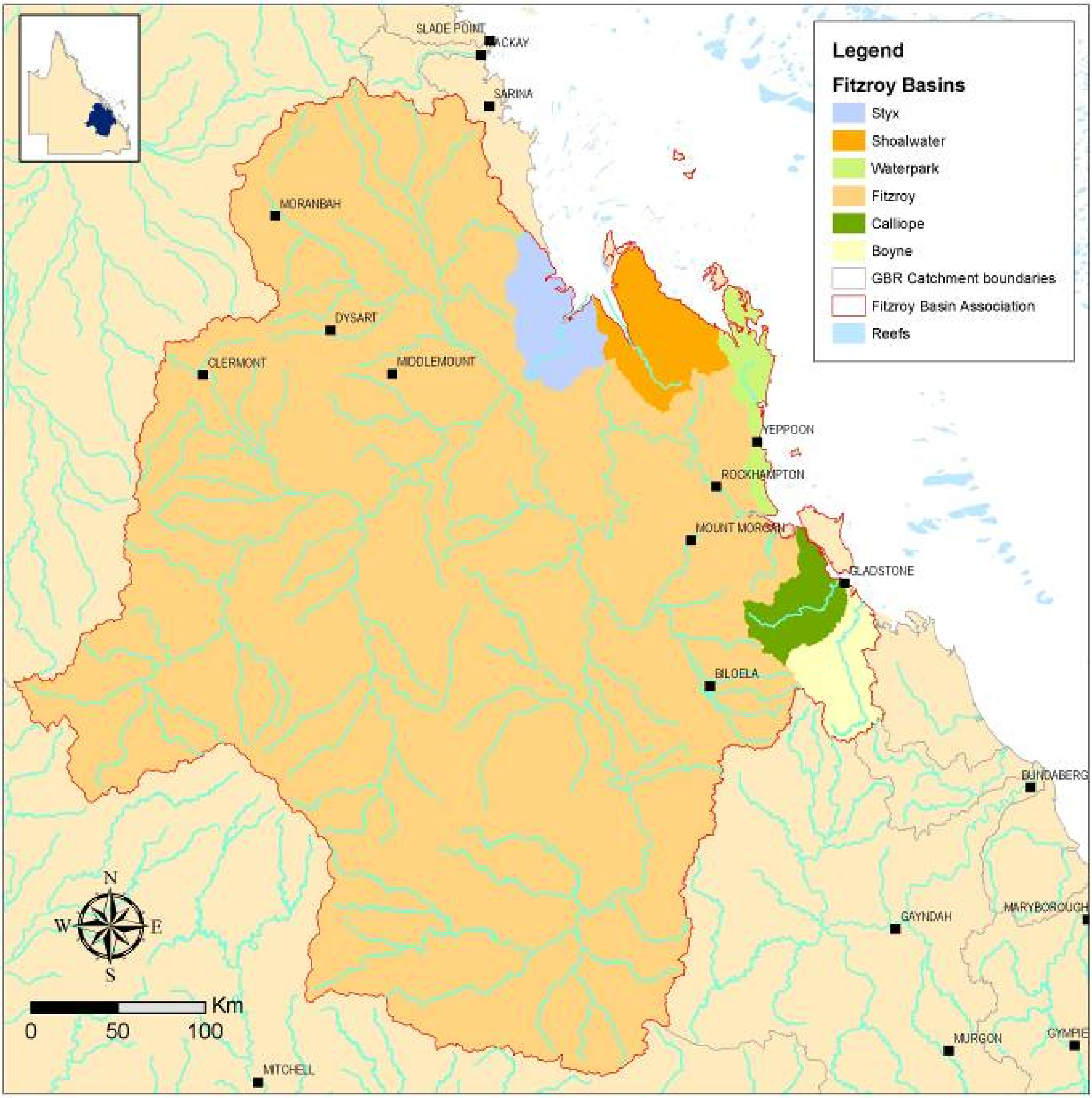


Figure 4.1b *Sub basins in the Fitzroy Basin.*

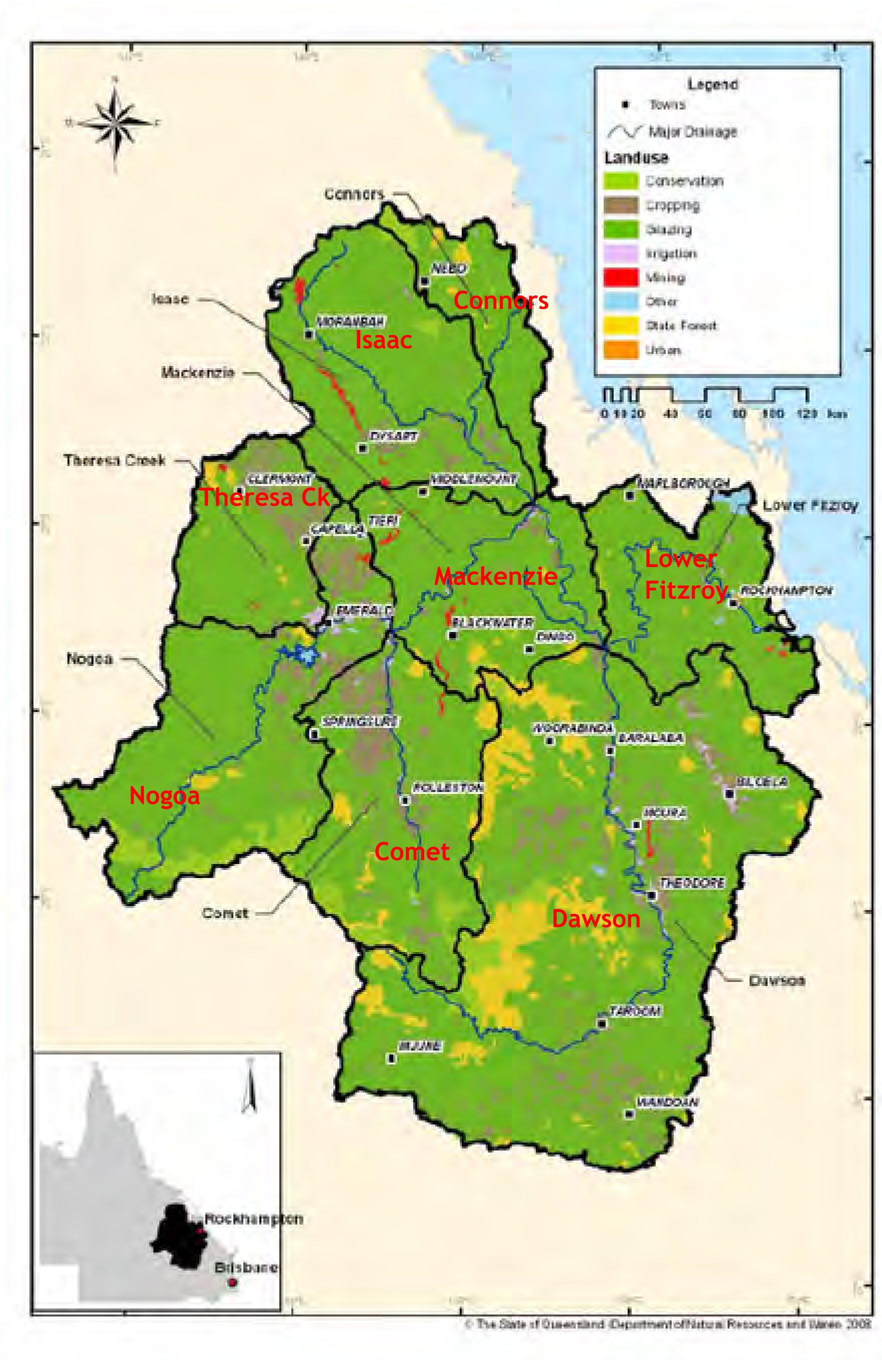


Table 4.1 summarises Current, Natural, Anthropogenic loads of total suspended sediments (TSS) and nutrient forms of N and P including dissolved inorganic (DIN, DIP), dissolved organic (DON, DOP) and particulate (PN, PP), as well as herbicides (PSII herbicides). **Attachment 4** presents the detailed spreadsheet. Note that cropping, mostly grains and cotton, listed as 'Other crops' land use, is spread over most of the Fitzroy basin.

4.3 Suspended Sediment in the Fitzroy Region

Which basin in the Fitzroy Region delivers the most suspended sediment on an annual basis to the GBR?

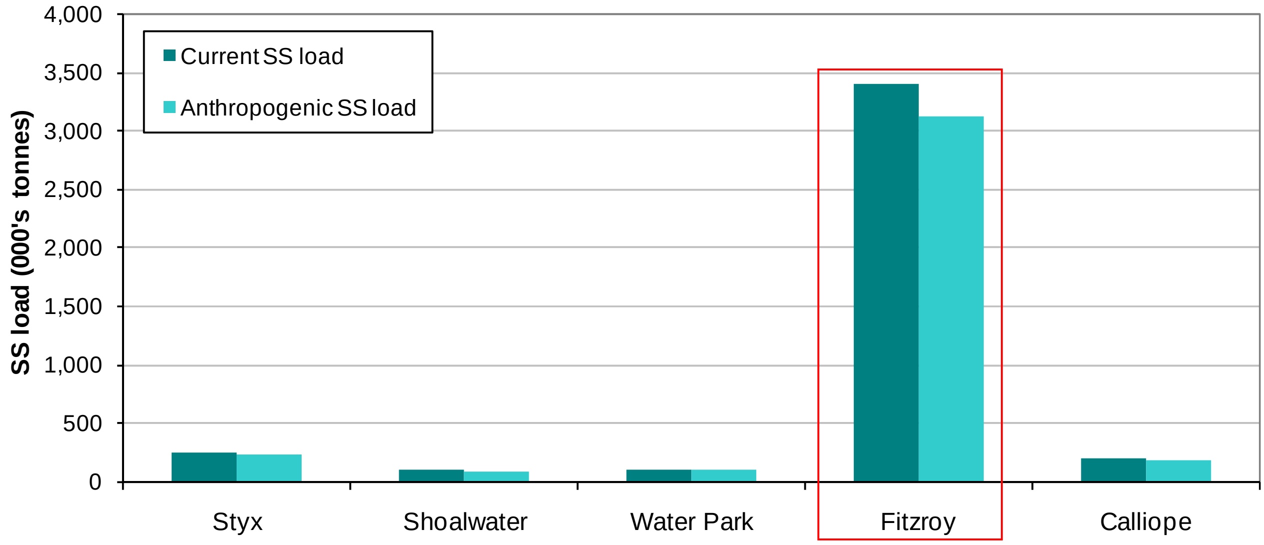
Approach: Rank basins using tonnes of suspended sediment (SS) based on current and anthropogenic figures.

Anthropogenic load is estimated for the Fitzroy basins using the same proportion of natural:current (~1:10) for the Fitzroy basin as a whole.

Table 4.2 *Suspended sediment loads delivered to the GBR from the Fitzroy Region*. Source: Brodie *et al*. (2009).

	Styx	Shoalwater	Water Park	Fitzroy	Calliope	Total Fitzroy
Current SS load to the GBR (000's tonnes)	250	100	100	3,400	200	4,050
Anthropogenic SS load to the GBR (000's tonnes)	225	78	90	3,125	180	3,698
Current SS load to the GBR per basin area (tonnes/ha)	0.94	1.12	0.33	0.24	0.98	0.27
Anthropogenic SS load to the GBR per basin area (tonnes/ha)	0.85	0.88	0.30	0.22	0.88	0.24

Figure 4.2 *Suspended sediment load (current and anthropogenic) delivered from the Fitzroy Region to the GBR.*



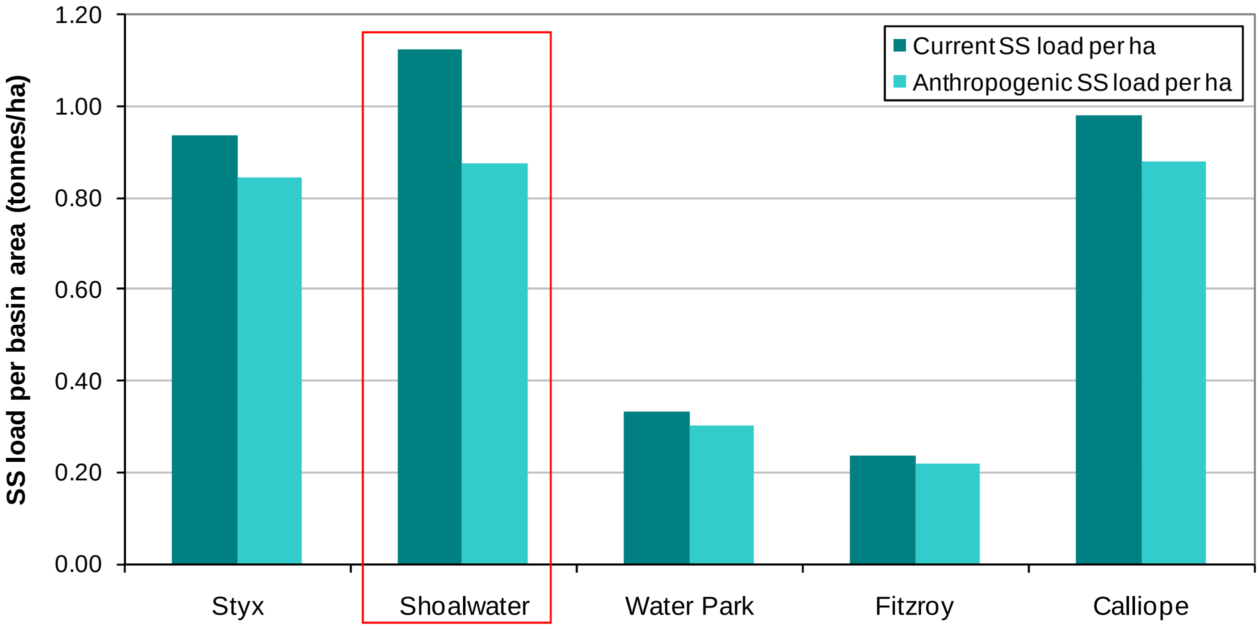
Rankings:

Current		Anthropogenic
1.	Fitzroy	Fitzroy
2.	Styx	Styx
3.	Calliope	Calliope
4.	Water Park	Water Park
5.	Shoalwater	Shoalwater

Conclusion: The Fitzroy basin within the Fitzroy Region currently delivers the most current and anthropogenic suspended sediment load on an annual basis to the GBR. This is clearly related to the massive areal dominance of the Fitzroy basin relative to the other, much smaller basins.

Data confidence: The data is sourced from a combination of monitored and modeled data and is considered to be high.

Figure 4.3 *Suspended sediment load (current and anthropogenic) per basin area delivered from the Fitzroy Region to the GBR.*



Rankings:

Current	**Anthropogenic**
1. Shoalwater	Shoalwater
2. Calliope	Calliope
3. Styx	Styx
4. Water Park	Water Park
5. Fitzroy	Fitzroy

Conclusion: The Shoalwater basin within the Fitzroy Region currently delivers the most current and anthropogenic suspended sediment load per basin area.

Note: The dominance of the Shoalwater basin (smallest area) and the low load per catchment area for the Fitzroy basin (by far the largest basin) is likely to be related to basin size. Wasson (1994) showed that sediment yield varied considerably with basin size, smaller basins had higher, though more variable sediment yields. This trend is probably due to more trapping and sediment sequestration in larger basins. For the Fitzroy basin, the Barrage (dam) at Rockhampton further increases coarse-sediment trapping. The reason for the small rate in the Water Park basin is unknown.

Within the basins, which land use contributes the majority of the suspended sediment?

Approach: Rank land use contributions for suspended sediment load. Land use contributions to suspended sediment load are not yet determined for any of the individual Fitzroy basins, however, land use can be shown at the catchment scale for some of the basins. Given the dominance of grazing land use in the Fitzroy Region, anthropogenic load by land use contributions has not been calculated as the difference is assumed to be around 10%, as indicated in Table 4.2 and Figure 4.2.

Figure 4.4 *Current suspended sediment loads by land use in the Fitzroy Region.* Source: Brodie *et al*. (2009).

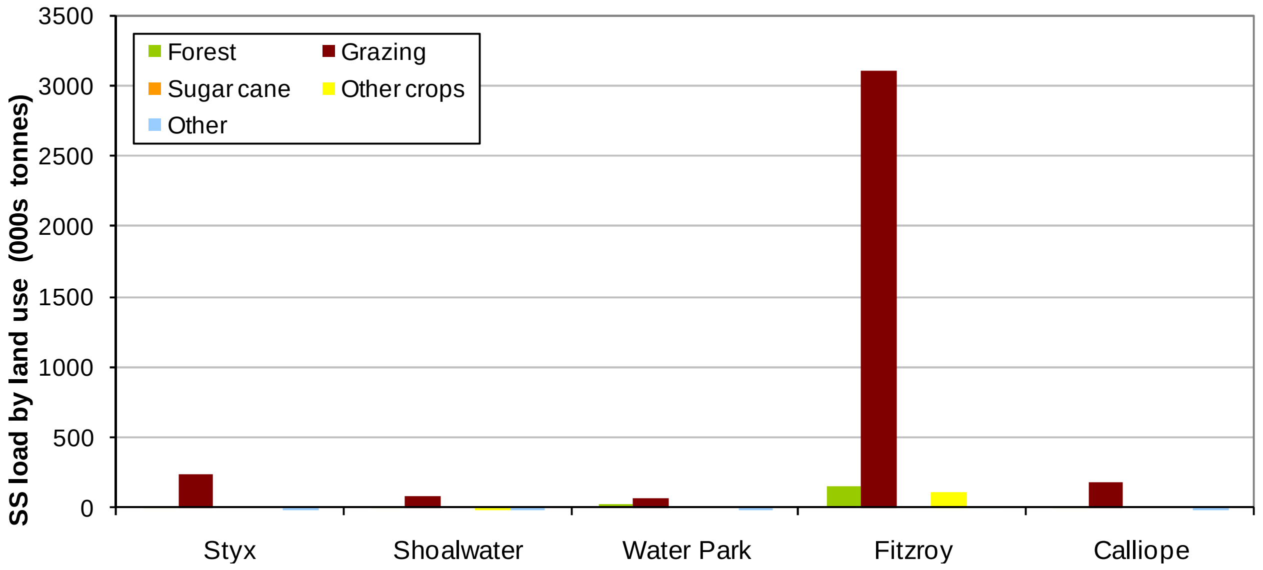
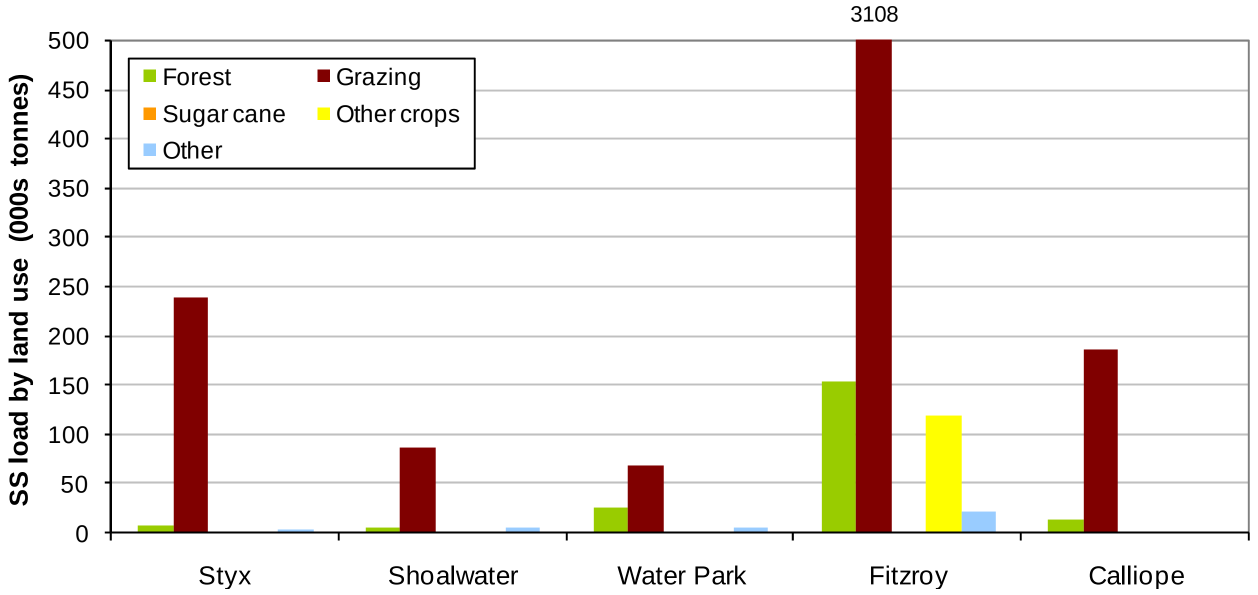


Figure 4.5 *Current suspended sediment loads by land use in the Fitzroy Region, with expanded y-axis.*



Rankings:

1. Grazing
2. Forest
3. Other cropping
4. Other
5. Sugar cane

Conclusion: Grazing land use is currently contributing most suspended sediment across the Fitzroy Region.

Data confidence: High level of confidence due to the known generation rates of grazing land uses and the large area of grazing in the region.

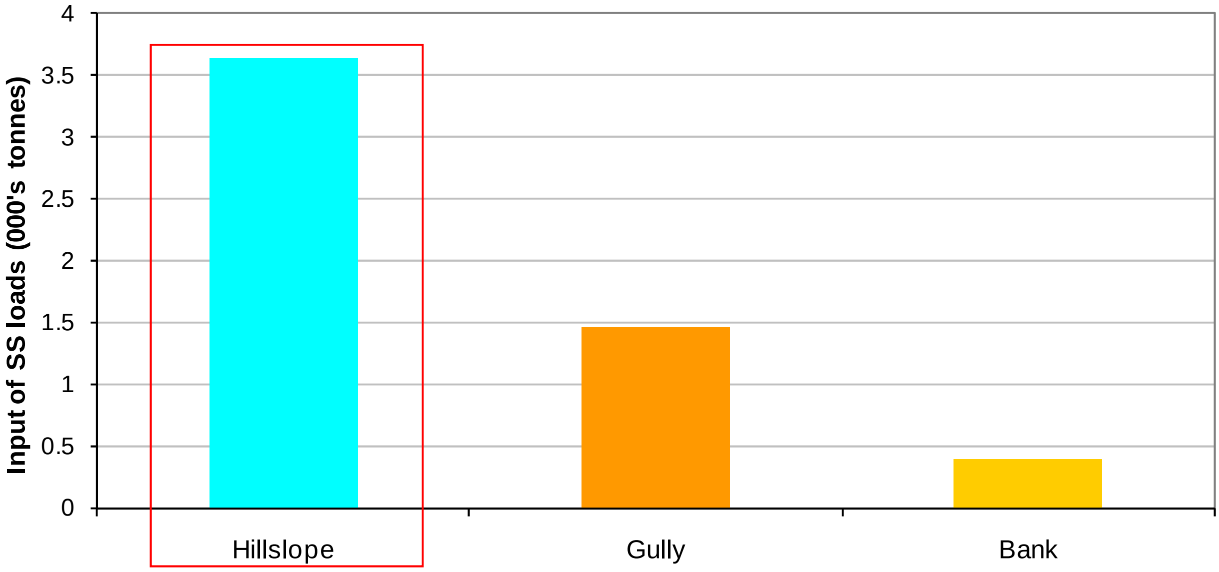
Within all of the basins what is the erosion type that generates the most suspended sediment?

Approach: Rank the input loads from hillslope, gully and bank erosion for each basin from modeled data. It is recognized that there is difficulty in separating natural erosion versus anthropogenic or historic erosion in relation to erosion type, and only current rates are presented here. **Note that this analysis is being done within each basin, <u>not to the GBR,</u> hence some differences will appear in the totals compared to Table 4.2.**

Table 4.3 *Total suspended sediment loads by erosion type in the Fitzroy basins based on current load*. Source: Tables 15 and 16 in Dougall *et al*. (2008) for Fitzroy; Note: Sediment inputs and delivery both shown for the Fitzroy basin; Data for other basins unavailable.

Source (000's tonnes)	Styx	Shoalwater	Water Park	Fitzroy (sediment inputs)	Fitzroy (sediment delivery)	Calliope	Whole Fitzroy
Hillslope				3,645	2,274		
Gully				1,450	821		
Bank				383	314		
Total Inputs				5,479	3,409		

Figure 4.6 *Total suspended sediment loads by erosion type in the Fitzroy basin.* Source: Dougall *et al*. (2008).



Rankings:

Fitzroy

1. Hillslope
2. Gully
3. Bank

Conclusion: Hillslope erosion is the dominant type of erosion in the Fitzroy basin. On this basis it is assumed that other directly neighbouring basins in the Fitzroy Region will have similar erosion patterns. Highest erosion inputs are seen from hillslope erosion in the Connors, Lower Fitzroy, Comet and Nogoa sub-basins of the Fitzroy basin (see Figure 22, Dougall *et al*. 2008).

Data confidence: Recent studies in the Fitzroy basin by Dougall *et al*. (2008) on quantifying the different types of erosion and by Trevithick *et al*. (2009) on gully density mapping provide good confidence for this finding.

There are limitations with knowledge regarding erosion types as the existing SedNet modeling does not model gully erosion well. New studies will improve this with the incorporation of more detailed gully mapping into SedNet. Therefore the results may present an under estimate of gully erosion. There is also difficulty in separating natural erosion versus anthropogenic or historic erosion in relation to erosion type, and only current rates are presented here.

Key findings for suspended sediment in the Fitzroy Region

- **The overall suspended sediment load to the GBR from the Fitzroy basin is by far the highest in the Fitzroy Region, linked to the large size of this basin.**
- **The key land use requiring management of suspended sediment in the Fitzroy Region is grazing.**
- **Highest erosion inputs are seen from hillslope erosion in the Connors, Lower Fitzroy, Comet and Nogoa sub-basins of the Fitzroy basin (see Figure 22, Dougall *et al*. 2008).**

Data confidence: Relatively high with the exception of erosion types and attribution to natural, current or anthropogenic loads.

4.4 Dissolved Inorganic Nitrogen in the Fitzroy Region

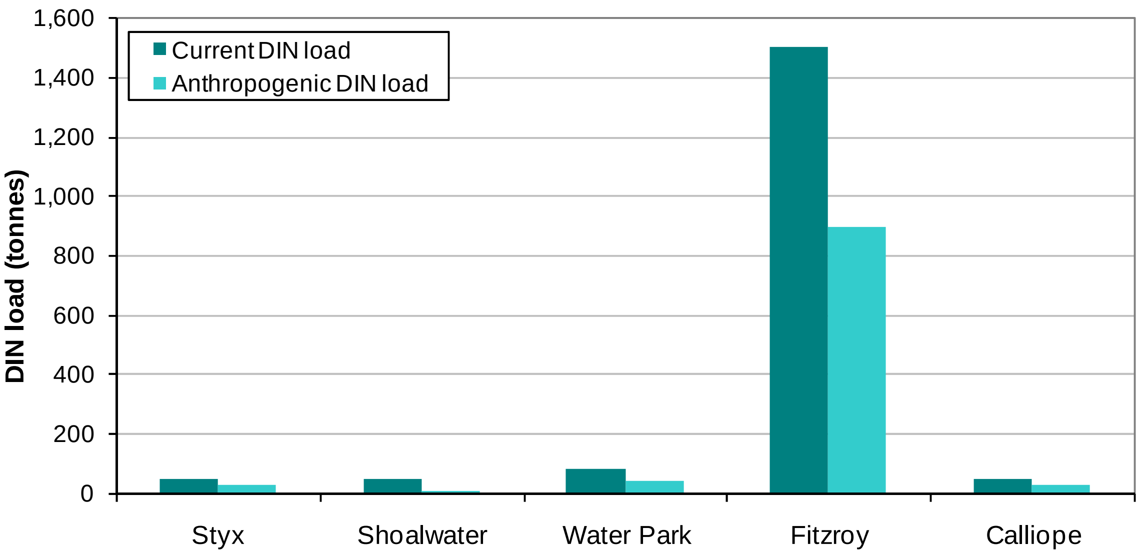
Which basin of the region delivers the most DIN on an annual basis to the GBR?

Approach: Rank the current and anthropogenic DIN loads by basin, and the DIN load per basin area (kg/ha). The anthropogenic load is calculated as the difference between the current and natural loads.

Table 4.4 *Current and anthropogenic DIN load to the GBR in the Fitzroy basins*. Source: Brodie *et al*. (2009)

Load (tonnes)	Styx	Shoalwater	Water Park	Fitzroy	Calliope	Total Fitzroy
Current DIN load	50	50	80	1,500	50	1,730
Anthropogenic DIN load	27	9	39	893	30	998

Figure 4.8 *Current and anthropogenic DIN loads in the Fitzroy Region.*



Rankings:

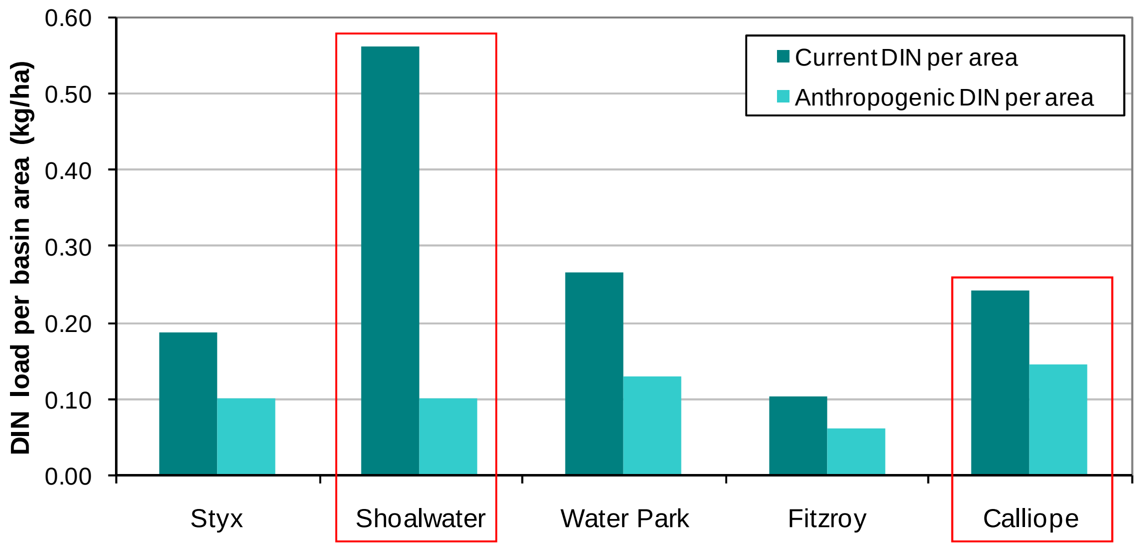
Current	Anthropogenic
1. Fitzroy	Fitzroy
2. Water Park	Water Park
3. Calliope	Calliope
4. Styx	Styx
5. Shoalwater	Shoalwater

Conclusion: The Fitzroy basin generates the most DIN load in the Fitzroy Region. Similary for suspended sediment, this finding mostly reflects the huge size of the Fitzroy basin relative to the sizes of the other basins as well as the very large area of cropping.

Table 4.4 *Current and anthropogenic DIN load per basin area to the GBR in the Fitzroy Region*.

Load per area	Styx	Shoalwater	Water Park	Fitzroy	Calliope	Total Fitzroy
Current DIN load per area (kg/ha)	0.19	0.56	0.27	0.11	0.24	0.11
Anthropogenic DIN load per area (kg/ha)	0.10	0.10	0.13	0.06	0.15	0.07

Figure 4.9 *Current and anthropogenic DIN load per basin area in the Fitzroy Region.*



Rankings:

Current	**Anthropogenic**
1. Shoalwater	Calliope
2. Water Park	Water Park
3. Calliope	Shoalwater
4. Styx	Styx
5. Fitzroy	Fitzroy

Conclusion: The Shoalwater basin delivers the most Current DIN load per basin area in the Fitzroy Region, while the Calliope basin delivers the most Anthropogenic DIN per basin area. The ranking for Current DIN per basin area follows the same pattern as suspended sediment (Figure 4.3), with the Shoalwater basin having the highest rate and the Fitzroy basin having the lowest. For the Anthropogenic DIN load rates, all basins are similar except for the Fitzroy basin with a very low rate. Unlike sediment, DIN cannot be trapped, so the reason(s) for these low rankings in the Fitzroy basin is not obvious. However, the DIN loads per basin area rates in the smaller basins are irrelevant when the sheer size and DIN load of the Fitzroy basin are considered. Hence, further analyses of DIN in the Fitzroy Region will concentrate only on the Fitzroy basin.

Within all basins, which land use contributes the majority of the DIN load in the Fitzroy Region?

Approach: For the Fitzroy basin, calculate anthropogenic load for each land use using the method described below. Rank land uses based on the Anthropogenic DIN load estimated for each land use.

'Natural' load has been calculated using proportional estimates based on the forest DIN generation figures, and the following assumptions:

'Natural' (Forest) generation rate for DIN =
'Natural' DIN load for forest = 120 tonnes
Fitzroy Region forest area = 1,362,180 ha
= 120 tonnes x 1000/ 1,362,180 ha
= 0.088 kg/ha

For Fitzroy basin:

1. Assume sugar cane area was forest prior to anthropogenic influence.
Natural sugar cane load = Current area of sugar cane x Generation factor
(presently almost no sugar) = 0 ha x 0.088 kg/ha
= 0 kg
Anthropogenic sugar cane load = Current load – Natural load
= 0 – 0
= 0 kg

2. Assume no change in the DIN load for grazing areas.
Anthropogenic grazing load = Current load – Natural load
= 1,287 kg – 1,287 kg
= 0 kg

3. Assume area of Other crops area was forest prior to anthropogenic influence.
Natural Other crops load = Current area of Other Crops x Generation factor
= 743,080 ha x 0.088 kg/ha
= 65,391 kg
Anthropogenic Other crops load = Current load – Natural load
= 1,480 tonnes – 65 tonnes
= 1,415 tonnes

4. Assume area of Other land uses was forest prior to anthropogenic influence.
Natural Other load = Current area of Other x Generation factor
= 91,210 ha x 0.088 kg/ha
= 8,026 kg
Anthropogenic Other load = Current load – Natural load
= 15 tonnes - 8 tonnes
= 7 tonnes

Land use areas are sourced from Brodie *et al*. (2003) and Current DIN load is estimated as mainly derived from 'Other crops'. A small Current DIN load of 15 tonnes is estimated to be exported from 'Other' land uses.

Note that with the application of this simple method, the Natural load may be calculated as being higher than the Current load which is due the broad assumptions about conversion of land uses from forest in calculating the Natural loads. In these instances, the Anthropogenic load is considered to be zero.

Within the basin delivering the highest load (overall and per unit area), which land use contributes the majority of the DIN?

Approach: Rank the anthropogenic DIN load by land use type in the Fitzroy basin (Figure 4.10) and by unit area of land use in the basin (Figures 4.11).

The anthropogenic DIN load for each land use is estimated using the current DIN load and assumes that the DIN load from forest and grazing areas has not changed from the natural load. It therefore is assumed that the majority of the anthropogenic DIN load derives from 'Other crops' (cereal grains and cotton) and to a small extent from 'Other' land uses. The calculated loads are in Table 4.5.

Table 4.5 *Current and anthropogenic DIN load (tonnes) by land-use type in the Fitzroy basin.* Source: Modified from Brodie *et al*. 2003 and Brodie *et al*. 2009).

Basin	Forest	Grazing	Sugar cane	Other crops	Other
Area (ha) (Brodie ***et al***. 2003)	1,362,180	12,078,760	0	743,080	91,210
Current DIN load (tonnes)	120	1,079	0	1,480	15
Anthropogenic DIN load (tonnes)	0	0	0	1,415	7
Anthropogenic DIN per land use area (kg/ha)	0	0	0	1.90	0.08

Figure 4.10 *Current and anthropogenic DIN load by land use type in the Fitzroy basin.*

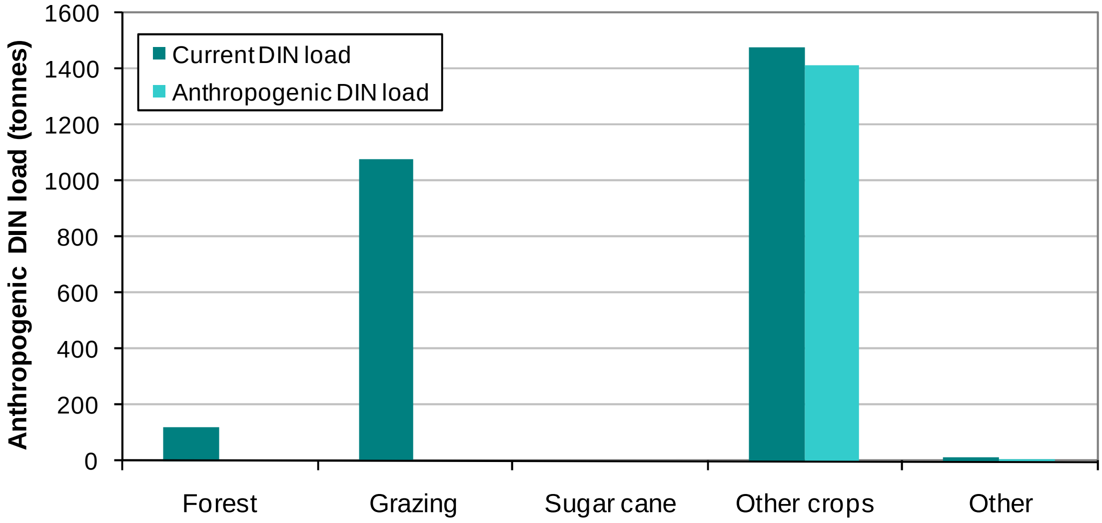
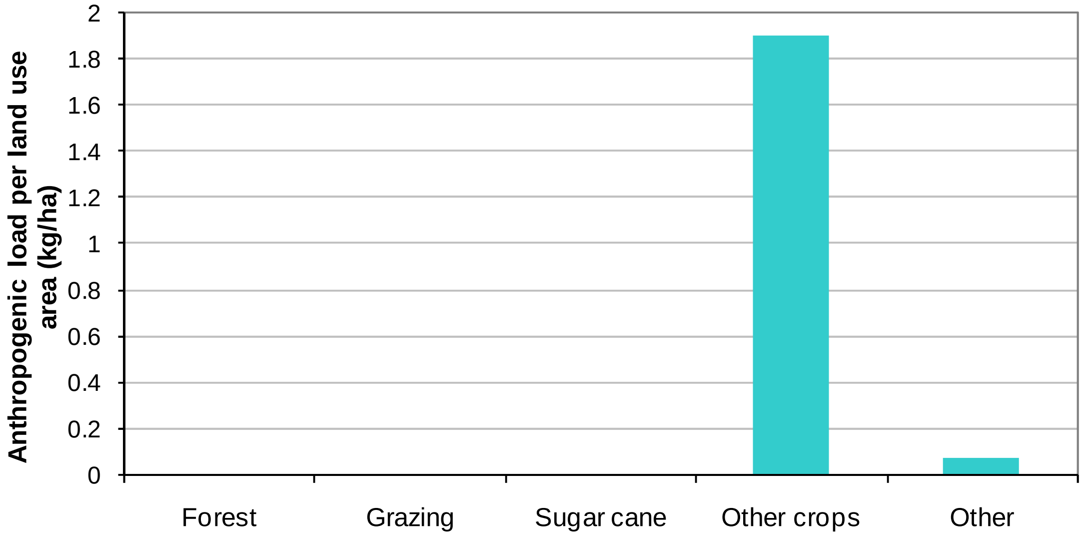


Figure 4.11 *Anthropogenic DIN load per land use area (kg/ha) by land-use type in the Fitzroy basin.*



Ranking:

1. Other crops
2. Other

Conclusion: From Figure 4.8, the basin with the highest DIN load in the Fitzroy Region is the Fitzroy basin, overwhelmingly. From Figures 4.10 and 4.11 the land uses with the highest anthropogenic DIN load or DIN load per land-use area in the Fitzroy basin are ‘Other crops’, followed by ‘Other’.

Within the land use contributing the largest proportion of the DIN, which process generates the most DIN?

For the Fitzroy basin, ‘Other crops’, including various grain crops and to a lesser extent, cotton cultivation, is the land use which generates most DIN. However, the fertiliser application rates per hectare for grain crops are known to be much less than that for sugar cane but cotton fertiliser application rates are similar to sugar cane.

Key findings for DIN in the Fitzroy Region

- **The overall DIN load to the GBR from the Fitzroy basin is the highest in the Fitzroy Region (Table 4.8), in part a reflection of the large size of this basin and the large area of cropping.**
- **The other coastal basins in the Fitzroy Region also contribute minor anthropogenic DIN loadings, but in total this is significantly less than that of the Fitzroy basin (Figure 4.8).**
- **The key contributing land use to DIN delivery to the GBR is ‘Other crops’ (Figures 4.10, 4.11), mainly grains and cotton. While the fertiliser application rates for grains crops are relatively low compared to sugar cane activity in other GBR catchments, cotton has comparable fertiliser application rates to sugar cane.**

4.5 PSII Herbicides within the Fitzroy Region

Which basins of the Fitzroy Region deliver the most herbicides on an annual basis to the GBR?

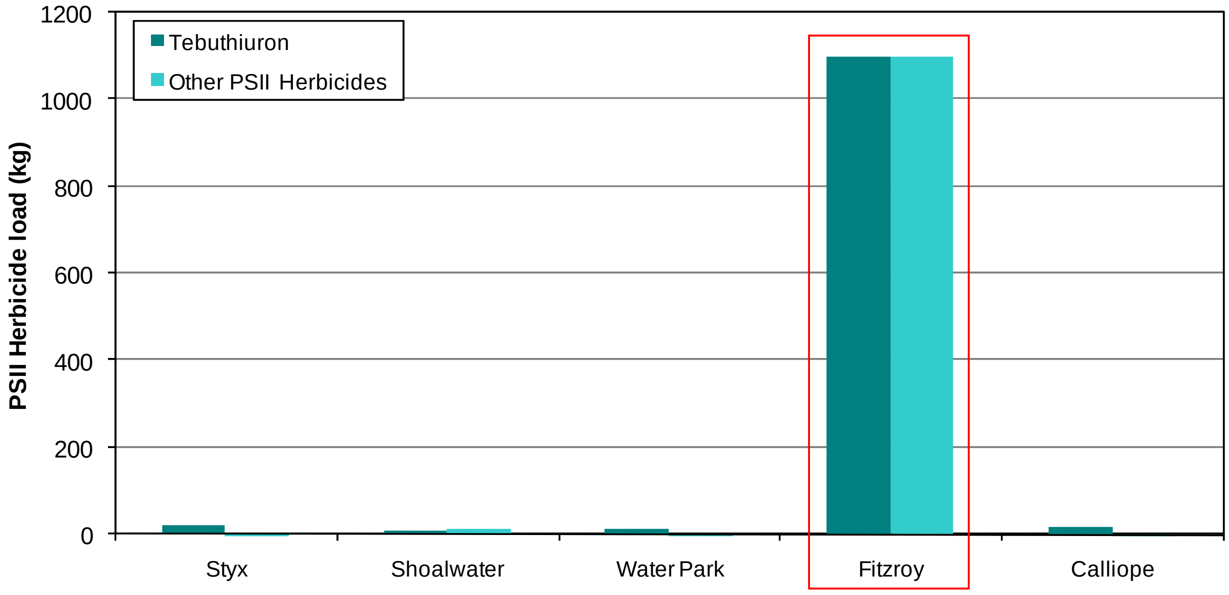
Approach: Rank the PSII Herbicide loads by basin using the herbicide assessment used in Brodie *et al*. (2009) (based on Lewis *et al*. (2009; unpublished)) which uses area of land use (sugar cane, grazing, dryland cropping) to predict loads of herbicides (refer to method described in the Approach). Note that the model assumes that herbicide delivery is not affected by dam trapping. The coefficient applied for tebuthiuron runoff from grazing lands of the Fitzroy Region has been developed using the monitoring data from the Fitzroy basin as reported in Packett *et al*. (2009).

Table 4.6 *PSII Herbicide loads to the GBR from the Fitzroy Region*. Source: Lewis, (unpublished).

Load	Styx	Shoalwater	Water Park	Fitzroy	Calliope	Total Fitzroy
PSII Total Herbicides (kg)	23	20	13	2,195	18	2,269
PSII Total Herbicide (g/ha)	0.09	0.22	0.04	0.15	0.09	0.15
PSII-Tebuthiuron (kg)	23	7	12	1,098	17	1,157
Other PSII Herbicides (kg)	0	13	0	1,098	0	1,112

Note: Monitoring results from the Fitzroy River show that the loads of tebuthiuron and atrazine are almost equal (Packett *et al*., 2009).

Figure 4.12 *PSII Herbicide load to the GBR from the Fitzroy Region.*



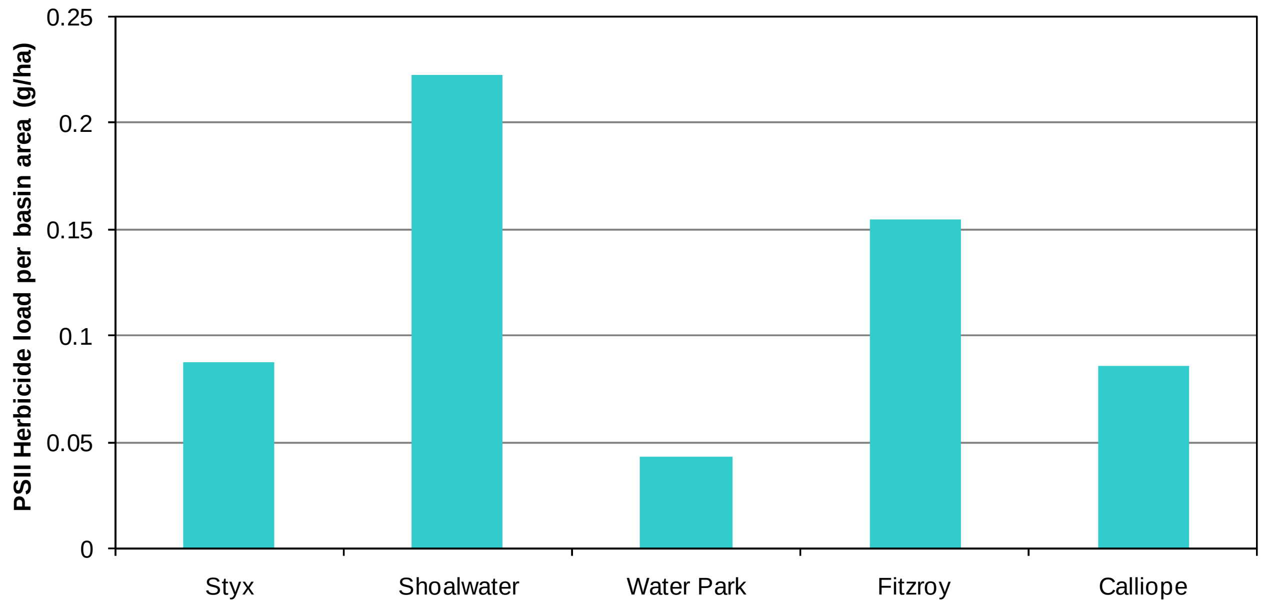
Rankings:

Tebuthiuron	**Other PSII Herbicides**
1. Fitzroy	Fitzroy
2. Styx	Shoalwater
3. Calliope	
4. Water Park	
5. Shoalwater	

Conclusion: The Fitzroy basin delivers more PSII Herbicides than any of the basins in the Fitzroy Region, largely due to its much larger size and area of grazing (tebuthiuron) and cropping (atrazine) than the other basins.

Data confidence: High confidence as for comparison purposes, the relationship between land use area and PSII Herbicide delivery is robust.

Figure 4.13 *PSII Herbicide load to the GBR in the Fitzroy Region (g/ha) per basin area.*

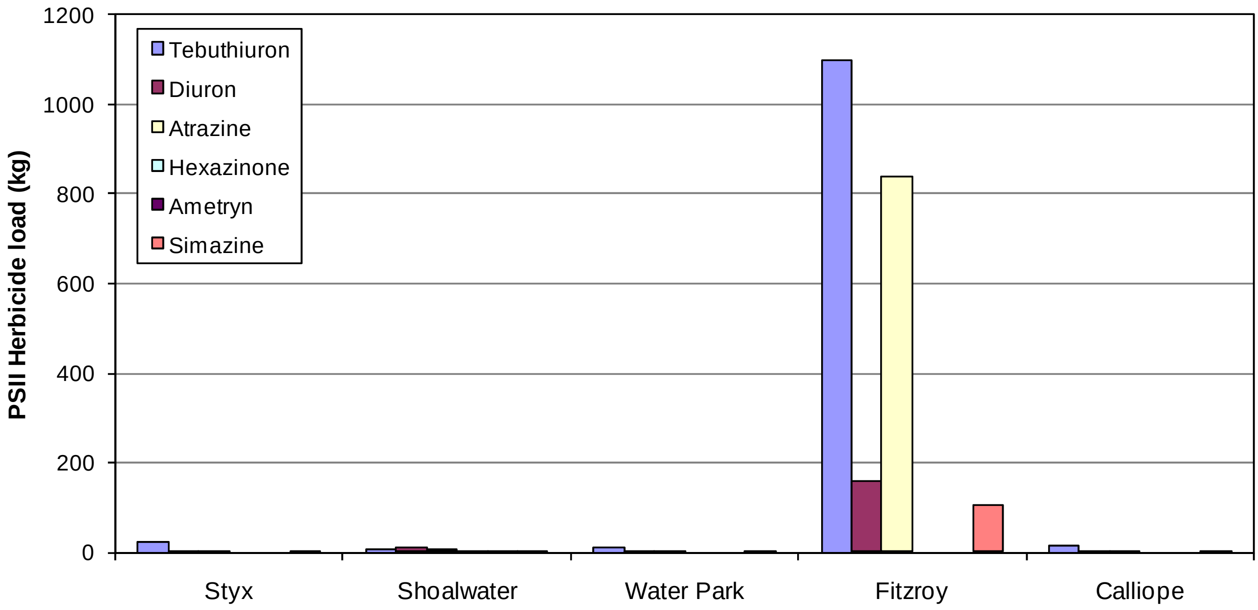


Conclusion: All of the basins in the Fitzroy Region deliver very low PSII Herbicide load per basin area compared to most other regions.

What kind of herbicide is delivered from which basins in the Fitzroy Region?

Approach: Rank loads of tebuthiuron and Other PSII Herbicides (diuron, atrazine, ametryn, hexazinone and simazine) by basin. The loads of both types are given in Table 4.6 and plotted in Figure 4.14.

Figure 4.14 *PSII Herbicide loads in the Fitzroy Region by herbicide type*.



Conclusion: The largest loads of tebuthiuron (associated with grazing land management) in the Fitzroy region are from the Fitzroy basin. The largest loads of other PSII Herbicides (associated with other crops cultivation) are also from the Fitzroy basin.

Key findings for PSII Herbicides in the Fitzroy Region

- **The Fitzroy basin delivers more tebuthiuron (herbicide) than any of the basins considered here in the four regions, largely due to its very large size and area of grazing. An approximately equal amount of Other PSII Herbicides, mostly atrazine, derives from the large cropping area in the Fitzroy basin.**
- **The Fitzroy basin delivers more PSII Herbicides than any of the basins in the Fitzroy Region (Figure 4.12) , largely due to its much larger size and area of cropping (atrazine) and grazing (tebuthiuron) than the other basins.**
- **All of the basins in the Fitzroy Region deliver low PSII Herbicide load per basin area.**
- **The PSII Herbicides delivered from basins in the Fitzroy Region are from two land uses:**
  - **Other crops, specifically grains are the primary source of PSII herbicides (primarily atrazine and diuron) other than tebuthiuron.**
  - **Grazing lands are the primary source of tebuthiuron.**
- **The largest loads of tebuthiuron (associated with grazing land management) in the Fitzroy Region are from the Fitzroy basin. The largest loads of other PSII Herbicides (associated with Other crops cultivation) are also from the Fitzroy basin.**

4.6 Sources of information

Refer also to spreadsheet in Attachment 4.

Information	Catchments	Source
Current loads		
Suspended Sediment	Fitzroy	Dougall *et al*. (2008)
	Styx, Shoalwater, Water Park, Calliope	Brodie *et al*. (2009)
Nutrients	All	Brodie *et al*. (2009)
PSII Herbicides	All	Lewis unpublished; Packett *et al*. (2009)
Natural loads	All	Brodie *et al*. (2009)
Erosion type	Fitzroy	Dougall *et al*. (2008)
	Styx, Shoalwater, Water Park, Calliope	Assumed same as Fitzroy
Land use area	All	Brodie *et al*. (2009) (from Brodie *et al*. 2003)
Land use loads by pollutant		
Suspended Sediment	All	Brodie *et al.* (2009)
DIN	All	Brodie and Waterhouse, (2009) (Stage 1 Report)

Summary and Conclusions

Measures of the current suspended sediment, anthropogenic suspended sediment, current and anthropogenic DIN and current PSII Herbicide deliveries for the four NRM regions (Burdekin, Wet Tropics, Mackay-Whitsunday, Fitzroy) are summarised in Figures 5.1-5.4 respectively. In each of these figures, the areas of each basin are plotted in the left-hand graph, with the most relevant land uses shown by a colour key for the DIN and PSII Herbicide export figures.

Suspended Sediment

For current and anthropogenic suspended sediment loads, there is a clear, increasing relationship with basin area (Figures 5.1 and 5.2). Large basins such as the Fitzroy and most sub-basins of the Burdekin have large suspended sediment loads, while small basins generally have relatively small loads (Figure 5.5). Hence, suspended sediment load among basins is primarily determined by basin area. However, this relationship is crude and the reasonable correlation coefficient is largely driven by the points from the Fitzroy and Upper Burdekin basins. The Bowen-Bogie sub-basin with the second-largest current suspended sediment load has only a moderate-sized basin area, much smaller than those of the Upper Burdekin and Belyando sub-basins with lower current suspended sediment loads. In a similar vein, some relatively small-sized basins have moderately large suspended sediment loads (e.g. Daintree, Johnstone, Pioneer and Styx). For anthropogenic suspended sediment loads, the relationship becomes slightly stronger because of the greater similarity between the Burdekin and Fitzroy anthropogenic loads.. When suspended sediment loads are expressed on a per area basis, a poor, inverse relationship with basin area becomes apparent (Figure 5.6). This is consistent with studies of suspended sediment load versus catchment area worldwide.

Dissolved Inorganic Nitrogen

Measures of the current and anthropogenic DIN loads are clearly unrelated to basin area (Figure 5.3a,b), except in a very poor inverse relationship. Rather, DIN loads are likely determined by the area of fertiliser-additive land use in each basin and subsequent leakage from fertiliser application. Hence, the higher DIN exports are typically observed in basins with Sugar cane and Other Crops as the most important land use (Figure 5.3b). The plot of anthropogenic DIN per land-use area (Figure 5.3d) is probably more relevant than the plot of anthropogenic DIN per basin area (Figure 5.3c).

The very high DIN rate in the Lower Burdekin basin is especially emphasized by Figure 5.3d. There are a number of explanations for high rates in this basin. Aside from errors in the estimates, the recommended fertiliser-application rates in the Lower Burdekin (BRIA) are up to twice as high as other areas, due to its high yield. The actual fertilizer rates may also be considerably higher than recommended for a significant fraction of farmers, up to 600 kg N/ha (Brodie and Bainbridge, 2008), taking into account all inputs (direct fertilizer, mill mud, groundwater-derived N). By contrast to the Lower Burdekin basin, Figure 5.3d appears to reduce the DIN load per sugar cane area for the Mackay-Whitsunday basins, relative to the basins in the Wet Tropics. No explanation is offered for this, except that there may be regional differences in the treatment-measurement of similar land uses. Also, while the scale of QLUMP is relatively fine, there may be considerable amalgamation of roads, runoff, drain and other areas, perhaps up to 30%, into that which is designated as ‘sugar cane’.

The relationship between land-use area and DIN load is also given here (Figure 5.7), but only for sugar cane (Daintree south to Plane), since there is a large variation in both the application rates of fertilizer between different crops and the runoff of DIN from different crops. Even with just this single crop, there is considerable variation in the relationship. Some of this variation is understandable; for example the relatively high DIN load from the Lower Burdekin basin may be partially explained by the higher fertiliser application rates noted in this basin. When DIN loads expressed on a per sugar cane area basis are compared to sugar cane area, the overall pattern is less clear. There is no second derivative relationship between anthropogenic DIN load per area and the area of sugar cane, indicating that the delivery of DIN is efficient and little trapping occurs. Note that despite the very large area of cropping in the Fitzroy basin, the DIN export load is only moderate and the rate of DIN load per land-use area is small, suggesting that fertilizer-application rates used on grains and cotton cropping are low compared to sugar cane.

Herbicides

Measures of PSII Herbicide loads are divided at least into ‘Tebuthiuron’ and ‘Other PSII Herbicides’ (Figure 5.4). The significance of this separation is that Tebuthiuron is used almost exclusively in grazing land use, albeit at low levels, while Other PSII Herbicides, mainly diuron and/or atrazine, are used in the land uses of sugar cane and Other crops, at considerably higher application rates. The data were obtained from monitoring and modeling studies of Lewis *et al*. (2009), Lewis (unpublished) and Packett *et al*. (2009). On these estimates, tebuthiuron is a relatively minor component in most basins, only equivalent to other PSII herbicides in the Fitzroy basin (Figure 5.4). Exports of other PSII Herbicides are mostly delivered from basins in which sugar cane is the most relevant land use. The rate of total PSII Herbicide loads per basin area varies somewhat between different sugar cane cultivation basins, with the highest rates seen in the Plane and Pioneer basins.

Overall, this study has shown that it is possible with current data to identify ‘hot-spots’ of pollutant delivery to the GBR with a reasonable degree of certainty. This then allows management prioritisation. However, the results also show that in some areas data are scarce and that quantitative uncertainty estimates are still beyond our current methods to measure.

The sources of data for this report have mainly relied on Brodie *et al*. (2009) and Brodie *et al*. (2003), though a number of recent Water Quality Improvement Plan reports have also been used. In an ideal comparison, identically-derived, consistent data would be used for each of the 27 basins. The reality is that data across these many basins are inconsistent in terms of different model runs, better modeling in more recent runs and very different time periods of monitoring as the observational baseline. To emphasize the latter point, the data sets range from one year to around 20 years. Hence, data consistency between the basins is low. Also, since a number of parameters (e.g. anthropogenic loads) are estimated by differences, this introduces a much larger error. Thus, because we use anthropogenic loads as a basis for comparison between basins, there is an inherent, high degree of inconsistency and uncertainty. However, these are the only data we have available. Despite all these caveats, we consider that confidence in these estimates should be considered fair or better.

Figure 5.1 *Summary of Current suspended sediment exports for GBR catchments.*

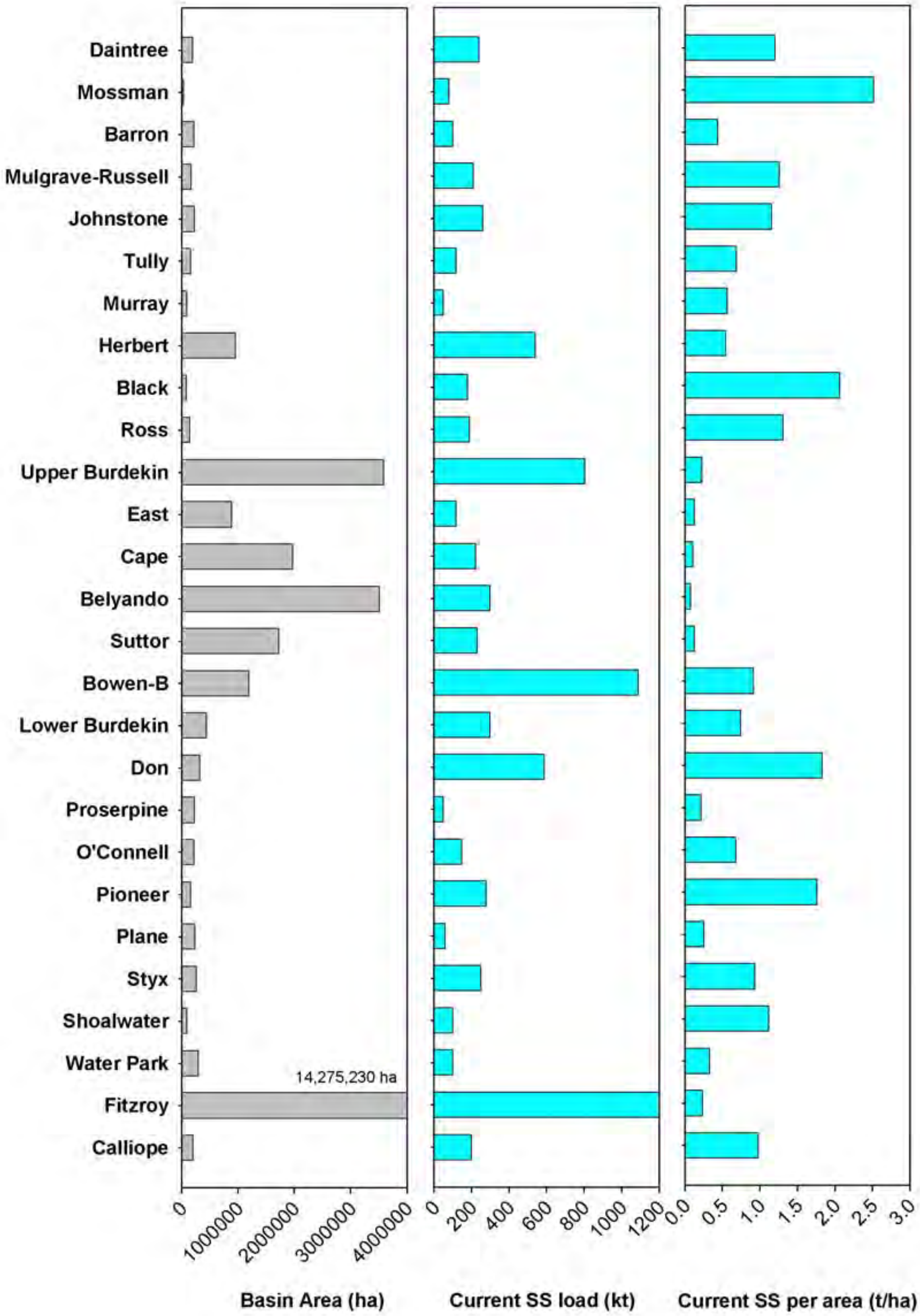


Figure 5.2 *Summary of Anthropogenic suspended sediment exports for the GBR catchments.*

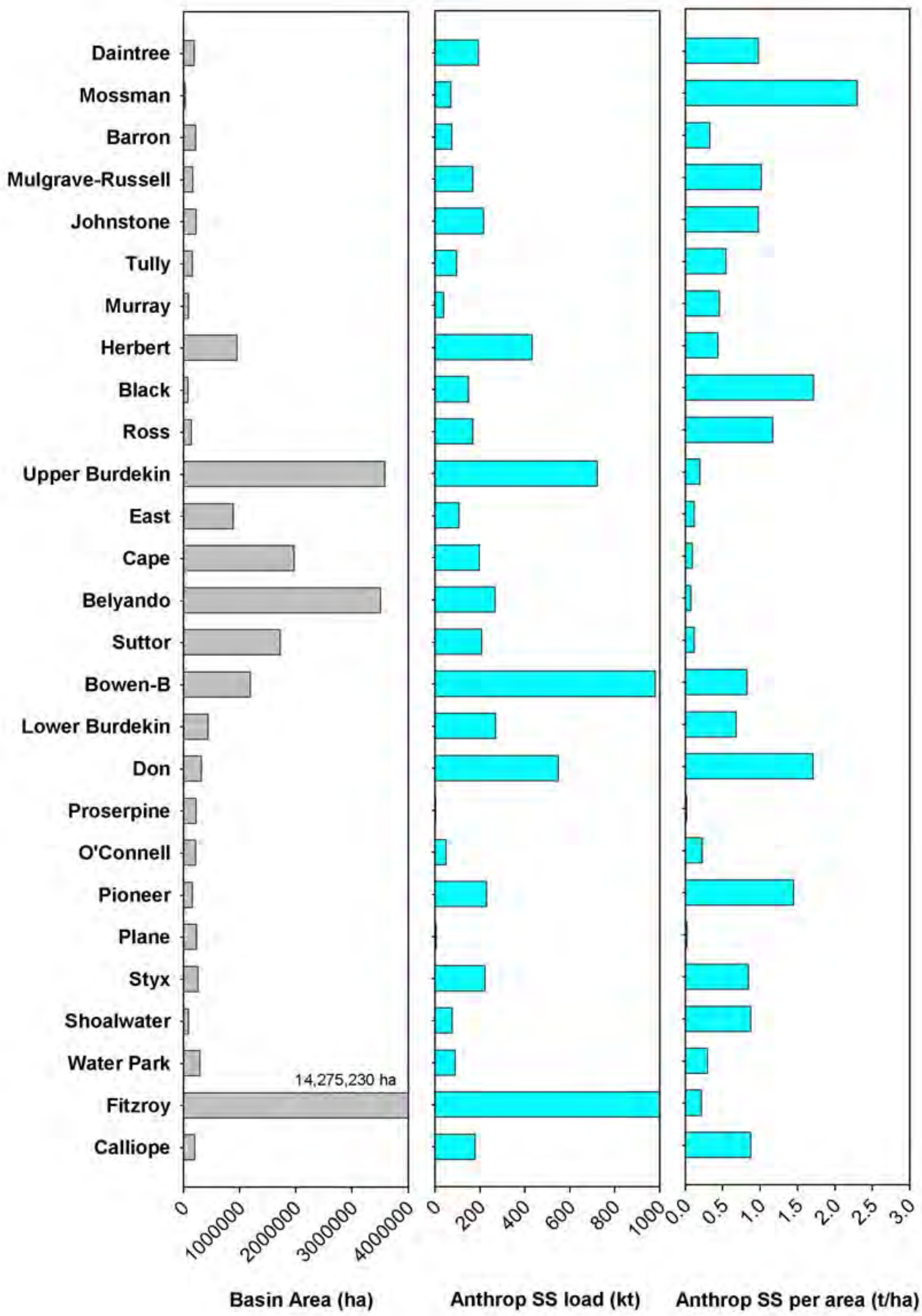


Figure 5.3 *Summary of DIN exports for GBR catchments.*

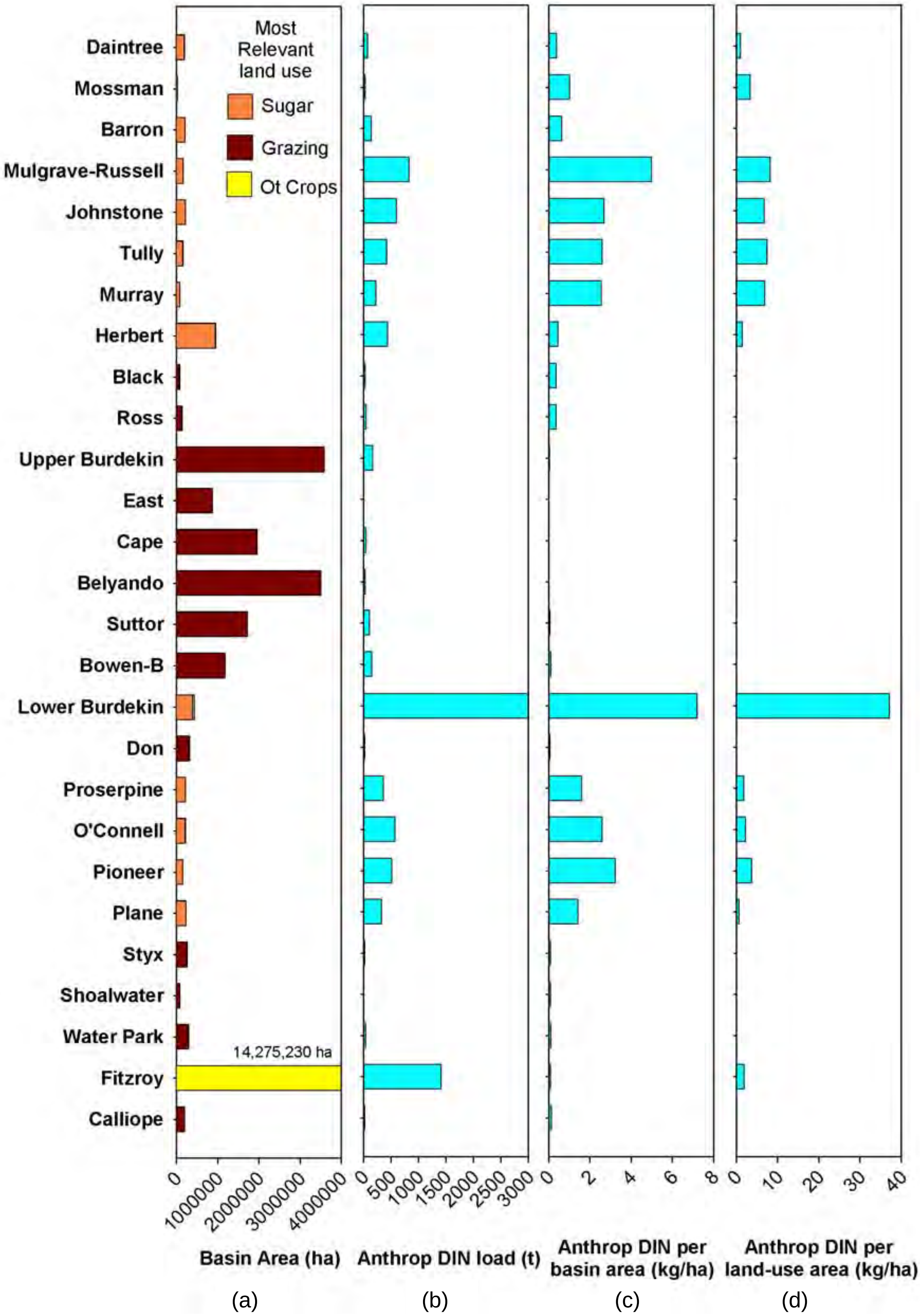


Figure 5.4 *Summary of PSII Herbicide exports for GBR catchments.*

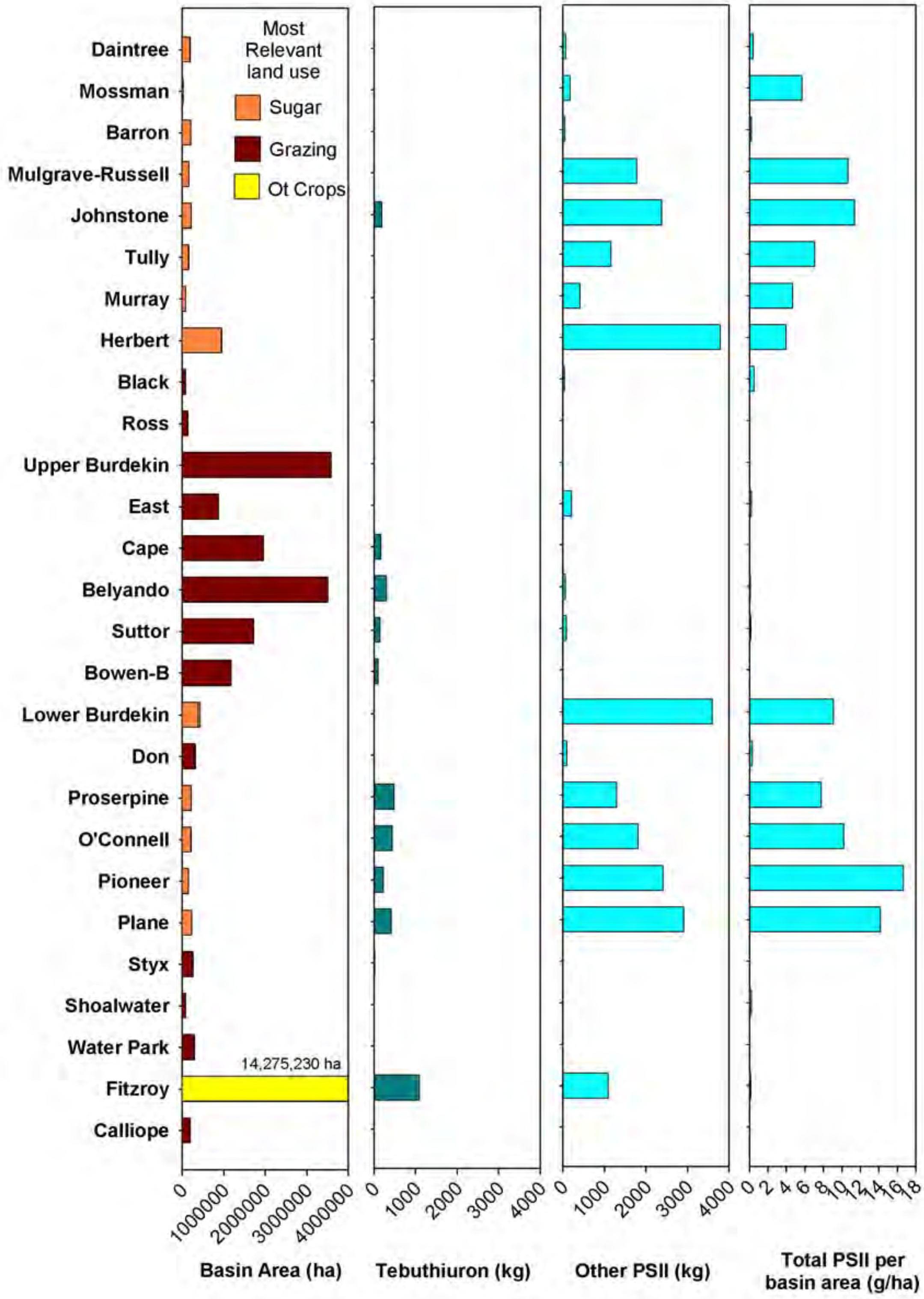
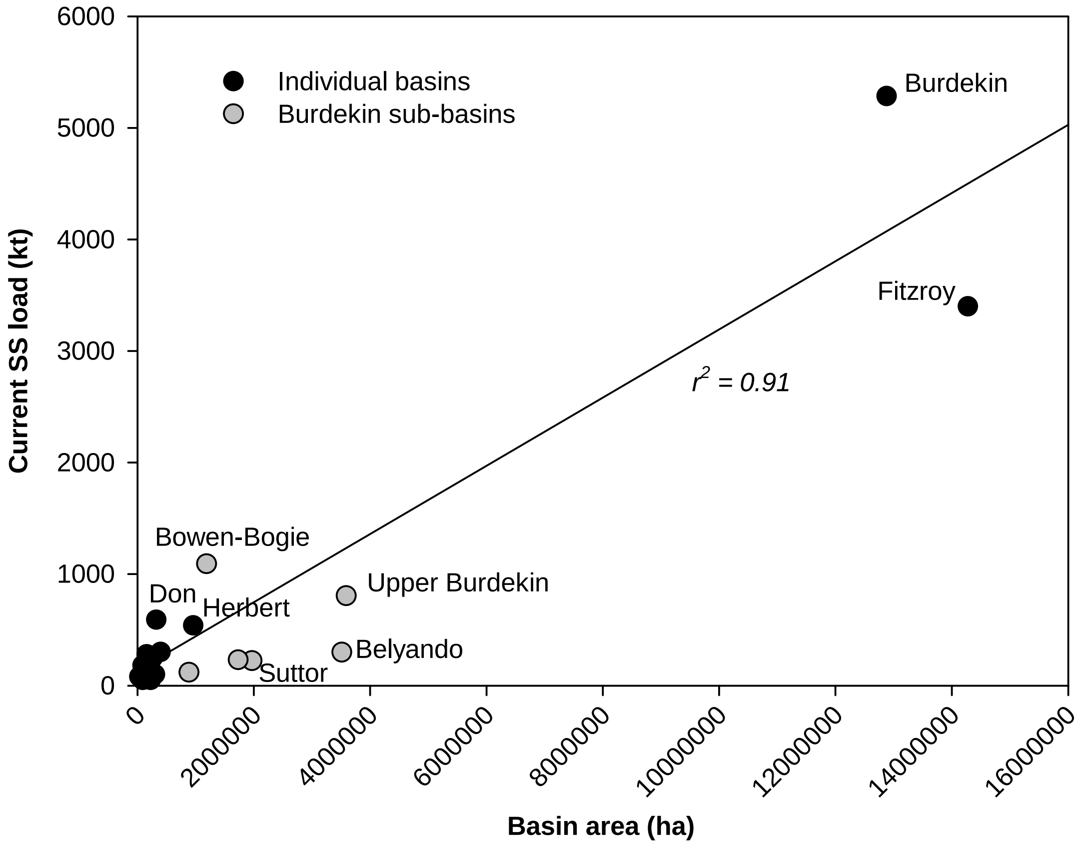


Figure 5.5 *Current and Anthropogenic suspended sediment loads (000's tonnes) versus basin area.*



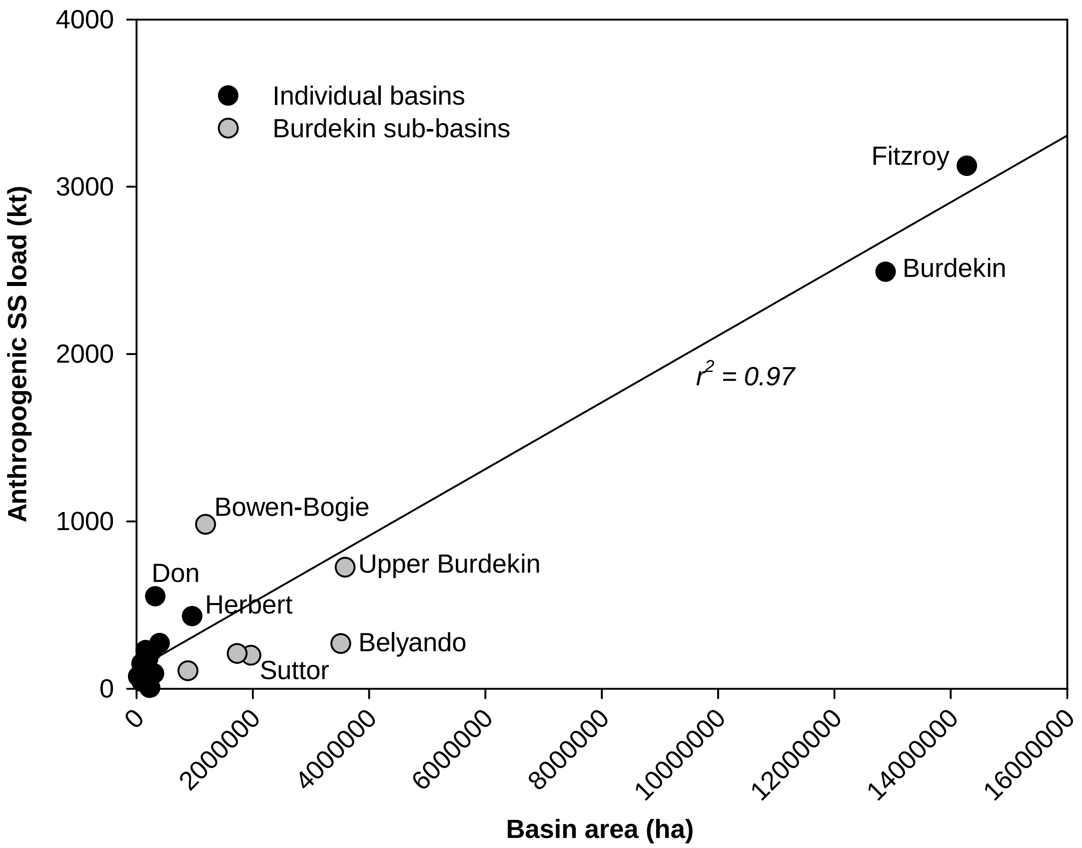
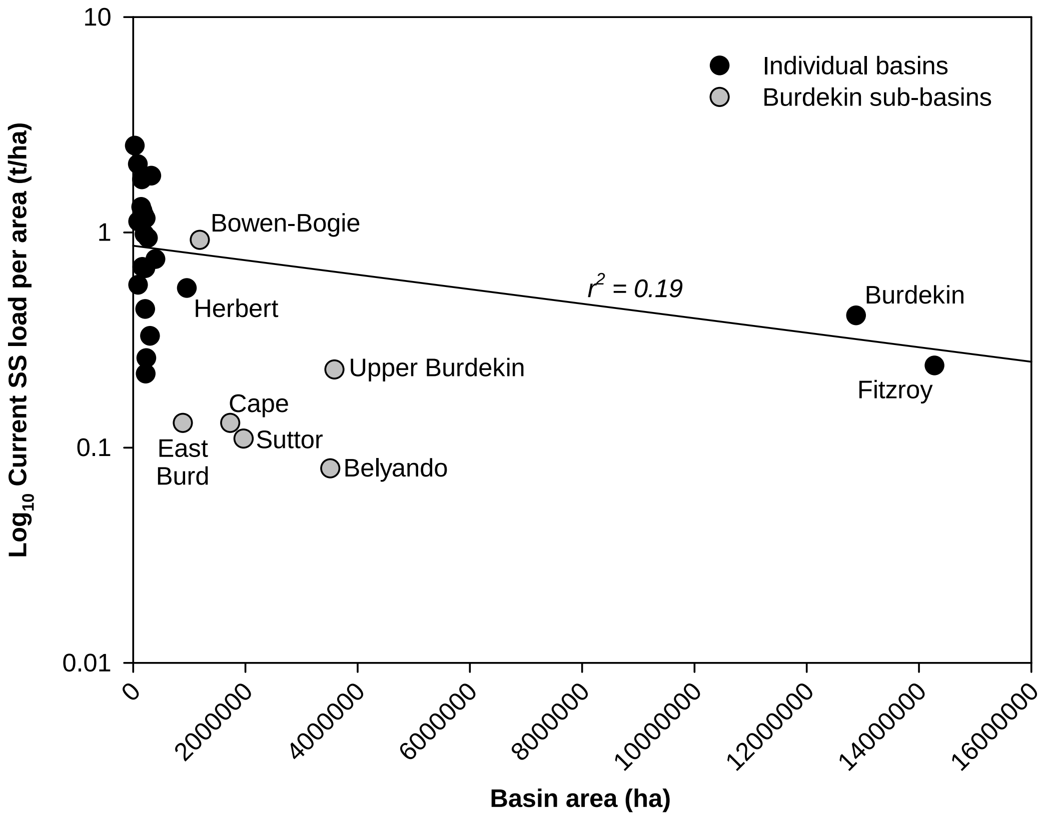


Figure 5.6 *Current and Anthropogenic suspended sediment loads per basin area (tonnes per hectare) versus basin area.*



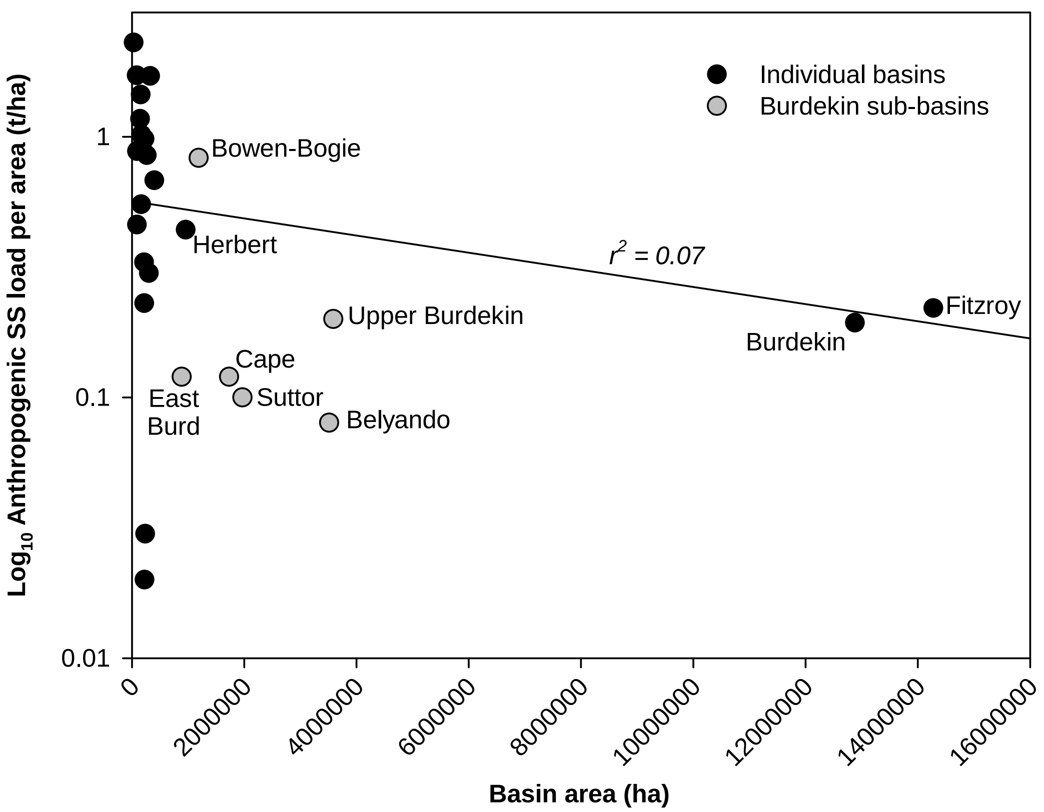
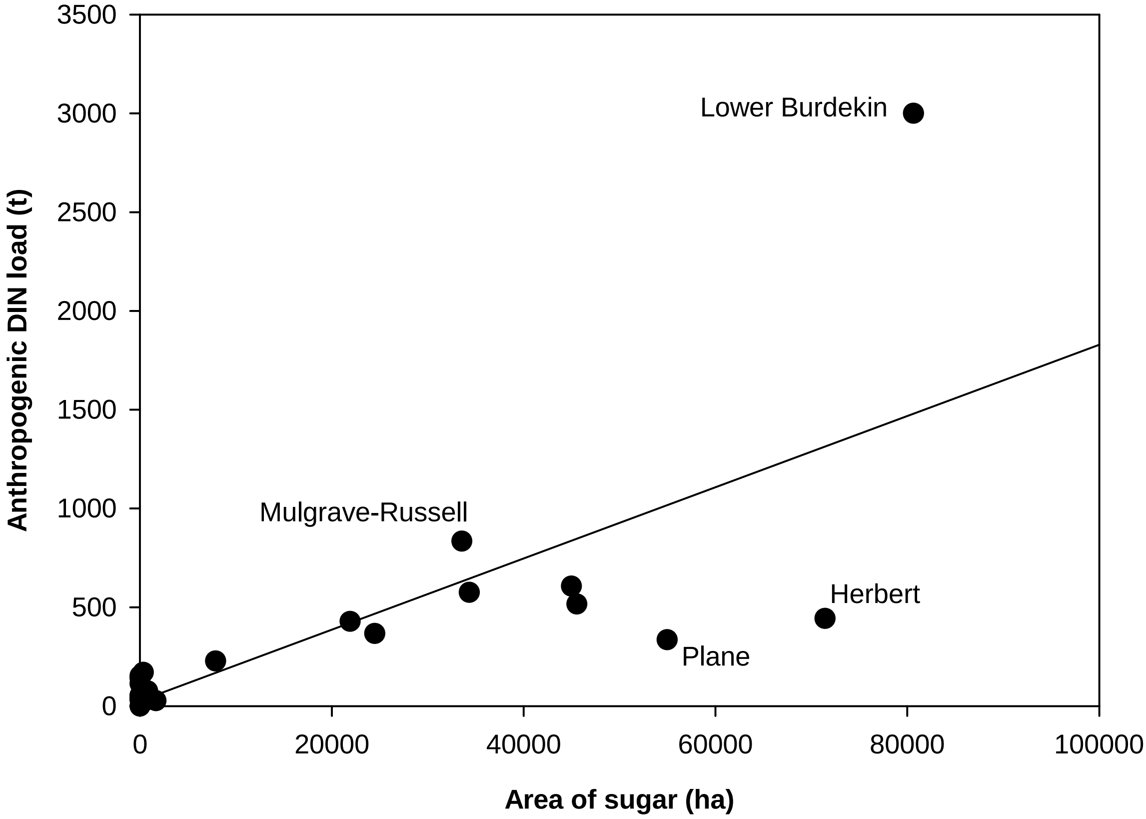
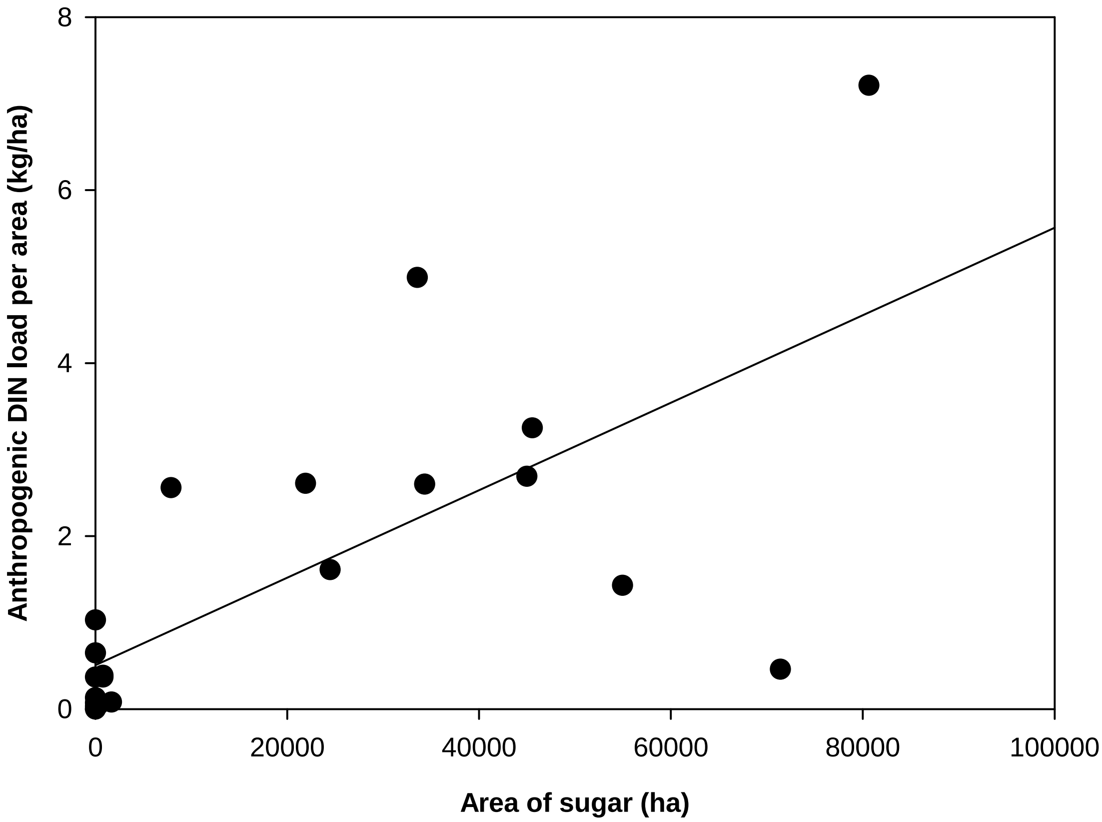


Figure 5.7 *Area of sugar* cane *(ha) versus Anthropogenic DIN load.*





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Attachment 1. Burdekin Region Load Data

Parameter	Category	Upper	East Burdekin	Cape	Belyando	Suttor	Bowen-Bogie	Lower Burdekin	Don	Black	Ross		
Burdekin Falls Dam position		**Above**	**Above**	**Above**	**Above**	**Above**	**Below**	**Adjac**	**Adjac**	**Adjac**	**Adjac**	**Total Burdekin Region**	**Reference**
Area (ha)		3,589,500	884,600	1,969,600	3,514,100	1,729,800	1,189,100	443,075	323,100	87,100	145,200	13,875,175	Derived from Brodie et al. 2003
Current Load													
TSS (000 tonnes)													
Total Erosion	Hillslope	1,174	705	269	415	257	823	584	432	146	157	**4,962**	**Kinsey-Henderson et al. 2007, Table 2**
	Gully	666	325	388	480	397	256	93	108	6	19	**2,738**	**Fentie et al 2006, Table 3.10**
	Bank	393	417	48	168	77	112	249	271	77	67	**1,879**	**Brodie et al. 2009**
Tot Inputs		**2,233**	**1,447**	**705**	**1,063**	**731**	**1,191**	**926**	**811**	**229**	**243**	**9,579**	
Export	Reservoir	0	1,050	0	0	0	12	0	0	0	0	**1,062**	
	Floodplain	218	100	151	316	151	88	267	226	47	57	**1,621**	
At end of sub-catchment	**Net Export**	**2,015**	**297**	**554**	**747**	**580**	**1,091**	**659**	**585**	**182**	**186**		
At end of river - to GBR (40%)	**Net Export**	**806**	**119**	**222**	**299**	**232**	**1,091**	**300**	**590**	**180**	**190**	**4,028**	
Current load per area (t/ha)	***Net Export***	***0.22***	***0.13***	***0.11***	***0.09***	***0.13***	***0.92***	***0.68***	***1.83***	***2.07***	***1.31***	***0.29***	
Nutrients (tonnes)													
DIN	Groundwater	2,768						1,000				**3,768**	**Brodie&Bainbridge 2008**
DIN	Surface	510	*0*	150	99	340	460	4,100	60	60	70	**5,849**	**Brodie&Bainbridge 2008**
DON	Surface	850	*-1,370*	315	545	560	380	100	100	50	50	**1,580**	**Bainbridge et al. 2007**
PN	Surface	2,140	*760*	330	600	820	1,730	400	500	300	200	**7,780**	Note: The DIN loads for the East Burdekin are based on a subtraction of monitored data for each of the other basins, from the monitored data for the whole of Burdekin. Inconsistencies in this monitoring data at different time periods produce a huge uncertainty in the estimates for the East Burdekin and our conclusion is that these
TN	Surface	**3,500**	**-739**	**795**	**1,244**	**1,720**	**2,570**	**5,600**	**660**	**410**	**320**	**16,080**	
DIP	Surface	77	*-20*	8	27	30	48	15	10	5	8	**208**	
DOP	Surface	21	*-16*	9	17	8	18	7	6	3	4	**76**	
PP	Surface	1,070	*-1,680*	110	310	420	1,130	120	150	70	50	**1,750**	
TP	Surface	**1,168**	**-1,717**	**127**	**354**	**458**	**1,196**	**142**	**166**	**78**	**62**	**2,034**	

Parameter	Category	Upper	East Burdekin	Cape	Belyando	Suttor	Bowen-Bogie	Lower Burdekin	Don	Black	Ross		
													estimates should not be used for comparison or decision making at this stage. These are reported as zero in the report.
Nutrient load per area (kg/ha)													
DIN	*Surface*	*0.14*	*0.00*	*0.08*	*0.03*	*0.20*	*0.39*	*9.25*	*0.19*	*0.69*	*0.48*	*0.42*	
PSII Herbicide (kg)	**Surface**	18	213	182	385	245	110	3,607	106	44	1	**4,910**	**Lewis, unpublished**
PSII Herbicide (g/ha)	***Surface***	*0.00*	*0.24*	*0.09*	*0.11*	*0.14*	*0.09*	*8.14*	*0.33*	*0.51*	*0.01*	***0.35***	
PSII-Tebuthiuron (kg)	**Surface**	0	0	171	311	154	105	4	0	0	0	**745**	
Other PSII Herbicides (kg)	**Surface**	18	213	11	73	91	5	3603	106	44	1	**4,165**	
Natural load													
TSS (000 tonnes)													
Tot Erosion	Hillslope							60	59	33	30		**Brodie et al. 2003**
	Gully							0	0	0	0		
	Bank							1	1	1	0		
	Total							**61**	**60**	**34**	**30**		
Export	Reservoir							0	0	0	0		
	Floodplain							31	20	4	10		
At end of river - to GBR	**Net Export**	**81**	**12**	**22**	**30**	**23**	**109**	**29**	**39**	**30**	**20**	**395**	
Natural load per area (t/ha)	***Net Export***	***0.02***	***0.01***	***0.01***	***0.01***	***0.01***	***0.09***	***0.07***	***0.12***	***0.34***	***0.14***	***0.03***	
Nutrients (tonnes)													
DIN	Groundwater												
DIN	Surface	340	0	100	66	227	307	100	33	28	16	**1,216**	
DON	Surface	567	-913	210	363	373	253	42	33	43	17	**988**	
PN	Surface	1,427	507	220	400	547	1,153	7	9	8	6	**4,283**	
TN	Surface	**2,333**	**-407**	**530**	**829**	**1,147**	**1,713**	**149**	**75**	**79**	**39**	**6,488**	
DIP	Surface	51	-14	6	18	20	32	2	1	1	0	**117**	
DOP	Surface	14	-11	6	11	5	12	4	3	4	2	**50**	

Parameter	Category	Upper	East Burdekin	Cape	Belyando	Suttor	Bowen-Bogie	Lower Burdekin	Don	Black	Ross		
PP	Surface	713	-1,120	73	207	280	753	6	6	6	3	**928**	
TP	Surface	**779**	**-1,144**	**85**	**236**	**305**	**797**	**12**	**10**	**11**	**5**	**1,095**	
PSII Herbicide (kg)	Surface	0	0	0	0	0	0	0	0	0	0	**0**	
Anthropogenic load													
TSS (000 tonnes)													
Tot Erosion	Hillslope							524	373	113	127	**1,137**	
	Gully							93	108	6	19	**226**	
	Bank							248	270	76	67	**661**	
	Total							**865**	**751**	**195**	**213**	**2,024**	
Export	Reservoir							0	0	0	0	**0**	
	Floodplain							236	206	43	47	**532**	
At end of river - to GBR	**Net Export**	**725**	**107**	**199**	**269**	**209**	**982**	**271**	**551**	**150**	**170**	**3,633**	
Anthropogenic load per area (t/ha)	***Net Export***	***0.20***	***0.12***	***0.10***	***0.08***	***0.12***	***0.83***	***0.61***	***1.71***	***1.72***	***1.17***	***0.26***	
Nutrients (tonnes)													
DIN	Groundwater												
DIN	Surface	170	0	50	33	113	153	3,000	27	32	54	**3,632**	
DON		283	-457	105	182	187	127	58	67	7	33	**592**	
PN		713	253	110	200	273	577	393	491	292	194	**3,497**	
TN								**5,451**	**585**	**331**	**281**	**6,648**	
DIP		26	-7	3	9	10	16	13	9	4	8	**91**	
DOP		7	-5	3	6	3	6	3	3	-1	2	**26**	
PP		357	-560	37	103	140	377	114	144	64	47	**822**	
TP								**130**	**156**	**67**	**57**	**410**	
Nutrient load per area (kg/ha)													
DIN	Surface	0.05	0.00	0.03	0.01	0.07	0.13	6.77	0.08	0.37	0.37	0.26	
PSII Herbicide (kg)													

Parameter	Category	Upper	East Burdekin	Cape	Belyando	Suttor	Bowen-Bogie	Lower Burdekin	Don	Black	Ross		
Total PSII Herbicide (kg)		18	213	182	385	245	110	3,607	106	44	1	**4,910**	
PSII Herbicide per area (g/ha)		*0.00*	*0.24*	*0.09*	*0.11*	*0.14*	*0.09*	*8.14*	*0.33*	*0.51*	*0.01*	***0.35***	
PSII-Tebuthiuron (kg)	**Surface**	0	0	171	311	154	105	4	0	0	0	**745**	
Other PSII Herbicides (kg)	**Surface**	18	213	11	73	91	5	3603	106	44	1	**4,165**	

Attachment 2: Wet Tropics Region Load Data

Parameter	Category	Daintree	Mossman	Barron	Mulgrave-Russell	Johnstone	Tully	Murray	Herbert	Wet Tropics	Reference
Basin Area (ha)		199,650	31,770	225,600	166,400	223,990	174,240	88,290	980,600	**2,090,540**	**Brodie et al. 2003**
Current Load											
TSS (000 tonnes)		**212**	**53**	**169**	**270**	**346**	192	**67**	**777**	**2,086**	**Hateley et al. 2006**
Total Erosion	Hillslope	155	31	103	159	149	86	48	427	**1,158**	
	Gully	0	1	25	5	24	6	3	179	**243**	
	Bank	55	22	41	105	173	100	16	171	**683**	
Tot Inputs		**210**	**53**	**169**	**270**	**346**	**192**	**67**	**777**	**2,084**	
At end of river - to GBR	**Net Export**	**240**	**80**	**100**	**210**	**260**	**120**	**50**	**540**	**1,600**	**Brodie et al. 2009**
Current load per area (t/ha)	***Net Export***	***1.20***	***2.52***	***0.44***	***1.26***	***1.16***	***0.69***	***0.57***	***0.55***	***0.77***	
Nutrients (tonnes)											
DIN	Groundwater										
DIN	Surface	200	50	200	1,000	850	600	300	700	**3,900**	
DON	Surface	250	*50*	150	500	400	250	150	500	**2,250**	
PN	Surface	300	*100*	150	700	1,000	450	170	700	**3,570**	
TN	Surface	**750**	**200**	**500**	**2,200**	**2,250**	**1,300**	**620**	**1,900**	**9,720**	
DIP	Surface	10	*2*	5	20	20	20	10	20	**107**	
DOP	Surface	15	*5*	25	50	60	15	8	30	**208**	
PP	Surface	80	*20*	40	250	300	90	40	200	**1,020**	
TP	Surface	**105**	**27**	**70**	**320**	**380**	**125**	**58**	**250**	**1,335**	
Nutrient load per area (kg/ha)											
DIN	*Surface*	*1.00*	*1.57*	*0.89*	*6.01*	*3.79*	*3.44*	*3.40*	*0.71*	***1.87***	
DON	Surface	1.25	1.57	0.66	3.00	1.79	1.43	1.70	0.51	**1.08**	
PN	Surface	1.50	3.15	0.66	4.21	4.46	2.58	1.93	0.71	**1.71**	
TN	Surface	**3.76**	**6.30**	**2.22**	**13.22**	**10.05**	**7.46**	**7.02**	**1.94**	**4.65**	
DIP	Surface	0.05	0.06	0.02	0.12	0.09	0.11	0.11	0.02	**0.05**	
DOP	Surface	0.08	0.16	0.11	0.30	0.27	0.09	0.09	0.03	**0.10**	
PP	Surface	0.40	0.63	0.18	1.50	1.34	0.52	0.45	0.20	**0.49**	
TP	Surface	**0.53**	**0.85**	**0.31**	**1.92**	**1.70**	**0.72**	**0.66**	**0.25**	**0.64**	
PSII Herbcide (kg)											
Total PSII Herbicide (kg)	Surface	84	181	52	1,780	2,578	1,162	418	3,799	**10,055**	**Lewis, unpublished**
PSII Herbicide (g/ha)	*Surface*	*0.42*	*5.71*	*0.23*	*10.70*	*11.51*	*6.67*	*4.74*	*3.87*	***4.81***	
Tebuthiuron (kg)	Surface	0	0	0	0	193	0	0	0	**193**	

Parameter	Category	Daintree	Mossman	Barron	Mulgrave-Russell	Johnstone	Tully	Murray	Herbert	Wet Tropics	Reference
Other PSII Herbicides (kg)	Surface	84	181	52	1780	2385	1162	418	3799	**9862**	
Natural load											
TSS (000 tonnes)											
Tot Erosion	Hillslope	34	6	21	36	24	15	9	114	**259**	**Brodie et al. 2003**
	Gully	0	0	0	0	0	0	0	0	**0**	
	Bank	25	3	15	15	37	21	2	37	**155**	
	Total	**59**	**9**	**36**	**51**	**61**	**36**	**11**	**151**	**414**	
At end of river - to GBR	**Net Export**	**45**	**7**	**25**	**41**	**41**	**24**	**9**	**107**	**299**	
Natural load per area (t/ha)	***Net Export***	***0.23***	***0.22***	***0.11***	***0.25***	***0.18***	***0.14***	***0.10***	***0.11***	***0.14***	
Nutrients (tonnes)											
DIN	Groundwater										
DIN	Surface	123	17	59	166	243	172	72	257	**1,109**	
DON	Surface	426	46	152	566	825	523	158	442	**3,138**	
PN	Surface	22	4	13	23	26	14	4	47	**153**	
TN	Surface	**571**	**67**	**224**	**755**	**1,094**	**709**	**234**	**746**	**4,400**	
DIP	Surface	9	1	3	14	26	17	8	10	**88**	
DOP	Surface	29	3	11	38	56	36	12	36	**221**	
PP	Surface	25	3	12	32	38	25	8	47	**190**	
TP	Surface	**63**	**7**	**26**	**84**	**120**	**78**	**28**	**93**	**499**	
PSII Herbicide (kg)	**Surface**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
Anthropogenic load	Note: Refer to the complete report for anthropogenic loads as different methods have been used to determine load by land use										
TSS (000 tonnes)											
Tot Erosion	Hillslope	121	25	82	123	125	71	39	313	**899**	
	Gully	0	1	25	5	24	6	3	179	**243**	
	Bank	30	19	26	90	136	79	14	134	**528**	
	Total	**151**	**44**	**133**	**219**	**285**	**156**	**56**	**626**	**1,670**	
At end of river - to GBR	**Net Export**	**195**	**73**	**75**	**169**	**219**	**96**	**41**	**433**	**1,301**	
Anth load per area (t/ha)	***Net Export***	***0.98***	***2.30***	***0.33***	***1.02***	***0.98***	***0.55***	***0.46***	***0.44***	***0.62***	
Nutrients (tonnes)											
DIN	Groundwater										
DIN	Surface	77	33	141	834	607	428	228	443	**2,791**	
DON	Surface	-176	4	-2	-66	-425	-273	-8	58	**-888**	

Parameter	Category	Daintree	Mossman	Barron	Mulgrave-Russell	Johnstone	Tully	Murray	Herbert	Wet Tropics	Reference
PN	Surface	278	96	137	677	974	436	166	653	**3,417**	
TN	Surface	**179**	**133**	**276**	**1,445**	**1,156**	**591**	**386**	**1,154**	**5,320**	
DIP	Surface	1	1	2	6	-6	3	2	10	**19**	
DOP	Surface	-14	2	14	12	4	-21	-4	-6	**-13**	
PP	Surface	55	17	28	218	262	65	32	153	**830**	
TP	Surface	**42**	**20**	**44**	**236**	**260**	**47**	**30**	**157**	**836**	
Nutrient load/area (kg/ha)											
DIN	Surface	0.39	1.04	0.63	5.01	2.71	2.46	2.58	0.45	**1.34**	
DON	Surface	-0.88	0.13	-0.01	-0.40	-1.90	-1.57	-0.09	0.06	**-0.42**	
PN	Surface	1.39	3.02	0.61	4.07	4.35	2.50	1.88	0.67	**1.63**	
TN	**Surface**	**0.90**	**4.19**	**1.22**	**8.68**	**5.16**	**3.39**	**4.37**	**1.18**	**2.54**	
DIP	Surface	0.01	0.03	0.01	0.04	-0.03	0.02	0.02	0.01	**0.01**	
DOP	Surface	-0.07	0.06	0.06	0.07	0.02	-0.12	-0.05	-0.01	**-0.01**	
PP	Surface	0.28	0.54	0.12	1.31	1.17	0.37	0.36	0.16	**0.40**	
TP	**Surface**	**0.21**	**0.63**	**0.20**	**1.42**	**1.16**	**0.27**	**0.34**	**0.16**	**0.40**	
PSII Herbicide (kg)											
Tebuthiuron	Surface	0	0	0	0	193	0	0	0	**193**	
Diuron	Surface	51	110	21	1,079	1,445	704	253	2,296	**5,960**	
Atrazine	Surface	24	52	25	513	687	335	120	1,099	**2,855**	
Hexazinone	Surface	8	17	3	164	219	107	39	348	**904**	
Ametryn	Surface	1	3	0	25	34	17	6	54	**140**	
Simazine	Surface	0	0	2	0	0	0	0	1	**3**	
Total PSII Herbicide (kg)	**Surface**	**84**	**181**	**52**	**1,780**	**2,578**	**1,162**	**418**	**3,799**	**10,055**	
PSII Herbicide (g/ha)	***Surface***	***0.42***	***5.71***	***0.23***	***10.70***	***11.51***	***6.67***	***4.74***	***3.87***	***4.81***	

Attachment 3: Mackay Whitsunday Region Load Data

Parameter	Category	Proserpine	O'Connell	Pioneer	Plane	Mack-Whit Total	Reference
Basin Area (ha)	Land use calcs	202,090	208,430	168,720	175,470	**754,710**	**Brodie et al. 2003**
Basin Area (ha)	Catchment calcs	227,470	221,020	159,020	234,700	**842,210**	**Drewry et al. 2008**
Current Load							
TSS (000 tonnes)							
Total Erosion	Hillslope	358	581	473	614	**2,026**	
	Gully	20	20	16	18	**74**	
	Bank	23	98	134	16	**271**	
Tot Inputs		**401**	**699**	**623**	**648**	**2,371**	
Export	Reservoir	52	0	284	49	**385**	
	Floodplain	35	74	36	47	**192**	
At end of river - to GBR	**Current Net Export**	**50**	**150**	**280**	**60**	**540**	**Brodie et al. 2009**
Current load per area (t/ha)	***Current export load/area***	***0.22***	***0.68***	***1.76***	***0.26***	***0.64***	
Nutrients (tonnes)							
DIN	Groundwater						
DIN	Surface	450	700	600	430	**2,180**	Note: This is taken from Brodie et al 2003 - variations exist between catchment boundaries in Drewry et al 2008 and Brodie et al 2003 (& 2009). As the latter is the most accessible land use data; used Brodie et al 2003 load estimate for DIN.
DON	Surface	160	250	120	200	**730**	
PN	Surface	200	400	800	200	**1,600**	
TN	Surface	**810**	**1,350**	**1,520**	**830**	**4,510**	
DIP	Surface	50	50	100	50	**250**	
DOP	Surface	10	15	50	15	**90**	
PP	Surface	50	150	300	100	**600**	
TP	Surface	**110**	**215**	**450**	**165**	**940**	
Nutrient load per area (kg/ha)							
DIN	Surface	2.23	3.36	3.56	2.45	**2.89**	
DON	Surface	0.79	1.20	0.71	1.14	**0.97**	
PN	Surface	0.99	1.92	4.74	1.14	**2.12**	
TN	Surface	**4.01**	**6.48**	**9.01**	**4.73**	**5.98**	
DIP	Surface	0.25	0.24	0.59	0.28	**0.33**	
DOP	Surface	0.05	0.07	0.30	0.09	**0.12**	
PP	Surface	0.25	0.72	1.78	0.57	**0.80**	
TP	Surface	**0.54**	**1.03**	**2.67**	**0.94**	**1.25**	
PSII Herbicide (kg)	Surface	1,782	2,260	2,648	3,329	**10,020**	**Lewis, unpublished**
PSII Herbicide (g/ha)	*Surface*	*8.82*	*10.84*	*15.70*	*18.97*	***13.28***	
Natural load							
TSS (000 tonnes)							
Tot Erosion	Hillslope	34	6	21	36	**97**	
	Gully	0	0	0	0	**0**	
	Bank	25	3	15	15	**58**	
	Total	**59**	**9**	**36**	**51**	**155**	
At end of river - to GBR	**Net Export**	45	99	50	54	**248**	

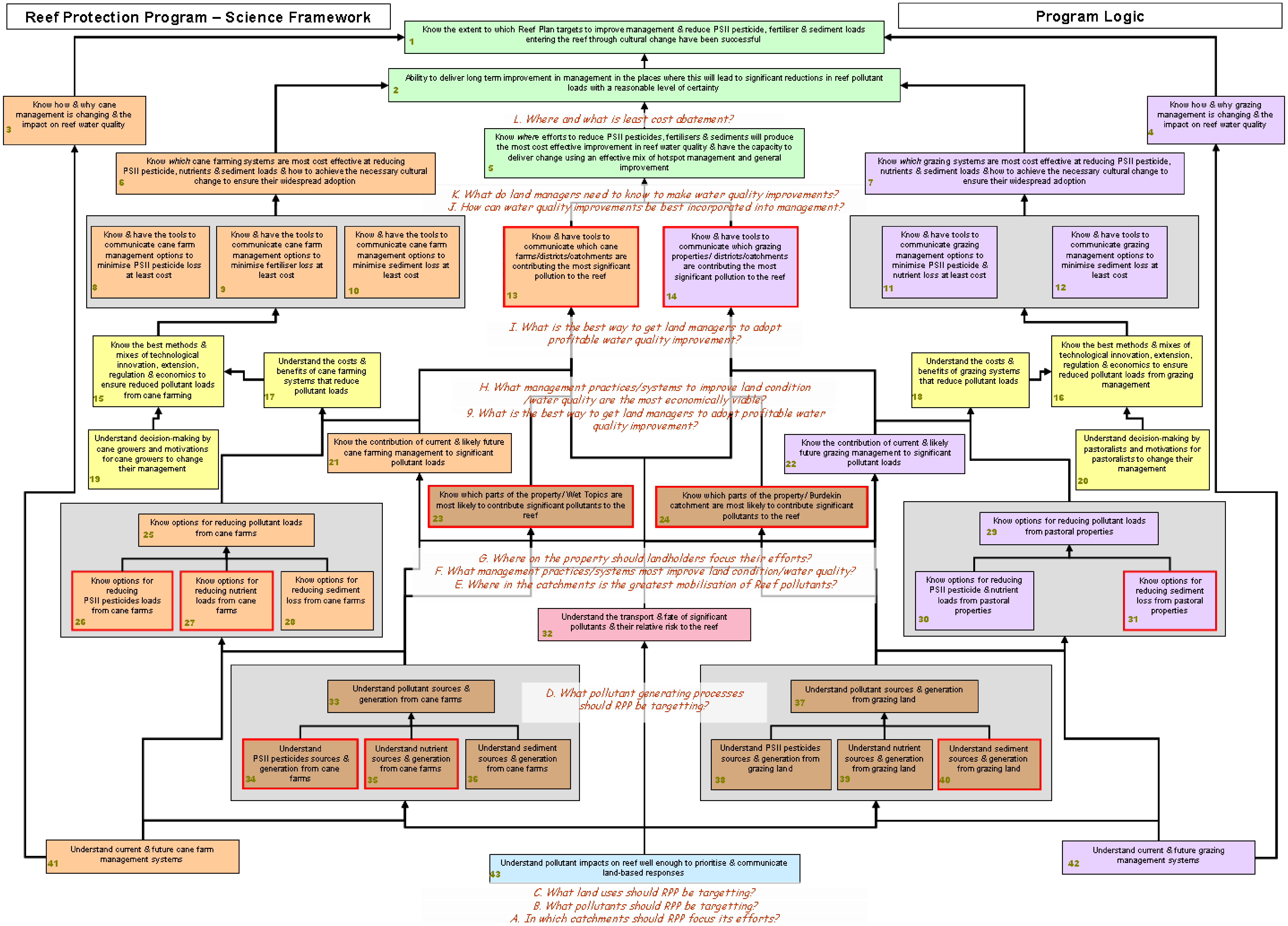
Parameter	Category	Proserpine	O'Connell	Pioneer	Plane	Mack-Whit Total	Reference
Natural load per area (t/ha)	***Net Export***	*0.20*	*0.45*	*0.31*	*0.23*	***0.29***	
Nutrients (tonnes)							
DIN	Groundwater						
DIN	Surface	83	125	84	**95**	**387**	
DON	Surface	111	152	111	103	**477**	
PN	Surface	9	18	10	11	**48**	
TN	Surface	**203**	**295**	**205**	**209**	**912**	
DIP	Surface	4	4	2	4	**14**	
DOP	Surface	10	14	10	10	**44**	
PP	Surface	19	31	22	20	**92**	
TP	Surface	**33**	**49**	**34**	**34**	**150**	
PSII Herbicide (kg)	Surface	**0**	**0**	**0**	**0**	**0**	
Anthropogenic load							
TSS (000 tonnes)							
Tot Erosion	Hillslope	324	575	452	578	**1,929**	
	Gully	20	20	16	18	**74**	
	Bank	-2	95	119	1	**213**	
	Total	342	690	587	597	**2,216**	
At end of river - to GBR	Surface	**5**	**51**	**230**	**6**	**292**	
Anthropogenic load per area (t/ha)	*Surface*	***0.02***	***0.23***	***1.45***	***0.03***	***0.35***	
Nutrients (tonnes)							
DIN	Groundwater						
DIN	Surface	**367**	**575**	**516**	**335**	**1,793**	
DON	Surface	49	98	9	97	**253**	
PN	Surface	191	382	790	189	**1,552**	
TN	Surface	**607**	**1,055**	**1,315**	**621**	**3,598**	
DIP	Surface	46	46	98	46	**236**	
DOP	Surface	0	1	40	5	**46**	
PP	Surface	31	119	278	80	**508**	
TP	Surface	**77**	**166**	**416**	**131**	**790**	
Nutrient load/area (kg/ha)							
DIN	*Surface*	*1.82*	*2.76*	*3.06*	*1.91*	***2.38***	
DON	Surface	0.24	0.47	0.05	0.55	**0.34**	
PN	Surface	0.95	1.83	4.68	1.08	**2.06**	
TN	Surface	**3.00**	**5.06**	**7.79**	**3.54**	**4.77**	
DIP	Surface	0.23	0.22	0.58	0.26	**0.31**	
DOP	Surface	0.00	0.00	0.24	0.03	**0.06**	
PP	Surface	0.15	0.57	1.65	0.46	**0.67**	
TP	Surface	**0.38**	**0.80**	**2.47**	**0.75**	**1.05**	
PSII Herbicide (kg)							
Tebuthiuron	Surface	483	439	233	415	**1569**	
Diuron	Surface	787	1103	1463	1766	**5119**	
Atrazine	Surface	375	525	695	839	**2434**	
Hexazinone	Surface	119	168	222	268	**777**	
Ametryn	Surface	19	26	34	42	**121**	
Simazine	Surface	0	0	0	0	**0**	
PSII Herbicide (kg)	Surface	**1,782**	**2,260**	**2,648**	**3,329**	**10,020**	
PSII Herbicide (g/ha)	*Surface*	***8.82***	***10.84***	***15.70***	***18.97***	***13.28***	

Attachment 4: Fitzroy Region Load Data

Parameter	Category	Styx	Shoalwater	Water Park	Fitzroy	Calliope	Total Fitzroy	Reference
Basin Area (ha)		266,260	88,890	299,350	14,275,230	204,310	15,134,040	**Brodie et al. 2009**
Current Load								
TSS (000 tonnes)								
Total Erosion	Hillslope				3,645			**Dougall et al. 2008**
	Gully				1,450			
	Bank				383			
Tot Inputs					**5,479**			
Export	Reservoir				2,070			
	Floodplain				0			
At end of river - to GBR	**Net Export**	**250**	**100**	**100**	**3,400**	**200**	**4,050**	**Brodie et al. 2009**
Current load per area (t/ha)	***Net Export***	***0.94***	***1.12***	***0.33***	***0.24***	***0.98***	***0.27***	
Nutrients (tonnes)								
DIN	Groundwater							
DIN	Surface	50	50	80	1,500	50	**1,730**	
DON	Surface	150	150	130	2,500	50	**2,980**	
PN	Surface	600	500	400	8,000	300	**9,800**	
TN	Surface	**800**	**700**	**610**	**12,000**	**400**	**14,510**	
DIP	Surface	20	20	20	300	5	**365**	
DOP	Surface	10	10	10	70	3	**103**	
PP	Surface	200	150	100	3,000	100	**3,550**	
TP	Surface	**230**	**180**	**130**	**3,370**	**108**	**4,018**	
Nutrient load/area (kg/ha)								
DIN	*Surface*	*0.19*	*0.56*	*0.27*	*0.11*	*0.24*	*0.11*	
PSII Herbicide (kg)								
PSII Herbicide (kg)	Surface	23	20	12	2,196	17	2,268	**Lewis, unpublished**
PSII per area (g/ha)	*Surface*	*0.1*	*0.2*	*0.0*	*0.2*	*0.1*	*0.1*	
Natural load								
TSS (000 tonnes)								
Tot Erosion	Hillslope							
	Gully							
	Bank							
	Total							
Export	Reservoir							
	Floodplain							
At end of river - to GBR	**Net Export**	**25**	**22**	**10**	**275**	**20**	**352**	
Natural load per area (t/ha)	***Net Export***	***0.09***	***0.25***	***0.03***	***0.02***	***0.10***	***0.02***	
Nutrients (tonnes)								
DIN	Groundwater							
DIN	Surface	23	41	41	607	20	**732**	
DON	Surface	24	41	41	634	21	**761**	
PN	Surface	5	5	4	70	5	**89**	
TN	Surface	**52**	**87**	**86**	**1,311**	**46**	**1,582**	
DIP	Surface	1	1	7	7	0	**16**	
DOP	Surface	2	4	4	62	2	**74**	

Parameter	Category	Styx	Shoalwater	Water Park	Fitzroy	Calliope	Total Fitzroy	Reference
PP	Surface	5	7	6	75	4	**97**	
TP	Surface	**8**	**12**	**17**	**144**	**6**	**187**	
Nutrient load/area (kg/ha)								
DIN	*Surface*	*0.09*	*0.46*	*0.14*	*0.04*	*0.10*	*0.05*	
PSII Herbicide (kg)	Surface	**0**	**0**	**0**	**0**	**0**	**0**	
Anthropogenic load								
TSS (000 tonnes)								
Tot Erosion	Hillslope							
	Gully							
	Bank							
	Total							
Export	Reservoir							
	Floodplain							
At end of river - to GBR	**Net Export**	**225**	**78**	**90**	**3,125**	**180**	**3,698**	
Anthropogenic load per area (t/ha)	***Net Export***	***0.85***	***0.88***	***0.30***	***0.22***	***0.88***	***0.24***	
Nutrients (tonnes)								
DIN	Groundwater							
DIN	Surface	27	9	39	893	30	**998**	
DON	Surface	126	109	89	1,866	29	**2,219**	
PN	Surface	595	495	396	7,930	295	**9,711**	
TN	Surface	**748**	**613**	**524**	**10,689**	**354**	**12,928**	
DIP	Surface	19	19	13	293	5	**349**	
DOP	Surface	8	6	6	8	1	**29**	
PP	Surface	195	143	94	2,925	96	**3,453**	
TP	Surface	**222**	**168**	**113**	**3,226**	**102**	**3,831**	
Nutrient load/area (kg/ha)								
DIN	*Surface*	**0.10**	**0.10**	**0.13**	**0.06**	**0.15**	**0.07**	
PSII Herbicide (kg)								
Tebuthiuron (kg)	Surface	23	7	12	1,098	17	1,157	
Other PSII Herbicides (kg)	Surface	0	13	0	1,098	0	1,112	
Total PSII Herbicide (kg)	Surface	**23**	**20**	**12**	**2,196**	**17**	**2,268**	
Total PSII Herbicide per area (g/ha)	Surface	***0.09***	***0.22***	***0.04***	***0.15***	***0.08***	***0.15***	

ROBERT SPEIRS STATEMENT ATTACHEMENT 10



Project No.	**Project Title & Location** *(Regulated catchments - Wet Tropics, Burdekin Dry Tropics, Mackay Whitsundays)*	**Project Description**
RP51C	Groundwater as a pollutant pathway to the Great Barrier Reef: a review of current knowledge – Regulated catchments	The surface pathways for pollutants reaching the Great Barrier Reef through streams and overland flow are well known, but little is known about subsurface pathways, and how important these are to total pollutant loads. This project will review and synthesise existing knowledge about the location, nature and function of groundwater systems draining to the Reef in order to identify and prioritise further research into groundwater pollutant pathways as well as identifying where excess fertilisers and pesticides potentially could enter the Reef through the groundwater. This will inform and focus delivery of extension advice about what on farm management practices could minimise this risk. It will also inform the Paddock to Reef modelling program's assessment of pollutant pathways, and hence its ability to measure progress towards targets for reducing nutrient and pesticide reaching the Reef.
RP52C	Options for treating pollutants in run-off from cane farms – Regulated catchments	Where cane farms use fertilisers and nutrients excess to crop needs, some pollutants will inevitably be found in run-off. There are a number of ways losses of these pollutants to waterways can be reduced, such as through vegetated treatment areas or sediment traps. This project will examine end-of-paddock options for trapping sediments, nutrients and pesticides from cane farms in tropical conditions. It will use scientific evidence to provide practical advice to cane growers about solutions to minimise pollutant loads that are suited to local environmental conditions.
RP53C	Groundwater pollutant transport – Burdekin Dry Tropics	Only recently has it become apparent that groundwaters may be an important pathway for pollution reaching the Reef. This project will monitor the prevalence of PSII pesticides and nutrients in groundwater associated with sugar cane cropping, as well as their transport to rivers, by sampling four sites in the lower Burdekin. This work will improve our understanding of the movement of pollutants through groundwater systems, informing the Paddock to Reef modelling program's assessment of pollutant pathways, and hence its ability to measure progress towards targets for reducing nutrient and pesticide reaching the Reef. The results will also inform the development of extension advice about what on farm management practices could minimise this risk, if required.
RP54C	Baseline groundwater pesticide data – Burdekin Dry Tropics and Wet Tropics	This project will undertake a preliminary assessment of the occurrence of pesticides in groundwater in the Lower Burdekin and Wet Tropics, which may impact on the Great Barrier Reef. It will do this by undertaking one-off measurements of concentrations of pesticides in groundwater aquifers associated with cane farms. These measurements will also provide a baseline for assessing the impact of management practice change on loss of pesticides to the Reef through groundwater pathways. The results will also inform the Paddock to Reef modelling program's assessment of pollutant pathways, and hence its ability

Project No.	Project Title & Location *(Regulated catchments - Wet Tropics, Burdekin Dry Tropics, Mackay Whitsundays)*	Project Description
		to measure progress towards targets for reducing nutrient and pesticide reaching the Reef.
RP55C	Environmental characteristics mapping of cane lands – Burdekin Dry Tropics and Mackay-Whitsundays	The likelihood of pollutants reaching the Great Barrier Reef from cane farms is affected by a number of environmental characteristics, such as drainage patterns, soil type and slope. This project will develop property-level maps of environmental characteristics that influence pollutant transport through overland flow. These maps will help Reef Protection Officers identify issues that may need to be discussed with growers to reduce losses from their properties of nutrients, pesticides and sediments to the Great Barrier Reef. The project extends a service that has already been developed for the Wet Tropics to support risk planning on property to the remaining regulated catchments with the focus of providing additional support to meeting existing nutrient and herbicide legislative requirements.
RP56C	Trends in pesticide use by cane farmers – Regulated catchments	Pesticide use on cane farms has changed through time in response to availability, effectiveness and cost of the various alternatives, as well as the influence of extension programs and regulations. This project will examine trends in the use of pesticides on cane farms in the regulated catchments, particularly whether there has been any movement away from the regulated PSII pesticides to environmentally damaging non-regulated pesticides.
RP57C	Monitoring alternative pesticide use – Regulated catchments	DERM's Great Barrier Reef Catchment Loads Monitoring Program currently monitors regulated pesticides in rivers that discharge to the Great Barrier Reef, along with loads of sediments and a variety of nutrients. This monitoring will be extended by this project to include environmentally damaging non-regulated pesticides of greatest concern that are beginning to be used in the sugar industry. This will allow an assessment of whether any shift in pesticide use is having an adverse impact on Reef water quality. This work will also ensure a more comprehensive estimate of total pesticide loads to the Reef, and will provide a baseline for comparing future loads.
RP58C	Legumes and the cane nitrogen cycle – Regulated catchments	Many cane growers use legume break crops to improve soil conditions and nitrogen available to the crop. However, the extent to which this practice improves the nutrient status of the crop is unclear. Extending existing trials, this project will clarify the contribution legume break crops make to cane nutrient budgets and provide advice for their use under different growing conditions, and adjustments that may need to be made to nutrient applications when using legumes. Results will be incorporated in to decision support tools (notably SafeGauge for Nutrients) and other extension products.
RP59C	Managing the cane nitrogen cycle – Regulated catchments	Nitrogen is a key limiting nutrient for cane crops, but there is still much to learn about its availability under wet tropical conditions. Extending existing trials funded under Reef Rescue, this project will clarify nitrogen availability to the cane crop from a number of sources. It will identify the key factors affecting nitrogen use efficiency in the cane cropping system and

Project No.	**Project Title & Location** *(Regulated catchments - Wet Tropics, Burdekin Dry Tropics, Mackay Whitsundays)*	**Project Description**
		incorporate this information into operator tools (notably SafeGauge for Nutrients) and other extension products. It will also ensure that results of all nitrogen trials by Reef Protection Package and Reef Plan partners are incorporated into Paddock to Reef modelling to allow more accurate assessment of management practice change needed to meet Reef Plan targets to reduce nutrient pollution of the Great Barrier Reef.
RP60C	Extension of cane growing nutrient trials – loss pathways – Burdekin Dry Tropics	Nitrogen applied to cane crops may be lost through leaching in well-drained soils or through denitrification in water-logged soils. This project will assess nitrogen losses from cane crops under different soil moistures in the Burdekin Dry Tropics. It will assess nitrogen budgets in both water logged and well-drained soils. The findings will be incorporated into decision support tools (notably SafeGauge for Nutrients) and other extension products advising on nitrogen application.
RP61C	Cane growing nutrient trials - Wet Tropics	The amount of nitrogen that should be added to a cane crop needs to be matched to the amount of cane that will be produced. However, the relationship between yield and optimum application rates varies between regions. This project will establish nutrient trials in the Wet Tropics (focusing on the Herbert River sub-catchment) to better define nitrogen needs of cane crops in the area. The results will enable Wet Tropics growers to improve efficiency and effectiveness of their nitrogen applications. The findings will be incorporated into decision support tools (notably Six Easy Steps, ReefWise Nutrient Calculator and SafeGauge for Nutrients) and other extension products advising on nitrogen application.
RP62C	Economics of pesticide management on cane farms – Regulated catchments	Improving the water quality of runoff leaving a cane farm requires changes in management. While some changes may lead to increased costs to the growers, this project aims to identify win-win pesticide management options that have both environmental and economic benefits. The project is closely linked to the Reef Rescue project RRRD039 examining the economics of nutrient management on cane farms. The two projects will combine to provide extension materials describing the best changes that can be made in pesticide and nutrient management to improve water quality at the least possible cost to the growers, and, wherever possible, will lead to improved profitability.
RP63G	Mapping erodible soils in grazing lands – Burdekin Dry Tropics	Knowledge of landscapes with a high erosion risk enables efforts to minimise soil loss through improved grazing management to be focused in areas that are likely to contribute the most sediment to the Reef. This project will produce digital soil maps of the erodibility of soils in the grazing lands of the Burdekin Dry Tropics. Assessment of erodibility will be based on modelling combining geology (especially the subsurface layer of weathered rock layer known as regolith), land type, soil type, rainfall and slope, and ground-truthed through field observations. These maps will support extension delivery as well as improving modelling of

Project No.	**Project Title & Location** *(Regulated catchments - Wet Tropics, Burdekin Dry Tropics, Mackay Whitsundays)*	**Project Description**
		sediment loss from the Burdekin catchments under Paddock to Reef Monitoring and modelling program.
RP64G	Ground Cover and Fire mapping in grazing lands - Reef catchments	Ground layer vegetation (particularly perennial, palatable and productive grasses) is important for water quality because it holds soil in place and funnels rainwater away from the surface, rather than allowing it to run off to form erosion channels. Knowledge of the extent of ground cover and where it is declining therefore provides information on the places most in need of rehabilitation to reduce erosion risk. Firescar mapping also indicates where soil may be exposed to erosion, and the extent to which fire is being used to regenerate healthy pastures. This project will extend and improve DERM's delivery of mapping of ground cover and firescars using satellite imagery across all catchments that drain to the Great Barrier Reef. It will use improved methods of ground cover assessment that give a better picture of how ground layer vegetation changes both through the year and in response to long term climatic conditions, and are able to distinguish between live and dead vegetative cover. Maps produced in this project will be used in to extension tools (such as FORAGE and VegMachine) that help land holders understand ground cover changes on their properties. They will also be incorporated into models assessing the risk of sediment loss to the Reef. The results of this project can be easily transferred to support ground cover assessment across Queensland.
RP65G	Erosion sources and drivers in grazing lands – Burdekin Dry Tropics	Almost one third of sediment reaching the marine environment is derived from the Burdekin Dry Tropics catchment. Reducing this sediment loss requires better knowledge of where the sediment is coming from, and what is triggering its loss. This project aims to identify the extent to which sediment reaching the end of the catchment is derived from gullies, hillslopes or stream banks, along with the land use factors that contribute to erosion in each case. This will enable attention to be focused on the management options in each area that will be most effective at reducing sediment losses to the Great Barrier Reef. It will also contribute to models assessing catchment-wide sediment losses and progress towards reducing them.
RP66G	Gully mapping and drivers in grazing lands – Burdekin Dry Tropics	Until recently gullies were not considered a significant contributor to Reef pollution. Recent work has established that, in some parts of the catchment, up to 70% of damaging sediment may be coming from gullies. It is therefore important to know where active gullies occur and the types of landscapes that are prone to gully formation. This project will map gully locations across the catchment; determine which gullies are actively eroding; quantify the rates of erosion and determine environmental conditions associated with gully formation. This work will help to prioritise the type of preventive actions or rehabilitation that should be undertaken to reduce gully erosion and where this should be done.

Project No.	**Project Title & Location** *(Regulated catchments - Wet Tropics, Burdekin Dry Tropics, Mackay Whitsundays)*	**Project Description**
RP67G	Paddock GRASP redevelopment – trialled for grazing in the Burdekin Dry Tropics.	The GRASP model underpins both extension and modelling tools that assess the relationships between stocking rates, ground cover, pasture production, sediment loss and runoff. It is critical to any assessment of the impacts of management changes on the quality of water reaching the Reef and the associated economic implications for pastoral enterprises. This project will improve the GRASP model to make its results applicable at the paddock scale and to allow users - extension staff and producers - to input climate and other environmental data to allow different management options to be tested. It will also ensure that the model incorporates findings from other sediment and pasture-related projects being undertaken as part of the Reef Protection Package R&D program. The framework developed as a result of this project could be transferred to support the management of grazing lands in other parts of Queensland in future state wide programs.
RP68G	Enhancing FORAGE for the Burdekin	FORAGE is an extension and landholder tool developed under the Queensland Government's State Rural Leasehold Lands Strategy that assists land managers to assess changes in ground cover and identify priority areas that might need improved management to restore pasture condition, and so reduce run-off and erosion. This project will extend FORAGE though a number of modifications including incorporating land types and ground cover thresholds in map outputs; providing seasonal climate and pasture outlooks and climate change projections; providing graziers with the option to download maps or upload their own climate information; and incorporating remote sensing and GIS products into map products. These modifications will allow graziers to make their own assessments of different management options and also provide extension officers with the ability to provide advice supported by the best available science. A future benefit is that the results of this project can be easily transferred to the provision of information for management grazing lands outside the Burdekin Dry Tropics.
RP69G	Grazing management systems report – Burdekin Dry Tropics	A wide range of publications are available about options for sustainable grazing, and it can be difficult for graziers to identify which are the most reliable. Furthermore, only some of these products include an assessment of water quality implications of different management approaches. This project will gather all available information into a single document that provides best bet options for sustainable grazing management to improve both enterprise profitability and water quality in the rangelands of the Burdekin Dry Tropics. This document, which will incorporate new and existing research, will provide a valuable extension tool that includes details of the evidence behind each recommended management change in plain English. It will also set the structure for investigating management impacts, management solutions and economics of all other grazing research projects in this Reef Protection

Project No.	**Project Title & Location** *(Regulated catchments - Wet Tropics, Burdekin Dry Tropics, Mackay Whitsundays)*	**Project Description**
		Package science portfolio, and will be updated at the end of 2013 to incorporate new work.
RP70G	Costs and benefits of improving grazing management – Burdekin Dry Tropics	Management for improved water quality is more likely to be adopted if it also improves enterprise profitability. It is therefore important to identify which changes in management are most likely to lead to both water quality improvement and improved profitability of pastoral enterprises. This project extends previous research aiming to demonstrate the profitability of reasonable and practical management systems that reduce water quality risks and the economics of moving from one system to another. It will also provide factsheets and other extension products that give realistic case study examples of how a property can improve its water quality management, while also benefiting economically.
RP71P	Historical land use change and pollutant loads – Regulated catchments	There is still some public conjecture over the extent to which land management changes have impacted on the health of the Great Barrier Reef. This project will examine how changes in land use and significant regional adjustments in cane and cattle management practices have led to changes in pollutant loads over time. This work will link historical records with environmental signals laid down in the corals of the Great Barrier Reef.
RP72P	Relative risk-assessment update Stage 2 – Reef catchments	The Reef Protection Package is based on the best available science to ensure that efforts to reduce reef pollution are directed in the most effective manner to improve reef health. One of the primary documents informing the program is the 2009 Relative Risk Assessment comparing the sources of different pollutants affecting the Great Barrier Reef. More recently Reef Plan/NERP commissioned a scoping project to identify the best way to integrate all new science undertaken since 2009 into the risk assessment. Funding contribution from RPP will extend this evidence base by updating the relative risk assessment to provide a better understanding of: • the relative risk of nutrient, sediment and pesticide to key reef ecosystem components and reef health • the natural loads of reef pollutants and how they have changed over time in response to land use change • how much of the pollutants are coming from cane, grazing and horticultural properties in each catchment • the significant sources of these pollutants in the reef catchments and sub-catchments. This work will be used to identify where the best areas are for investing in management to improve Reef water quality under Reef Plan.
RP73P	Reef Protection Package modelling, analysis and integration – Regulated catchments	Models are useful for improving understanding of natural processes that lead to sediment, nutrient and pesticide losses to the Great Barrier Reef, and for predicting the water quality implications of any change in management practices. This project will avail the Reef

Project No.	Project Title & Location *(Regulated catchments - Wet Tropics, Burdekin Dry Tropics, Mackay Whitsundays)*	Project Description
		Protection Package with the modelling capacity of the Paddock to Reef (P2R) program. It will develop and examine different management improvement options to determine which leads to the best water quality outcomes, focusing future extension and investment. Several of the Reef Protection Package's R&D projects will be collecting, generating or analysing data that can contribute to these models. The current project will therefore have a coordinating role in ensuring all projects are using the best available data and that their findings are incorporated back into P2R's models and, where appropriate, used in other Reef-related programs.
RP74C	Benchmarking use of nutrients and pesticides in cane farming – Regulated catchments	Any assessment of the impact of management practice change on water quality improvement or identification of where management improvement is most needed requires access to good data. In this project, the Reef Protection Package will work with partners to set up a data gathering program to map recent, current and future trends in nutrient and pesticide use in relation to crop and sugar yields. This data capture will build on existing mechanisms (e.g. Reef Rescue, Project Catalyst and Q2) to capture management information through organisations (e.g. productivity boards and NRM groups) that have established relationships with growers. Findings from this work will inform the targeting of future efforts to improve water quality management.
RP75C	Management advice on how cane management systems can be adapted to prevent groundwater pollution – Regulated catchments	Several Reef Protection Package projects assessing the groundwater pathway for delivering agricultural pollution to the Great Barrier Reef will identify information cane growers need to minimise their contribution pollution to groundwater systems. Post this work, extension products will be developed under this project to explain how growers can address minimising groundwater pollution, such as through reducing leakage of nutrients and pesticides in light textured soils. If appropriate, it will build on existing projects assessing environmental characteristics influencing overland flow to include consideration of subsurface pollution pathways.
RP76C	Regional Integrated Weed Management in cane lands – Wet Tropics	Considerable effort is being invested in managing weeds on cane farms to reduce reliance on pesticides. However, many cane farms (especially in the Wet Tropics) are faced with continual reinfestation of weeds from surrounding areas. In consultation with stakeholders, this project will examine the relative contribution of on and off-farm processes to weed problems on cane farms in pilot areas of the Wet Tropics. It will then test weed management initiatives that could form the basis of a regionally-based weed management strategy.
RP77C	Cane socio-analysis to inform extension and regulation farming – Regulated catchments	If management for water quality improvement is to be adopted, it must be presented in a way that cane growers can relate to, and with an understanding of the other pressures on their lives and businesses. This project will bring together social scientists and extension staff who have knowledge about how growers make decisions, and the best ways to influence growers

Project No.	**Project Title & Location** *(Regulated catchments - Wet Tropics, Burdekin Dry Tropics, Mackay Whitsundays)*	**Project Description**
		to make changes that have water quality benefits. This will follow previous work identifying motivations and barriers to improving water quality management funded by the Reef Protection Package. These insights will ensure the Reef Protection Package's extension and support efforts are focused on the activities that are most likely to deliver water quality improvement to the Reef. It will also identify what additional research may be required to improve understanding of the cane growing community to improve uptake of management improvements.
RP78C	Safegauge for Pesticides (web-enabled) – Regulated catchments	The main threat from pesticides to the Great Barrier Reef is through application at the wrong rates or at the wrong time. Cane growers therefore need information about the best options for pesticide application. Reef Protection Package has already invested in the updating of Safegauge for Pesticides, which allows growers to examine different options for applying pesticides on their properties to assess the risk of losses through run-off. Also being funded is the conversion of an equivalent package for nutrients to a web base for easier access by growers (anticipated mid 2012). Informed by the outcomes of Safegauge for Nutrients (web-enabled), this additional project will aim to make the Pesticides component web-available improving access under extension and support programs. Update to the Safegauge package over the next 2 years will also see emerging science made available in a form that can be accessible to the wider cane community.
RP79C	Cane management effectiveness review – Regulated catchments	There is a broad consensus on the principles that are integral to profitable and environmentally sustainable management of cane farms, regardless of the management systems used. However, there is no single point-of-truth document that both enumerates these principles and provides concrete examples of what management systems based on these principles look like. This project will produce a report synthesising information on the best bet management approaches to incorporate water quality improvement into cane farming. This report will set the structure for investigating management impacts, management solutions and economics of all other cane research projects in this Reef Protection Package science portfolio and will be informed and inform work under Action 4 of Reef Plan and will be updated at the end of 2013 to incorporate new knowledge and research findings.
RP80C	Support adaptive management trials – Regulated catchments	Farmers are most likely to adopt improved management when they have played a part in identifying both the problem and the solution. In order to identify specific linkages between sugarcane farm management practices and water quality leaving the farm, this project will directly engage the farmers in regulated catchments to undertake combined research and extension projects. The first stage will see engagement with regional stakeholders to identify two or three local trials addressing the issue of nutrient and pesticide loss that is most

Project No.	**Project Title & Location** *(Regulated catchments - Wet Tropics, Burdekin Dry Tropics, Mackay Whitsundays)*	**Project Description**
		important in a region. The trials will then involve local extension organisations working with their growers and groups using mapping tools and diagnostic engagement techniques to identify where nutrients or pesticides may be leaving the farm and what potential changes to farm systems could minimise this risk. The findings from these trials will focus both on the type of the management adaptations have been successful at reducing pollutant loads, and the approaches that have been successful in achieving grower acceptance and management practice change.
RP81G	Rehabilitation of degraded grazing lands – Burdekin Dry Tropics	Much work has been done by graziers in the Burdekin Dry Tropics to rehabilitate degraded land, often with the assistance of NRM groups, and with funds provided by the Commonwealth (e.g. Landcare, Envirofund and Reef Rescue). The lessons learned from these efforts would inform good land management across the region, however, the successes and failures of these attempts have yet to be documented in an accessible guide. This project will ensure that the wealth of experience in rehabilitation of degraded grazing lands is compiled in a report that can be used to inform further rehabilitation work. Case studies will be included covering a range of environmental settings, grazing management systems and remediation methods.
RP82G	Grazing socio-analysis to inform extension and regulation farming – Burdekin Dry Tropics	For graziers to adopt management aimed at improving reef water quality, they must receive information from a credible source. It needs to demonstrate how grazing land management can influence sediment loads reaching the Reef and identify improvement options that are unlikely to reduce enterprise profitability or quality of life. This project will bring together social scientists and extension staff who have knowledge about how graziers make decisions that affect land condition, and how best to influence them to make changes that have water quality benefits. This will follow previous work funded by the Reef Protection Package identifying motivations and barriers affecting water quality management, as well as a detailed re-assessment of the characteristics of the grazing communities across the Burdekin Dry Tropics. It will provide a framework within in which further socio-economic research needs will be identified. The insights provided by this project will ensure the Reef Protection Package's extension and support efforts are focused on the activities that are most likely to deliver water quality improvement to the Reef.



Reef Water Quality Protection Plan 2009

For the Great Barrier Reef World Heritage Area
and adjacent catchments

Australian Government

Queensland Government

Copies of this publication can be obtained by contacting (07) 3225 8050 or at www.reefplan.qld.gov.au

Foreword

The Great Barrier Reef World Heritage Area (the Reef) is internationally recognised as a superlative natural phenomenon with outstanding natural, social and economic values. It is priceless to the people of Queensland and Australia.

Unfortunately, the quality of water flowing into the Reef lagoon from the land has deteriorated dramatically over the past 150 years. This has contributed to coral bleaching, algal blooms and pesticide pollution and made the reef less resilient to other pressures such as climate change.

The Reef Water Quality Protection Plan (Reef Plan), first introduced in 2003, contained a list of 65 actions that built on existing government policies and industry and community initiatives to achieve a sustainable future for the Reef and the industries in the Reef's catchments.

As we have now passed the halfway mark of this 10-year program, it is appropriate to renew Reef Plan in a contemporary context.

In reviewing our progress and moving forward, it is important that we acknowledge the positive outcomes that have been achieved since 2003. We would like to commend those people who have worked tirelessly over the last five years to help improve water quality in Reef catchments, including Natural Resource Management groups, landholders, industry groups, community monitoring groups, government officers, environmental education officers, scientists and extension officers.

Collectively, we recognise that reef water quality is not a short-term problem with a simple solution. It will take many years to improve water quality throughout the catchments adjacent to the Reef and in the Reef lagoon itself.

This has been confirmed by leading scientists who have agreed that water discharged from rivers into the Reef continues to be of poor quality and that current management actions are not addressing the problem effectively.

This updated Reef Plan helps redirect our focus to ensure that reef water quality is improved and that the Reef has the resilience to cope with the stresses of a changing climate. It includes the continuation and expansion of incentive schemes and extension work but also incorporates a regulatory safety net to accelerate uptake of better management practice. It also establishes an integrated monitoring and evaluation strategy so that we can measure our progress more effectively.

By working together, we can protect the Reef for future generations.

Hon Peter Garrett AM MP
Minister for the Environment, Heritage and the Arts.

Hon Anna Bligh MP
Premier of Queensland.


Image courtesy of the Great Barrier Reef Marine Park Authority

Summary

Over the last 150 years, the land catchment areas adjacent to the Great Barrier Reef World Heritage Area (the Reef) have undergone extensive modification for urban and transport infrastructure, agricultural production, tourism and mining. This modification has led to significant pollutant loads entering the Reef, the largest contribution being from agricultural land use activities in the catchment areas.

To address this issue, the Reef Water Quality Protection Plan (Reef Plan) was endorsed by the Prime Minister and Premier in October 2003. It primarily built on existing government programs and community initiatives to encourage a more coordinated and cooperative approach to improving water quality.

Action undertaken through Reef Plan to date has not been effective in solving the issue of declining water quality in the Reef. Latest available evidence indicates that water discharged from rivers to the Reef continues to be of poor quality in many locations and current management interventions are not working. Land derived contaminants, including suspended sediments, nutrients and pesticides are still present in the Reef at concentrations likely to cause environmental harm. In 2007, an estimated 6.6 million tonnes of sediment, 16,600 tonnes of nitrogen and 4180 tonnes of phosphorous reached the waters of the Reef lagoon due to loss from the catchments.

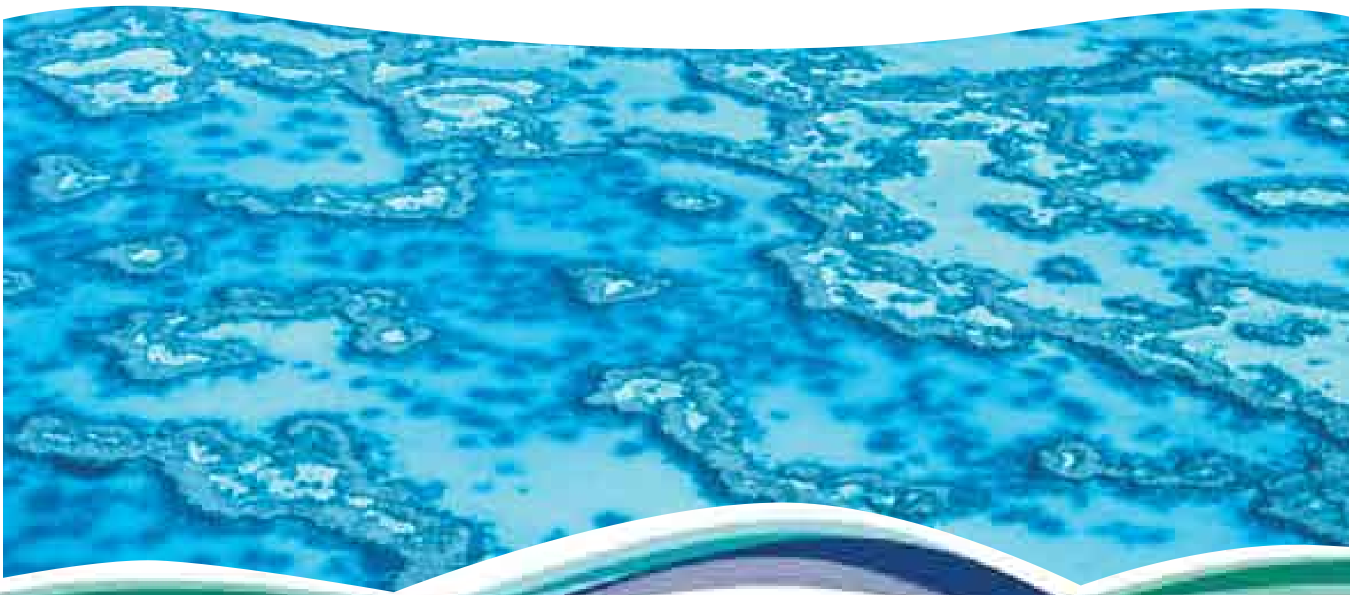
The impending threat of climate change to the Reef has been recognised as far more serious since the commencement of Reef Plan in 2003 and escalated the urgency of taking remedial action. Without taking this action the future livelihood of Queensland's industries and the lifestyle that Queenslander's enjoy could be under threat. Consequently, this plan has been reinvigorated to promote a more assertive approach to resolving the issue. Ambitious but achievable targets have been provided and both the Australian and Queensland Governments have committed significant resources to ensure they are met.

This updated Reef Plan builds on the 2003 Plan by targeting priority outcomes, integrating industry and community initiatives and incorporating new policy and regulatory frameworks. Reef Plan is now underpinned by clear and measurable targets, improved accountability and more comprehensive and coordinated monitoring and evaluation.

Reef Plan has two primary goals. The immediate goal is to halt and reverse the decline in water quality entering the Reef by 2013. The long-term goal is to ensure that by 2020 the quality of water entering the Reef from adjacent catchments has no detrimental impact on the health and resilience of the Reef. Achievement of these goals will be assessed against quantitative targets established for land management and water quality outcomes.

To help achieve the Reef Plan goals and objectives, three priority work areas (Focusing the Activity, Responding to the Challenge, Measuring Success) have been identified and specific actions and deliverables outlined for completion between now and 2013.

Reef Plan will be reviewed again in 2013 to ensure that it is delivering the intended outcomes. Throughout the course of Reef Plan there will also be regular reviews and improvements to the Plan to ensure its currency and effectiveness.



Reef Plan history

2001	The Great Barrier Reef Ministerial Council accepted the Great Barrier Reef Marine Park Authority's report on the decline in water quality in the Great Barrier Reef and the importance and urgency in addressing the issue.
2002	An independent panel of experts was commissioned to review the scientific evidence linking land use, water quality and reef degradation. The Panel prepared *A Report on the Study of Land Sourced Pollutants and their impacts on Water Quality in and adjacent to the Great Barrier Reef.*
2002	The Productivity Commission reported on the importance of different industries in the Reef catchments and examined and evaluated a number of policy options to address declining water quality entering the Reef.
2003	The Reef Water Quality Protection Plan was released for public consultation. Following consideration of the public comment, a revised plan was developed and endorsed by the Great Barrier Reef Ministerial Council.
2005	An *Audit of the Reef Water Quality Protection Plan* was conducted by Howard Partners Pty Ltd. This audit report formed the basis of the *Report to the Prime Minister and the Premier of Queensland—Progress to Date, Challenges and Future Directions.*
2007	The Reef Water Quality Partnership was established involving five regional Natural Resources Management (NRM) bodies and the Australian and Queensland Governments to enable coordinated, scientifically robust and collaborative target setting, monitoring and reporting arrangements.
2008	A Task Force of scientists reviewed the 2002 report and advised what scientific advances had been made in our understanding of reef water quality. The outcome was the *Scientific Consensus Statement on Water Quality in the Great Barrier Reef.*
2008	The *Reefocus Summit* was held to seek stakeholder views on an updated Reef Plan.
2009	The updated Reef Water Quality Protection Plan was endorsed by the Queensland and Australian Governments.

Introduction

The Great Barrier Reef is a World Heritage Area, internationally recognised for its unique values. The long-term conservation of the Reef for future generations of Australians and visitors from overseas requires collective action from government and non-government stakeholders. The Australian and Queensland Governments have a responsibility to take action and in particular to work with key stakeholders – including industry, catchment and conservation groups, and landholders – in order to protect the values of the Reef.

Governments agree that there is an overwhelming case for halting and reversing the decline in the quality of water entering the Reef. Most of the nutrient, sediment and pesticide pollutants affecting water quality in waterways entering the Reef come from non-point sources arising from agricultural land use activities in Reef catchments.

Improved land management practices have been developed by the agricultural industry over the last five years, including new strategies that minimise the flow of nutrients, sediments and chemicals into the waterways. This Plan acknowledges the work undertaken cooperatively by government and industry; however, leading scientists agree that there has not been sufficient improvement and further urgent action is required to improve water quality.

Land-based farming activities and the Reef can comfortably coexist in the future. Both contribute significantly to Queensland's social and economic profile.

The Reef contributes $5.4 billion[1] to the Australian economy and supports significant regional employment through tourism, fishing and other industries. The beef, cane and horticulture industries in Reef catchments contribute approximately $3.7 billion a year in gross value of production[2] and also support significant regional employment.

Reef Plan is a joint commitment of the Queensland and Australian Governments. It identifies actions that will help minimise the risk to the Reef from a decline in the quality of water entering the Reef from the adjacent catchments. The Plan is a significant part of the overall strategy of both governments to protect and preserve the Reef. It incorporates and supports the actions of government, industry and community groups that impact on Reef health and has links with a number of other legislative and planning initiatives.

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1 2006–07 data based on Access Economics 2008 *Economic contribution of the GBRMP, 2006–07,* prepared for the Great Barrier Reef Marine Park Authority. Note this includes both direct and indirect contributions from tourism, commercial fishing and recreational use (including fishing).

2 Based on Australian Bureau of Statistics (ABS) data for 2007–2008 and an estimate of the contribution Reef catchments make to each of the industries based on the Productivity Commission. This does not include value adding such as processing.

Scope

Reef Plan's scope is to address non-point source pollution from broad-scale land use.

Non-point source pollution is pollution that comes from a wide range of different sources and cannot be directly attributed to one point of dispersal, such as a pipe or waste outlet.

Broad-scale land use includes agriculture (such as grazing, cropping, horticulture and forestry) and other tenures of public land (e.g. national parks and reserves). It does not include urban land uses.

Reef Plan outlines actions to minimise non-point source pollution from broad-scale land use and reduce the entry of those pollutants to the Reef. It specifically targets nutrients, pesticides and sediment that wash into wetlands and waterways, leach into groundwater or flow overland across floodplains and ultimately enter the Reef lagoon because of agricultural activities in Reef catchments.

By improving water quality, governments along with rural industry groups and landholders can help the Reef become more resilient and better able to withstand the impacts of climate change. Just as healthy humans are more able to resist and recover from diseases and injuries, healthy ecosystems can recover from acute disturbances or adapt to chronic stressors such as climate change.

There are a number of other threats to the Reef such as shipping accidents, tourism, coastal development and fishing that are not within the scope of Reef Plan. Urban non-point and point sources of pollution such as sewage and waste from ore processing or mining operations are also beyond the scope of the Plan. These issues are specifically dealt with under a range of regulatory and planning processes managed by both the Queensland and Australian Governments.

Figure 1: Map of the Great Barrier Reef World Heritage Area and catchments.

Revising Reef Plan 2003

An independent audit and report to the Prime Minister and Premier on the implementation of the Reef Water Quality Protection Plan was undertaken in 2005. This report provided an evaluation of progress to date and identified challenges and potential future directions. While satisfactory progress had been achieved, the 2005 report to the Prime Minister and Premier made the following recommendations to both governments to ensure it met its goals:

- recommit to Reef Plan
- improve consultation and communication with key stakeholders
- develop more effective partnerships with stakeholders
- update and publicly launch the refreshed Reef Plan
- improve monitoring of land condition.

In 2008, Reef Plan passed the halfway mark of the original 10-year plan. Therefore, it was considered timely to review progress and reflect advances in knowledge that support implementation of Reef Plan and other initiatives of governments, industry and the community.

This updated Reef Plan has been informed by the substantial work undertaken in the first five years, particularly that done by the Reef Water Quality Partnership (RWQP), Regional Implementation Group (RIG) and the Scientific Advisory Panel (SAP). In addition to the 2005 report to the Prime Minister and Premier, the following reports were integral to updating the plan:

- *Reef Water Quality Protection Plan Annual Report 2006–07*
- *Scientific Consensus Statement on Water Quality in the Great Barrier Reef*
- *Outcomes from the Reefocus Summit*
- *Reef Water Quality Partnership Strategic Plan 2007–2013*
- *Research and Information Priorities for Great Barrier Reef Water Quality Management—Workshop Outcomes.*

Achievements to date

The 2006–07 Annual Report noted that 41 of the 65 actions within Reef Plan had met their original milestone, 18 had not but were progressing well, while six actions showed unsatisfactory progress. This report also highlighted that while significant progress was made in some areas, one of the challenges was the need to improve the speed of uptake of best management practice and its measurement.

The following are some of the key achievements of the first five years:

- The Reef Water Quality Partnership was established to enable coordinated and integrated water quality target setting, monitoring and reporting. This was a collaborative arrangement between the five regional natural resource management bodies in Reef catchments and the Australian and Queensland Governments.
- Broad-scale clearing of remnant vegetation was phased out in 2006.
- The Delbessie Agreement (rural leasehold strategy) commenced implementation in 2008, providing extended leases to those landholders that improved land condition.
- Water Quality Improvement Plans (WQIPs) have been completed for key catchments and identify regional targets for improvement and key management changes to be made to reach those targets.
- Nutrient Management Zones have been identified that will help focus work in ‘hot spot’ locations.
- Hot spots for sediment loss have been identified.
- A number of collaborative education and extension projects involving regional NRM bodies, industry and the Queensland Government have been completed that promote and support uptake of sustainable agriculture, such as: the Reef Extension program; Farm Management Systems; Mackay Whitsundays Sustainable Landscapes program; Rural Water Use Efficiency (RWUE) initiative; community-based water quality monitoring through ‘Waterwatch’; the fertiliser industry’s ‘Fertcare’ program and others.
- Industry-led changes to land management practices have taken place in the agricultural industry through the development of Farm Management Systems and codes of practice. The broad principles for effective management of pollutants are also well known for most industries. These principles are starting to be incorporated into management practices being implemented across the Reef catchments by industry through initiatives such as the ‘Six Easy Steps’ for nutrient management in sugarcane and the AgForward program within the grazing industry.
- The five-year Queensland Wetland Program, established in 2003, has delivered more than 38 projects including a range of mapping, information and decision-making tools to enable land managers and regional bodies to protect and manage wetlands.
- Significant community monitoring, education and extension has occurred through regional NRM bodies.

Scientific consensus

The establishment of Reef Plan in 2003 was supported by a body of scientific evidence showing a decline in water quality of the Reef. Since that time, there have been significant advances in knowledge to support implementation of the Plan. Significant research through major research initiatives such as the Cooperative Research (Reef and Rainforest) Centre Catchment to Reef program (2002–2007), the CSIRO Water for a Healthy Country Great Barrier Reef node (2004–present) and more recently, the Marine and Tropical Science Research Facility research program (2006–present), has further confirmed the changes to water quality in the Reef. These initiatives have significantly improved our understanding of the sources and fates of pollutants and the impacts of declining water quality in both the catchments and the marine ecosystems of the Reef.

In 2008, a taskforce of scientists was established to prepare a synthesis paper that reviewed the 2003 summary statement of evidence and where appropriate, updated that statement based on the results of more recently published and peer-reviewed articles. This synthesis was released in October 2008 as the *Scientific Consensus Statement on Water Quality in the Great Barrier Reef.* It is available on the Reef Plan website (www.reefplan.qld.gov.au).

Based on analysis of the latest available evidence, the taskforce concluded that:

- Water discharged from rivers to the Reef continues to be poor in many locations.
- Land-derived contaminants, including suspended sediments, nutrients and pesticides are present in the Reef at concentrations likely to cause environmental harm.
- There is strengthened evidence of the causal relationship between water quality and the coastal and marine ecosystem health.
- The health of freshwater ecosystems is impaired by agricultural land use, hydrological change, riparian degradation and weed infestation.
- Current management interventions are not effectively solving the problem.
- Climate change and major land use change will have confounding influences on Reef health.
- Effective science coordination to collate, synthesise and integrate disparate knowledge across disciplines is urgently needed.

Scientists also agree that improving water quality improves the resilience of the Reef to the pressures from climate change by reducing recovery time after catastrophic events such as coral bleaching, increasing resistance to effects such as raised sea temperatures and increasing the tolerance of species to these relatively rapid fluctuations.

Reefocus Summit

The Reefocus Summit was held on 24 October 2008 to bring together governments and key stakeholder groups, including representatives from agricultural peak bodies, natural resource management bodies, researchers and the conservation sector, to collectively review progress in halting and reversing the decline in water quality and to discuss the need for a renewed and reinvigorated Reef Plan.

The Summit recognised that significant work has been done by industry and natural resource management bodies to address water quality issues, but that changes have not been adopted at a scale necessary to achieve the objectives of Reef Plan.

The Summit acknowledged the most recent scientific evidence, which suggests that water quality continues to be poor and agreed that the goals of Reef Plan are not being met.

It was acknowledged that the Reef is under increasing pressure from declining water quality. Excessive nutrient, pesticide and sediment run-off entering the rivers flowing into the Reef are impacting on its resilience in the face of climate change.

The Summit agreed that the Reef Plan needed to be revisited and strengthened. A refreshed Reef Plan would provide a framework for accelerating and expanding efforts made to date, helping to achieve the goals of Reef Plan.

Attendees at the Summit discussed a more strategic approach to Reef Plan that focused on priority areas, better monitoring to measure progress against quantitative targets, and greater accountability to achieve defined actions. The Summit also discussed new initiatives that may be needed to ensure that goals can be met, including the use of regulation.

Stakeholder involvement

The updated Plan is based upon engagement and partnerships with key stakeholders to ensure it achieves its goals. It has been prepared through close consultation with key stakeholders. A stakeholder working group was formed involving regional natural resource management body, industry and conservation group representatives to work closely with the Australian and Queensland Governments in updating Reef Plan goals, objectives, actions, deliverables and accountabilities. This partnership approach will continue during the implementation of the updated Plan as outlined in the revised institutional arrangements.

Reef Plan in 2009

The updated Reef Plan is focused on priority areas for action. It ensures that government and stakeholders are accountable for delivering on the actions.

The Plan moves away from a long list of actions (65 in the original to 11 in 2009), to a much more strategic and adaptive plan. It is focused on outcomes, incorporates and recognises industry and community initiatives and takes into account new policy and regulatory frameworks. Reef Plan is underpinned by clear and measurable targets, improved accountability and comprehensive and coordinated monitoring, evaluation and reporting in order to measure progress.

To help achieve the Reef Plan goals and objectives, three priority work areas are identified and specific actions and deliverables outlined for completion between now and 2013. Work is focused in the most critical areas and there are clear accountabilities for delivering on the actions.

Two independent reviews of Reef Plan are scheduled, one in 2010 and another in 2013, to ensure that adequate progress is being made in implementing actions and achieving the Plan's goals and objectives. Ongoing evaluation of the Plan will ensure that it continues to reflect progress in land management practices, new knowledge in science and continuous improvement in natural resource management.

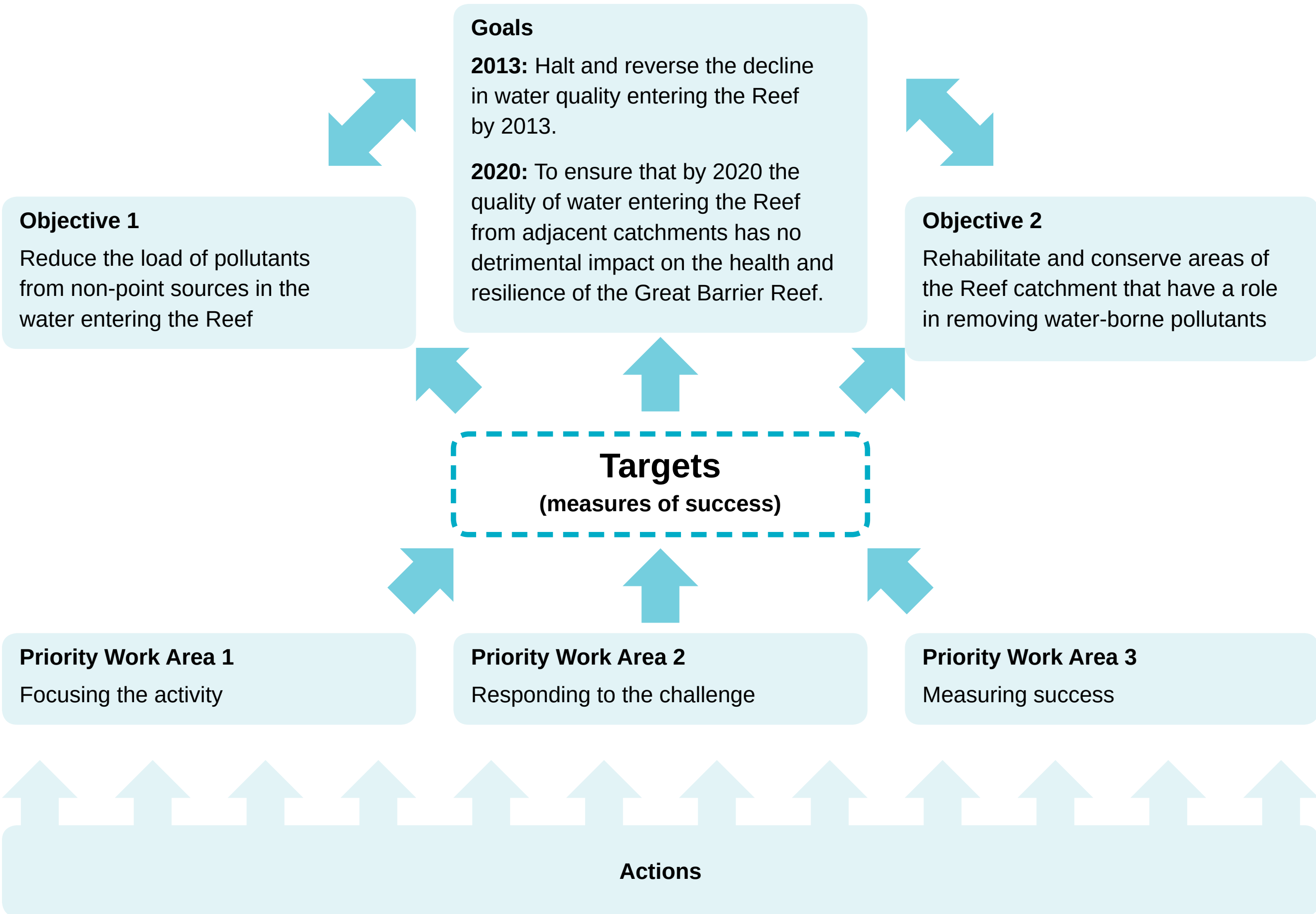
Reef Plan structure

In 2003, Reef Plan outlined 65 actions across nine strategies. Milestones for each action were outlined, as well as the agencies responsible for contributing to the action.

The updated Plan is more strategically focused and identifies the priority work areas (Figure 2) and the actions that will be undertaken to achieve the 2013 goals and objectives. Within the priority work areas there are 11 actions, with clearly identified deliverables and accountabilities.

Another new component of Reef Plan's structure is a set of quantitative targets that will be the critical measures of whether the actions are helping achieve the goals and objectives.

Figure 2: Priority work areas and actions to be undertaken to achieve 2013 goals and objectives.



Goals

Immediate goal

To halt and reverse the decline in water quality entering the Reef by 2013.

- **Halt the decline** means that there is no further decrease in the quality of water entering the Reef attributable to human actions (e.g. there is no measurable increase in nutrients, pesticides and/or sediments) from 2003 levels.
- **Reverse the decline** means that there is a measurable improvement in the quality of water entering the Reef attributable to human actions (e.g. there is a measurable decrease in the amount of nutrients, pesticides and/or sediments) from 2003 levels.
- **Entering the Reef** includes water from all land-based non-point sources (e.g. river/estuarine flows, groundwater and overland flow).

Long-term goal

To ensure that by 2020 the quality of water entering the Reef from adjacent catchments has no detrimental impact on the health and resilience of the Great Barrier Reef.

- **Adjacent catchments** means those catchments that border and/or have flows into the Great Barrier Reef World Heritage Area.
- **Detrimental impact** means something that causes harm or injury to organisms and/or their habitat either individually or collectively.
- **Health** is the state of wellbeing of organisms both individual and holistic.
- **Resilience** means the capacity of an ecosystem to resist or recover from disturbances or damage, without changes in state, so as to maintain key functions and processes.

Water quality parameters, like most others in the natural world, are a dynamic feature of the environment and this is particularly relevant for Reef catchments. For many parameters (e.g. sediment) significant variations occur over time even under natural conditions.

The Plan's goals are aimed at reducing human impacts to levels where they will be having no detrimental impact on Reef health. This relies on our ability to:

- clearly define what 'healthy' water quality is for the Reef
- demonstrate the achievement of the identified water quality parameters for all waters entering the Reef.

Objectives

The Reef Plan has two key objectives. The first aims to reduce the amount of pollutants entering the waterways and the Reef, while the second promotes protection and improvement of natural filters that capture these pollutants prior to entering the Reef.

Objective 1

Reduce the pollutant load from non-point sources in the water entering the Reef.

- **Pollutants** are contaminants at concentrations known to cause environmental harm.
- **Contaminants** are any material that can be detected in water at above 'natural' concentrations.
- **Non-point sources of pollution** are those that enter the Reef lagoon from a wide range of different sources and that cannot be directly attributed to one point of dispersal, such as a pipe or waste outlet. Such pollution includes nutrient, chemicals and sediment that wash into waterways, leach into groundwater or flow overland through the floodplains and ultimately enter the Reef lagoon.

The main pollutants are:

- total suspended solids (i.e. soil that has run off the land and is suspended in water)
- nutrients such as nitrogen and phosphorus (in dissolved or particulate form)
- pesticides such as ametryn, atrazine, diuron, hexazinone and tebuthiuron.

Suspended solids can smother inshore reefs, limit light availability and therefore reduce productivity of reefs. Increased nutrients encourage algal growth, which inhibits growth of coral. It can also result in weakened coral skeletons, making them more susceptible to storm damage. High concentrations of pesticides can cause fish kills and can have long-term impacts on ecosystem function that are difficult to see.

Historically, flushing of sediments has occurred as a natural result of flood events. The ecosystem, when healthy, is somewhat resilient to these events. Reef ecosystems, when damaged by events such as cyclones, are highly susceptible to the effects of poor water quality. Therefore, increases in sediment loads beyond natural levels, which have occurred as a result of land clearing and soil disturbance, need to be addressed.

Objective 2

Rehabilitate and conserve areas of the Reef catchment that have a role in removing water-borne pollutants.

- **Reef catchments** are those catchments adjacent to the Great Barrier Reef, from Cape York in the north, to the Burnett-Mary in the south.

Actions such as land clearing, the intensification of agriculture and disturbance and/or destruction of wetlands can result in increased sediment and/or nutrients and pesticides flowing into river systems. Water quality can, however, improve as it moves through natural filters such as floodplains, riparian areas and wetlands. Therefore, a key objective of Reef Plan must be to encourage rehabilitation of damaged wetlands and riparian areas and conservation of remaining wetland and riparian areas.

Targets

There are two types of targets in this Plan:

- water quality targets
- management practice targets.

The two are closely linked, in that improvements in management practice will result in improvements in water quality. Together these targets highlight the outcomes that are to be achieved, and, as the basis of the monitoring and reporting system, will help measure our success in meeting the Reef Plan's goals and objectives.

These targets are designed to:

- ensure there is appropriate commitment from partners in delivering Reef Plan actions
- ensure we can appropriately monitor and measure our progress in meeting Reef Plan's goals and objectives
- inform the development of new regulation
- promote continuous improvement.

To ensure that the targets accurately reflect the success of the updated Reef Plan, they are based on comparisons with 2009 baseline levels (e.g. a reduction in nutrients from 2009 levels).

Water quality targets

These reef-wide water quality targets quantify the amount of improvement to be achieved in water quality parameters including nutrient, pesticide and sediment loads. They build upon work done by NRM groups in developing Water Quality Improvement Plans and will be supported by continued work at the regional level to achieve these reef-wide and other catchment-specific targets.

Measurement of these water quality targets will need to take into account episodic events in catchments in order to accurately portray trends in water quality. The targets will be measured via trend analysis and modelling, rather than by using absolute measures. This is in recognition of the natural fluctuations observed in discharges over short periods, particularly for sediment in large dry catchments.

By 2013 there will be:

- a minimum 50 per cent reduction in nitrogen and phosphorus loads at the end of catchments
- a minimum 50 per cent reduction in pesticides at the end of catchments
- a minimum of 50 per cent late dry season groundcover on dry tropical grazing land.

By 2020 there will be:

- a minimum 20 per cent reduction in sediment load at the end of catchments.

Management practice targets

These targets relate to changes in land management, which contribute to improved water quality. Changes in management practice are expected to be more evident than improvements in water quality in the short term. As catchment models are continuously updated, improvements in land practices can be used to determine likely improvements in water quality.

By 2013:

- 80 per cent of landholders in agricultural enterprises (sugarcane, horticulture, dairy, cotton and grains) will have adopted improved soil, nutrient and chemical management practices
- 50 per cent of landholders in the grazing sector will have adopted improved pasture and riparian management practices
- there will have been no net loss or degradation of natural wetlands
- the condition and extent of riparian areas will have improved.

Measuring targets

There are a suite of monitoring programs already in place collecting data on water quality and ecosystem health. These programs are undertaken by various state and Australian government agencies as well as by community groups and other stakeholders. Data is collected at the catchment and sub-catchment level, as well as in marine areas. There are also a range of monitoring and mapping technologies available, such as remote sensing, that provide valuable information on land condition (e.g. riparian and wetland extent, groundcover etc).

Many of the targets will be measured through these existing monitoring programs. However, to report effectively on progress towards the Reef Plan targets, these programs will be enhanced and coordinated through the development and implementation of the Reef Plan Integrated Monitoring and Reporting Program. This program will use existing data as well as modelling tools to generate information from the paddock to the reef. New information will also need to be collected, including data about adoption rates of improved management practices. The integration of existing information and the filling of information gaps is considered a high priority for Reef Plan, to ensure progress towards targets can be measured effectively in both the short and long term.

Further details of how the targets are to be measured will be outlined in the Monitoring and Evaluation Strategy.

Priority work areas

To help organise activities and prioritise actions, three priority work areas have been established as follows:

1. Focusing the activity – resources are focused at the most critical areas using the most cost-effective measures.
2. Responding to the challenge – landholders adopt land management practices that maximise reef water quality improvements.
3. Measuring success – to gauge the efficiency and effectiveness of Reef Plan in achieving its goals and objectives through monitoring and evaluation.

There are 11 key actions grouped according to these priority work areas. The actions are relatively broad and may encompass a number of deliverables. This provides flexibility and adaptability to ensure that other activities can be undertaken that contribute to achieving the targets.

A single entity is accountable for coordinating implementation and reporting progress against each action to help ensure that actions are completed and milestones met.

Priority area 1:
Focusing the activity

Desired outcome:

Resources are focused at the most critical areas using the most cost-effective measures.

To achieve this, issues need to be clearly defined at the appropriate scales and actions prioritised through a risk assessment process that takes into consideration current initiatives and new information, while identifying opportunities for research, development and innovation.

Action	Deliverables	Accountability	Supporters
1. Develop, implement and maintain a Research, Development and Innovation (R,D&I) Strategy for agreed reef water quality priorities.	• A three-year R,D&I Strategy for agreed reef water quality priorities by September 2009. • An updated R,D&I Plan by July each year.	DPC	DERM, GBRMPA, AGLC, DEEDI, R&D organisations, Science Panel, WWF
2. Coordinate and integrate agreed R&D priorities into programs of work.	• An evaluation report outlining the extent of uptake of R&D priorities by research providers by July each year.	DPC	R&D organisations, Science Panel
3. Prioritise and align investments for reef water quality based on catchment scale and reef-wide risk assessments of key pollutants and source areas.	• Reef Rescue investment for 2009–2010 and onwards is delivered based on a multi-criteria analysis.	AGLC	DEWHA, DERM, DPC, GBRMPA, DEEDI, industry groups, NRM bodies, R&D organisations, WWF
	• The Queensland Integrated Waterway Monitoring Risk Assessment is used to inform cooperative agreements and other water quality monitoring activities for 2009–2010.	DERM	DPC, DEEDI, AGLC, GBRMPA, industry groups, NRM bodies, R&D organisations, WWF
	• A prioritisation process to guide investment in future water quality initiatives (other than Caring for our Country) is agreed by September 2009 for funding 2009–2010 and beyond.	DERM	DPC, DEEDI, AGLC, GBRMPA, industry groups, NRM bodies, R&D organisations, WWF
	• A Reef Plan Investment Strategy is developed and implemented by September 2009 to coordinate investments across programs, while acknowledging the different objectives of the various programs.	DPC	DEWHA, AGLC, relevant Queensland agencies, WWF

Priority area 2: Responding to the challenge

Desired outcome:

Landholders adopt land management practices that maximise reef water quality improvements.

To achieve this, programs that proactively engage landholders need to be developed, implemented, adopted and continuously improved and policy tools including incentives, regulation and extension services need to be delivered.

Actions	Deliverables	Accountability	Supporters
4. Identify improved land management practices to maximise reef water quality improvements.	• Improved land management practices for high-risk catchments are identified based on best available knowledge by September 2009. • Improved land management practices are revised based on new information and made available to all land managers by June 2010. • Evaluate the actual costs and benefits of adopting improved land practices that have been identified and promoted to landholders by June 2011 and June 2013.	DEEDI	R&D organisations, industry groups, NRM bodies, DERM, AGLC
5. Implement improved land management practices that maximise reef water quality improvements as part of property level management systems.	• Landholders implement improved land management practices.	QFF, Canegrowers, Growcom, Agforce	NRM bodies, DEEDI, DERM, DEWHA, AGLC
	• Report annually by industry sector on uptake of improved land management practices as part of industry-led property level management systems.	QFF, Canegrowers, Growcom, Agforce	NRM bodies, DEEDI, DERM, DEWHA, AGLC
	• Develop and implement a strategy to coordinate improvement of water quality management on public land in Reef catchments by December 2009.	DERM	Local governments, DEEDI, DEWHA, Department of Defence

Actions	Deliverables	Accountability	Supporters
6. Provide coordinated education and extension services to landholders to assist with uptake of land management practices that maximise reef water quality improvement.	• Undertake education and extension services targeting water quality improvement on an ongoing basis. • Review extension and education services with recommendations for improvement and resourcing by December 2009. • Review recommendations and implement appropriate changes to the extension and education program by June 2010.	DEEDI	NRM bodies, industry groups, DERM and local governments
	• Develop an education and extension strategy for coordination of activities across different programs and agencies by December 2009.	DEEDI	AGLC, DPC, DERM, DEWHA, GBRMPA, NRM bodies, industry groups, WWF

7. Review existing, and develop and implement new regulations and policies for improving reef water quality and the conservation and protection of wetland and riparian areas with emphasis on property level planning and action.	• Implement the following new or amended regulations:
	  • Reef regulatory package to be developed by mid-2009 and implemented by 2010.
	  • Wetlands regulation implemented in priority areas by December 2009.
		DERM	DEEDI, DPC, industry groups, NRM bodies, WWF

	• Implementation of Land Management Agreements commences by September 2009 in high priority Reef catchments where leases trigger the Delbessie Agreement requirements.	DERM	DEEDI
	• Annually report on the implementation of conservation agreements and covenants in high priority Reef catchments.	DERM	
	• Reef Plan objectives incorporated into existing statutory regional plans, planning policies and Coastal and Water Resource Management Plans by June 2010 and into new plans as they are developed.	DIP	DERM, DEEDI, DPC, LGAQ, GBRMPA
8. Develop, review and implement non-regulatory policies and incentives for improving reef water quality and the conservation and protection of wetland and riparian areas.	• Reef Rescue investment strategies are updated annually. • Reef Rescue outcomes and targets met by June 2013 with annual reporting on progress.	AGLC	Industry groups, NRM bodies, IOC, JSIP, WWF
	• New cooperative agreement and NRM program for 2009–2013 agreed by September 2009.	Joint Strategic Investment Panel	DEWHA/DAFF, industry groups, Queensland Government, WWF

Priority area 3: Measuring success

Desired outcome:

To be able to gauge the efficiency and effectiveness of Reef Plan in achieving its goals and objectives through monitoring and evaluation.

Actions	Deliverables	Accountability	Supporters
9. Develop and implement a Reef Plan Monitoring and Evaluation Strategy to measure the efficiency and effectiveness of the Reef Plan.	• A Reef Plan Monitoring and Evaluation Strategy is endorsed by September 2009. • Reef Plan targets are monitored, reported and reviewed annually. • Reef Water Quality Report prepared to report annually on implementation of Reef Plan and water quality and associated ecosystem health. • Independent audit and evaluation report undertaken by June 2010. • Undertake further independent audits prior to June 2013 as necessary.	DPC	GBRMPA, DERM, DEEDI, DEWHA, DAFF, AGLC, NRM bodies, industry groups, Great Barrier Reef Foundation, WWF
10. Develop and implement an integrated and coordinated paddock to Reef monitoring (modelling) and reporting program as part of the Reef Plan Monitoring and Evaluation Strategy.	• Integrated paddock to reef monitoring and reporting Program designed and implemented by September 2009 including the following components:	DPC	GBRMPA, DERM, DEEDI, DEWHA, AGLC, NRM bodies, research organisations, industry groups
	• Monitoring of uptake of improved management practices. • Paddock scale water quality monitoring and modelling to measure effectiveness of management practices.	NRM bodies	DERM, DEEDI, industry groups
	• Catchment and sub-catchment water quality and land condition monitoring and modelling program.	DERM	DEEDI, NRM bodies, industry groups
	• Wetland mapping.	DERM	
	• Marine water quality and ecosystem health monitoring and modelling.	GBRMPA	DERM
11. Improve data and information management to support data sharing, assessment and reporting.	• A scoping document on information management needs and a review of existing systems by September 2009. • Improved information management system implemented by December 2009.	DERM	DEEDI, GBRMPA, industry groups, NRM bodies, R&D organisations, Independent Science Panel

Key strategies

As part of the actions and deliverables, there is a requirement to deliver a number of key strategies, namely:

1. Monitoring and Evaluation (M&E) Strategy.
2. Research, Development and Innovation Strategy.
3. Investment Strategy.
4. Extension and Education Strategy.
5. Communications Strategy.

These strategies will ensure a more strategic and coordinated approach to more complex issues. They are primarily related to initiatives where there are multiple agencies or programs that contribute to the overall outcome. They are designed to ensure a consistent, complementary approach to these issues. The strategies will be developed in close consultation with stakeholders and government agencies to ensure appropriate linkages across various programs and initiatives undertaken by government and non-government organisations.

The Monitoring and Evaluation Strategy will enable evaluation of the efficiency and effectiveness of Reef Plan implementation and facilitate reporting on progress towards the Reef Plan goals and objectives and inform adaptation and improvement of Reef Plan. Development of the Monitoring and Evaluation Strategy will be coordinated by the Department of the Premier and Cabinet (DPC) and will identify gaps in information and establish a process for more integrated 'paddock to reef' monitoring, modelling, data sharing and annual reporting.

The Research, Development and Innovation (R,D&I) Strategy will identify priority areas for research that will improve knowledge about the impacts of poor water quality on the Reef. It will improve knowledge about the most effective ways of improving water quality. The R,D&I Strategy will be led by DPC in consultation with research providers, stakeholders and other Queensland and Australian government agencies.

The Investment Strategy will provide an overarching framework for coordinating and prioritising investments across relevant incentive programs that contribute to Reef Plan objectives (both Queensland and Australian Government investment). It will be developed by DPC in consultation with agencies responsible for administering relevant programs. The Strategy will recognise the objectives and approved business plans for the various incentive programs.

The Extension and Education Strategy will ensure a coordinated and focused approach to extension across various government agencies, regional bodies and industry groups. It will identify the range of current extension programs in place and establish strategies for better integrating and focusing those programs to achieve the best education and adoption outcomes. The Strategy will also establish a process for the review of existing programs (e.g. as per action 6).

In addition to the strategies outlined in the actions, a Communications Strategy will be developed by DPC to inform the public, as well as relevant stakeholders, about Reef Plan and the need to look after water quality in the catchments and the Reef lagoon to improve its resilience to deal with impacts such as those expected from climate change. This strategy will ensure the latest knowledge on water quality is communicated to stakeholders and the public and will help promote ownership of Reef Plan at a grass roots level.

Implementing Reef Plan

Reducing the impacts of land use on reef water quality is not solely the responsibility of governments. Achieving the objectives of Reef Plan will rely on a partnership approach between all levels of government, industry, community groups and individual landholders.

The updated Reef Plan builds upon existing programs but will also help to establish new partnerships and initiatives to enable the achievement of the Reef Plan objectives.

Governments will incorporate Reef Plan goals, objectives and actions into relevant planning processes (e.g. business and strategic plans) to make sure certain actions are achieved in appropriate timeframes.

To ensure the timely implementation of actions, implementation plans will be developed for each priority work area and/or individual action by the accountable agency or group. This accountable entity is responsible for driving implementation of the action and working with the identified supporters to deliver outcomes.

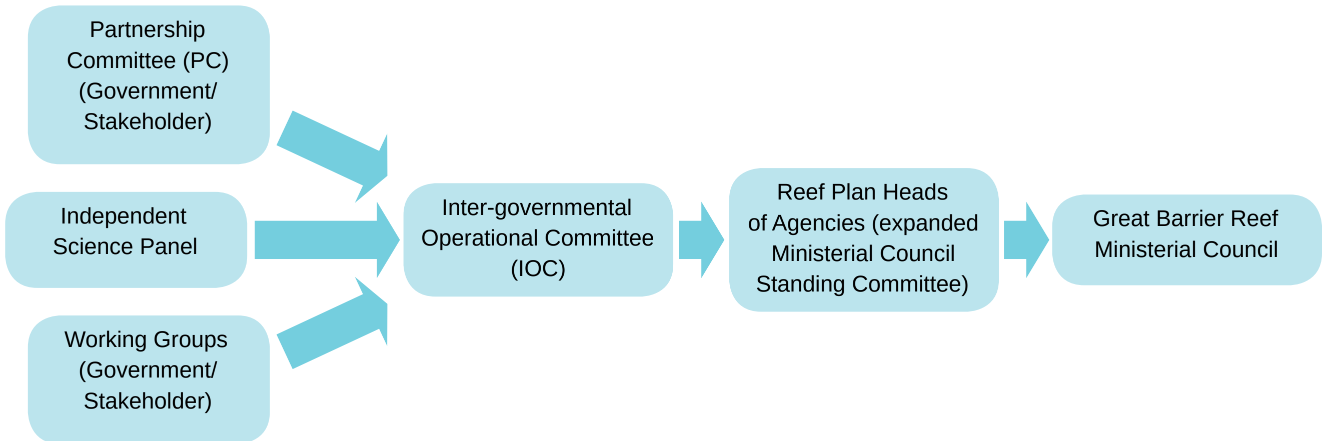
Implementation plans will describe how the actions in Reef Plan are to be implemented, including tasks, timeframes and milestones; who is involved and their roles and responsibilities; programs and resources that will support delivery; and indicators for reporting on implementation outcomes. This will ensure appropriate planning occurs and will improve the likelihood of actions being achieved. Implementation plans will be developed in consultation with key supporters and stakeholders.

Overseeing implementation

Reef Plan establishes institutional arrangements that will ensure that actions are implemented in a timely way and properly coordinated across agencies and programs.

The key decision-making body will be the Great Barrier Reef Ministerial Council. The Council will consider various sources of information related to Reef Plan implementation, including scientific and government advice, and views of stakeholders. To ensure this information is provided to Ministerial Council in the most appropriate format, a number of committees have been established (Figure 3). The committees will help ensure a coordinated and cohesive approach to implementation, and appropriate commitment of resources to implement individual actions.

Figure 3: Institutional arrangements for Reef Plan.



The **Partnership Committee** will be primarily made up of stakeholders such as industry groups, conservation organisations, NRM bodies and government officials and will be chaired by an independent person. The Partnership Committee will ensure a partnership approach to implementation of Reef Plan at the operational level. They will oversee and drive implementation of Reef Plan by contributing to the development of implementation plans and monitoring appropriate progress against actions. The Partnership Committee provides advice to the Intergovernmental Operations Committee (IOC) on the operational implementation of the Reef Plan. The independent chair will also provide an annual report to the Great Barrier Reef Ministerial Council on the operation of the committee, describing any emerging issues identified by stakeholders. This will ensure stakeholder feedback is fed through to the ministerial level in an independent context. The Terms of reference for the Partnership Committee are at Annexe 1.

The **Intergovernmental Operational Committee** (IOC) is responsible for overseeing the operational implementation of the Reef Plan and comprises nominated senior officers from the Queensland departments of Premier and Cabinet (DPC), Environment and Resource Management (DERM), Employment, Economic Development and Innovation (DEEDI) and Infrastructure and Planning (DIP), as well as the Australian Government departments of the Environment, Water, Heritage and the Arts (DEWHA), Agriculture, Fisheries and Forestry (DAFF) and the Great Barrier Reef Marine Park Authority (GBRMPA). It is the key decision- making body on operational matters and will take direction from and report to the Reef Plan Heads of Agencies group.

The IOC will also establish an **Independent Science Panel** to provide scientific advice as necessary. The Panel will be made up of approximately five members with relevant scientific expertise and will have an independent chair with a scientific background. The Panel will provide an advisory and review role on matters referred to it by the IOC.

IOC may also establish working groups to deal with emerging issues or specific tasks. This will ensure the appropriate agencies and stakeholders are involved in specific aspects of Reef Plan implementation.

The **Reef Plan Heads of Agencies** will oversee the implementation of Reef Plan at a strategic level. The committee comprises chief executives (or equivalent) from DAFF, DEWHA, GBRMPA, DERM, DEEDI and DPC.

These committees will continue to be supported by a secretariat based in the Queensland Department of the Premier and Cabinet.

Reporting progress

Agencies or organisations accountable for an action will be responsible for reporting progress against that action and the relevant implementation plan. Progress reports will be compiled annually and provided to the Partnership Committee and IOC to ensure that adequate progress is being made in completing the actions and deliverables. Progress reports will also be made publicly available through the Reef Water Quality Protection Plan annual report. These reports will be considered by the Reef Plan Heads of Agencies and the Great Barrier Reef Ministerial Council. Progress against the actions will also be carefully scrutinised as part of the independent audits in 2010 and 2013.

Supporting initiatives

Protection of the Reef is a continuing high priority for both the Australian and Queensland Governments.

Reef Plan includes a range of actions that require funding support to communities and industries facing the challenge of halting and reversing the decline in water quality entering the Reef. The Plan also includes a number of actions that will require policy and legislative changes to promote accelerated uptake of improved land practices.

To achieve this, several existing and new initiatives will be developed and implemented during the life of the Plan.

Australian Government's commitment to Reef Plan

The Australian Government has a number of programs and initiatives that will contribute to the realisation of Reef Plan goals and objectives. Chief among them is Caring for our Country, the Australian Government's $2.25 billion initiative to restore the health of Australia's environment and improve land management practices. It represents a new, coordinated approach to environmental management in Australia that is built on transparent and consistent national targets.

Caring for our Country includes a number of components relevant to the Reef Plan, most notably the Reef Rescue package. Reef Rescue's objective is to improve the water quality of the Reef lagoon by increasing the adoption of land management practices that reduce the run-off of nutrients, pesticides and sediments from agricultural land.

Reef Rescue is made up of five integrated components that work together to achieve the above objective:

- Water Quality Grants ($146 million over five years)
- Reef Partnerships ($12 million over five years)
- Land and Sea Country Indigenous Partnerships ($10 million over five years)
- Reef Water Quality Research and Development ($10 million over five years)
- Water Quality Monitoring and Reporting, including the publication of an annual Great Barrier Reef Water Quality Report Card ($22 million over five years).

Through Reef Rescue, the Australian Government has committed to delivery of the following five-year outcomes:

- Reduce the discharge of dissolved nutrients and chemicals from agricultural lands to the Great Barrier Reef lagoon by 25 per cent.
- Reduce the discharge of sediment and nutrients from agricultural lands to the Great Barrier Reef lagoon by 10 per cent.
- In Reef catchments, increase the adoption of improved land management practices by at least 30 per cent of agricultural land managers.

Queensland Government's commitment to Reef Plan

Since the commencement of Reef Plan in 2003, the Queensland Government has invested approximately $25 million annually on natural resource management in Reef catchments, including reef water quality related projects. This is an investment in the health of the entire catchment that ultimately supports a healthy reef ecosystem.The Queensland Government is committed to continuing its contribution and has identified that the total Queensland investment in saving the Reef over the next five years will be increased by an additional $50 million to support the reef regulatory package, bringing the total investment to $175 million over the next five years.

Policy and legislative initiatives

One of the new directions for the updated Reef Plan is the implementation of new regulatory measures to ensure the adoption of minimum standards of land management that will improve water quality across the catchments and into the Reef. This is designed to be a 'safety net' to ensure clarity and fairness so that the good efforts of many are not undermined by the poorer practices of a few.

The package of regulatory measures is a new initiative that aims to:

1. phase out clearly unacceptable farm management practices from Reef catchments within a reasonable timeframe
2. increase the number of primary producers in priority Reef catchments who have implemented accredited property management plans that will ensure measurable water quality benefits are achieved.

The new measures will accelerate primary producers' adoption of improved land management practices and complement the Reef Rescue and other Caring for our Country grants programs. New regulations will be developed in 2009 in close consultation with industry and other relevant stakeholders and will be led by the Queensland Environmental Protection Agency.

Industry and community-based initiatives

Industry and the community play a vital role in delivering the objectives of the Plan. A number of existing initiatives are already being implemented, including the Rural Water Use Efficiency Program and Blueprint for the Bush, which is a 10-year partnership plan between the Queensland Government, AgForce and the Local Government Association of Queensland to foster and support sustainable, liveable and prosperous rural communities in Queensland.

Other industry and community-based initiatives include:

- implementation of improved agricultural practices by individual landholders
- community groups, including Waterwatch, Catchment Management, Landcare and Coastcare groups, that play a significant role in raising community awareness and implementing actions
- work of Statutory Authorities such as River Improvement Trusts and the Wet Tropics Management Authority
- indigenous groups that have developed land use agreements (ILUAs) or management agreements (e.g. TUMRAs)
- regional NRM Bodies that play a key role in implementing actions at the regional level
- local governments that have a strong role in water quality improvement, land management and ecosystem protection.

Reef Plan strongly supports continued partnerships between government and industry to develop innovative new ways to manage our land and improve water quality.

Acronyms

ABS	Australian Bureau of Statistics
AGLC	Australian Government, Lands and Coasts
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFF	Australian Government, Department of Agriculture, Fisheries and Forestry
DEEDI	Queensland Government, Department of Employment, Economic Development and Innovation (includes the former Department of Primary Industries and Fisheries)
DERM	Queensland Government, Department of Environment and Resource Management (includes the former Department of Natural Resources and Water and the Environmental Protection Agency)
DEWHA	Australian Government, Department of Environment, Water, Heritage and the Arts
DIP	Queensland Government, Department of Infrastructure and Planning (includes the local government section of the former Department of Local Government, Sport and Recreation)
DPC	Queensland Government, Department of the Premier and Cabinet
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
IOC	Intergovernmental Operational Committee
Joint AG NRM Team	Joint Australian Government Natural Resource Management Team
JSIP	Joint Strategic Investment Panel
LGAQ	Local Government Association of Queensland
NRM bodies	Natural Resource Management bodies
QFF	Queensland Farmers Federation
R&D	Research and Development
RIG	Regional Implementation Group
RWQP	Reef Water Quality Partnership
SAP	Scientific Advisory Panel
TUMRA	Traditional Use of Marine Resources Agreement
WQIP	Water Quality Improvement Plan
WWF	World Wildlife Fund Australia

Annexe 1

Terms of reference for the Partnership Committee

Background

A key component of Reef Plan to date has been the Reef Water Quality Partnership (RWQP). This Partnership was formed to ensure ongoing collaboration between Australian and Queensland government agencies and regional natural resource management (NRM) bodies of the Great Barrier Reef Catchments. The RWQP had a Management Committee, Regional Implementation Group and Science Advisory Panel, which collectively facilitated and oversaw the implementation of work plans to deliver coordinated reef water quality monitoring and reporting activities.

The review of Reef Plan in 2005 highlighted the need to develop more effective partnerships with industry sectors, regional NRM bodies and the wider community.

The RWQP Management Committee is reconstituted as the Partnership Committee (the Committee) in the updated Reef Plan. Membership of the Committee is expanded to include representatives of the agricultural industry and conservation groups with an independent chair. The terms of reference for the Committee are set out below.

Independent Chair

An independent person appointed by the Great Barrier Reef Ministerial Council will chair the Committee.

The Chair will provide an annual report to the Great Barrier Reef Ministerial Council on the operation of the committee. The report should:

- describe the number of meetings held and summarise the issues considered
- comment on stakeholders contributions to the Committee
- provide a summary of stakeholders views on Reef Plan progress
- identify any key issues raised by stakeholders that influence timely implementation of Reef Plan
- recommend any changes to the function of the Committee or additional actions that need to be taken to ensure adequate progress in implementing Reef Plan.

Members

Membership of the Committee comprises two nominated senior representatives (with identified alternatives) from each of the following:

- State Government of Queensland
- Australian Government
- the agricultural industry
- Natural Resource Management regional bodies
- conservation organisations.

The Reef Plan Secretariat, based in the Queensland Department of the Premier and Cabinet, provides Secretariat support.

Role

The Partnership Committee promotes a partnership approach to implementation of Reef Plan. It is responsible for providing advice directly to the Intergovernmental Operational Committee (IOC) on the operational implementation of the Reef Plan. Its role is to:

- consider and provide advice to the IOC on Reef Plan actions, strategies and implementation plans developed by action managers
- consider and provide advice to the IOC on the reporting by action managers against implementation plans
- consider and provide advice to the IOC on annual reports on Reef Plan implementation
- propose to the IOC possible areas of work to continuously improve the implementation of the Reef Plan
- as requested by the IOC, provide advice on membership and terms of reference for working groups and other committees that may be established by the IOC
- other tasks as requested by the IOC.

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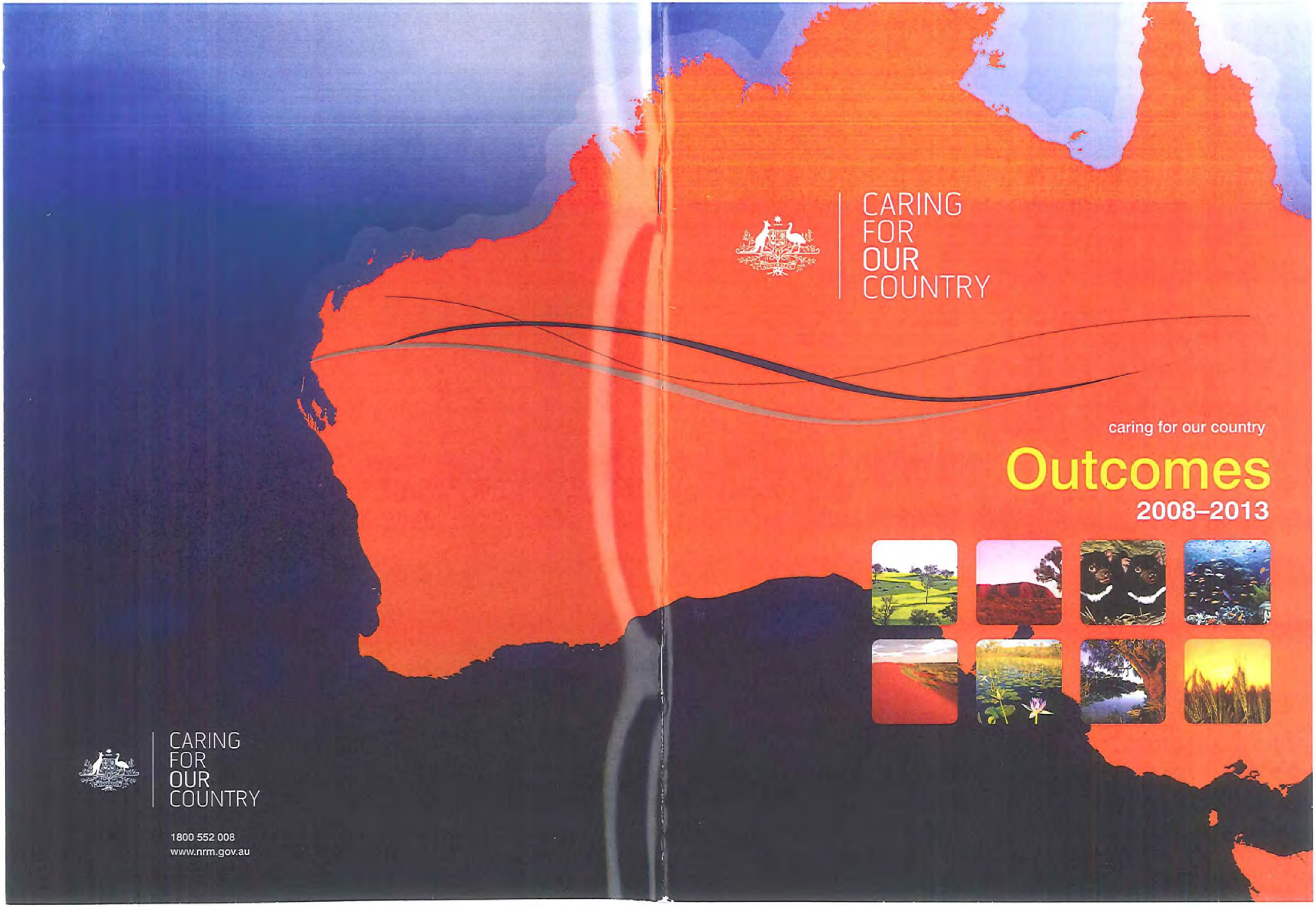
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Ministers' Foreword

Australia's environment, natural icons and productive landscapes are central to our national identity. We derive a significant proportion of our nation's wealth from our environmental assets through agriculture, mining and tourism.

The Australian community, farmers and other land managers have worked hard to improve the health of our environment and the way in which we manage our resources.

However, the recent State of the Environment report (2006) provides evidence of the continuing vulnerability of Australia's natural environment and threats to its capacity to support sustainable food and fibre industries.

Climate change coupled with increased climate variability contributes to this vulnerability, and emphasises the need to improve Australia's environment and natural resource base.

Through Caring for our Country, we will work with governments, regional and local communities, industries and land managers to achieve an environment that is healthier, better protected, well managed, resilient and can provide essential ecosystem services, particularly in a changing climate.

Our investment of $2.25 billion over the first five years of Caring for our Country will be targeted at achieving a real and measurable difference to Australia's environment.

We believe it is no longer good enough to invest public funds without the discipline of establishing clear national investment priorities or articulating the outcomes we expect to achieve with the investment of those funds.

The attached statements outline what we consider to be ambitious but achievable outcomes for the first five years of Caring for our Country.

These outcome statements will be used to help determine our priorities for investing Caring for our Country funds and to help us make decisions about the most efficient way of taking action.

Each year, we will provide the Australian community with a report on our progress towards achieving these outcomes. We anticipate that climate change will bring with it more severe weather events which may hamper our efforts, but believe that this creates an even greater need for clear goals.

We invite all Australians to join us in building a sustainable future under Caring for our Country.

The Hon Peter Garrett AM MP
Minister for the Environment, Heritage and the Arts

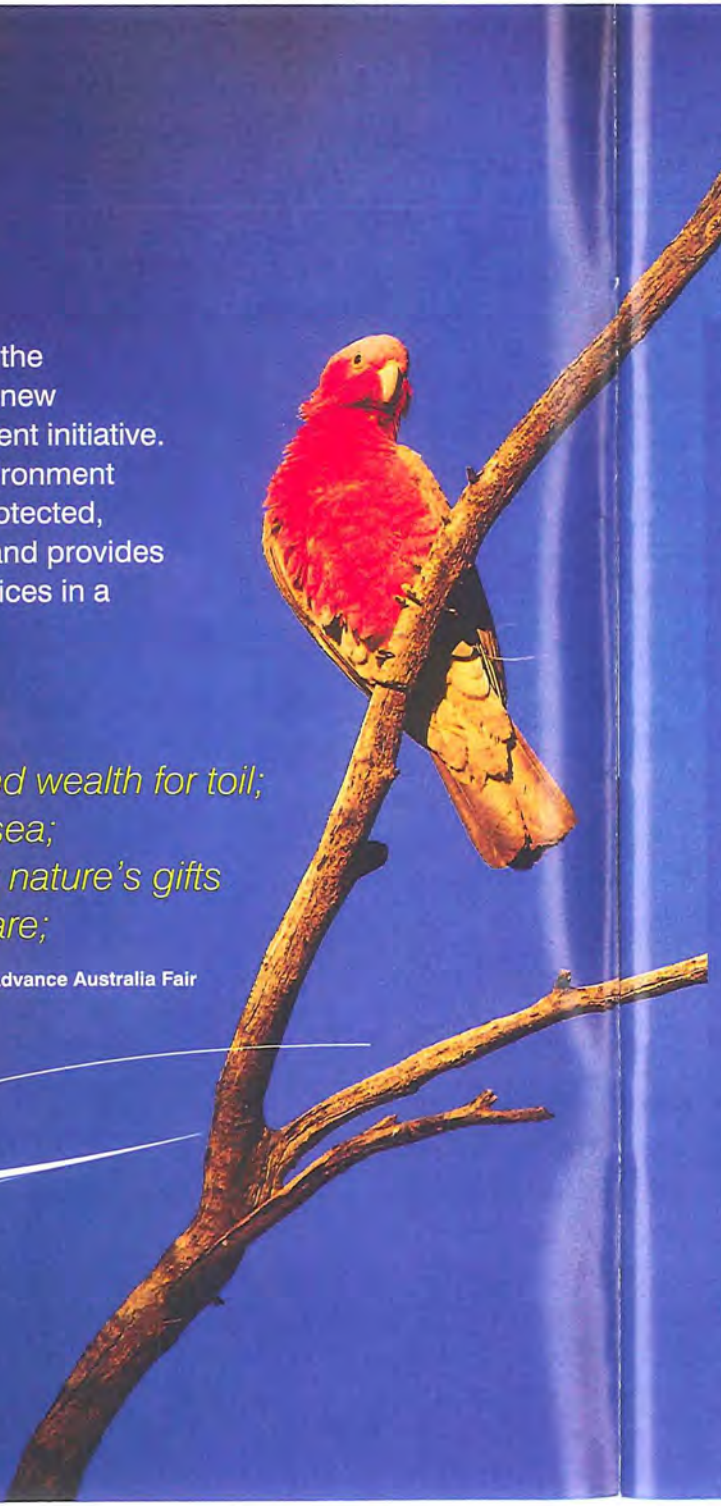
The Hon Tony Burke MP
Minister for Agriculture, Fisheries and Forestry

Introduction

Caring for our Country is the Australian Government's new environmental management initiative. It aims to achieve an environment that is healthier, better protected, well managed, resilient, and provides essential ecosystem services in a changing climate.

We've golden soil and wealth for toil;
Our home is girt by sea;
Our land abounds in nature's gifts
Of beauty rich and rare;

– Advance Australia Fair



In its first five years (from July 2008 to June 2013), the Australian Government will invest $2.25 billion through Caring for our Country to secure improved strategic outcomes across six national priority areas:

- the National Reserve System
- biodiversity and natural icons
- coastal environments and critical aquatic habitats
- sustainable farm practices
- natural resource management in northern and remote Australia, and
- community skills, knowledge and engagement.

Caring for our Country will be delivered in partnership with regional natural resources management groups, local, state and territory governments, Indigenous groups, industry bodies, land managers, farmers, landcare groups and communities.

This document outlines the specific outcomes that Caring for our Country will deliver in its first five years of operation, and the potential strategies for achieving these outcomes.

The document places these outcomes in the context of 20 year projections of the results the Australian Government expects Caring for our Country to deliver in each of the six national priority areas.

The strategies and investments delivered under Caring for our Country will frequently contribute to multiple outcomes across different priority areas.

For example, investments in improving the biodiversity of Australia's landscapes, and in improving sustainable farm practices, will in many cases be mutually supporting.

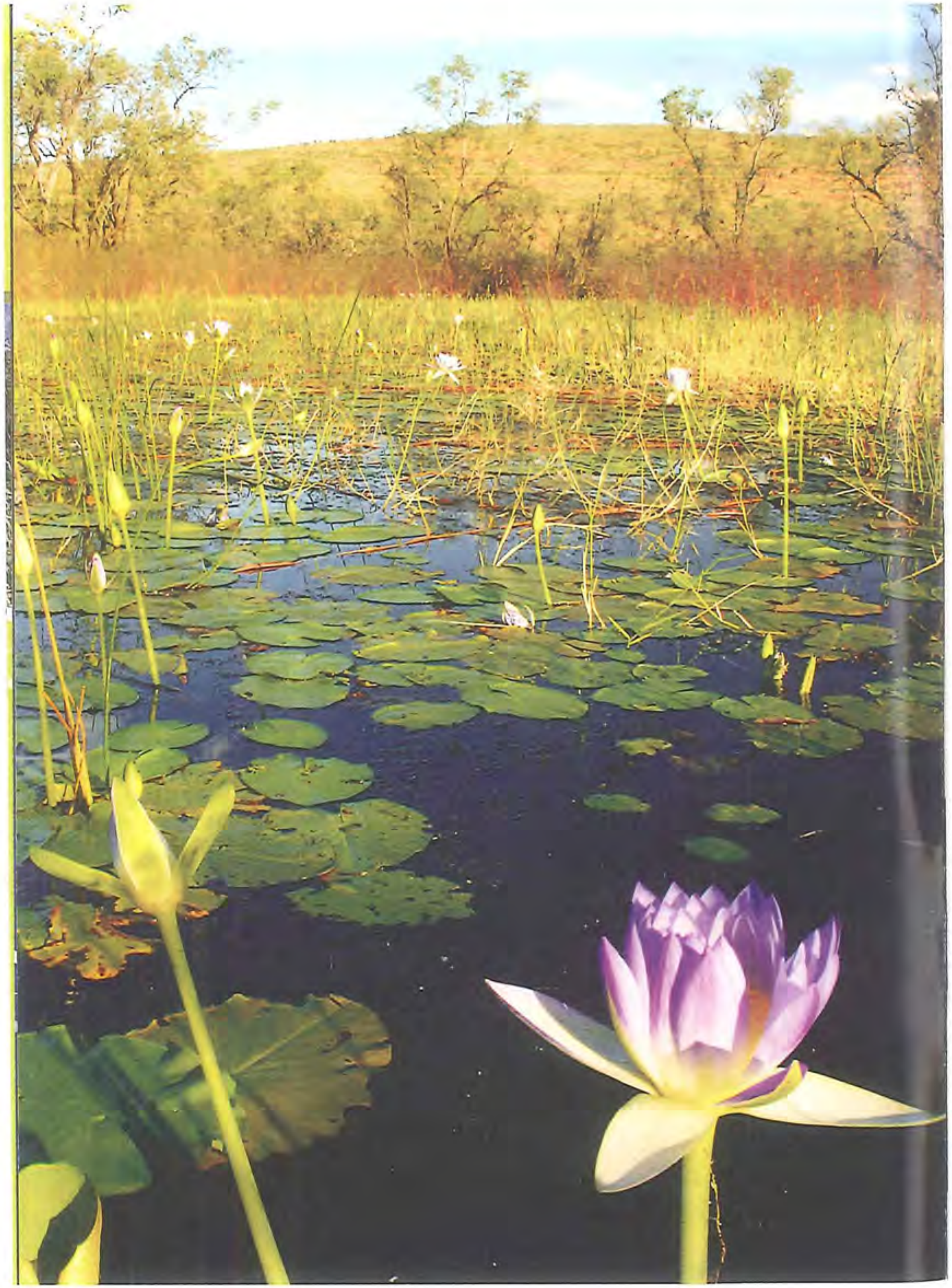
Caring for our Country investments will also complement other Australian Government programs such as Water for the Future and Australia's Farming Future.

Caring for our Country annual business plans will be released towards the end of each year, and will outline 1-4 year targets to ensure we stay on track to achieve the outcomes.

These business plans will invite proposals to deliver against the strategic objectives set out in the outcomes statements.

A Caring for our Country monitoring, evaluation, reporting and performance improvement strategy will provide specific details on measuring progress towards achieving the outcomes.

Progress will be reported through an annual report card. The report card will inform the Australian Government and community on how future Caring for our Country investments should be delivered and focused.



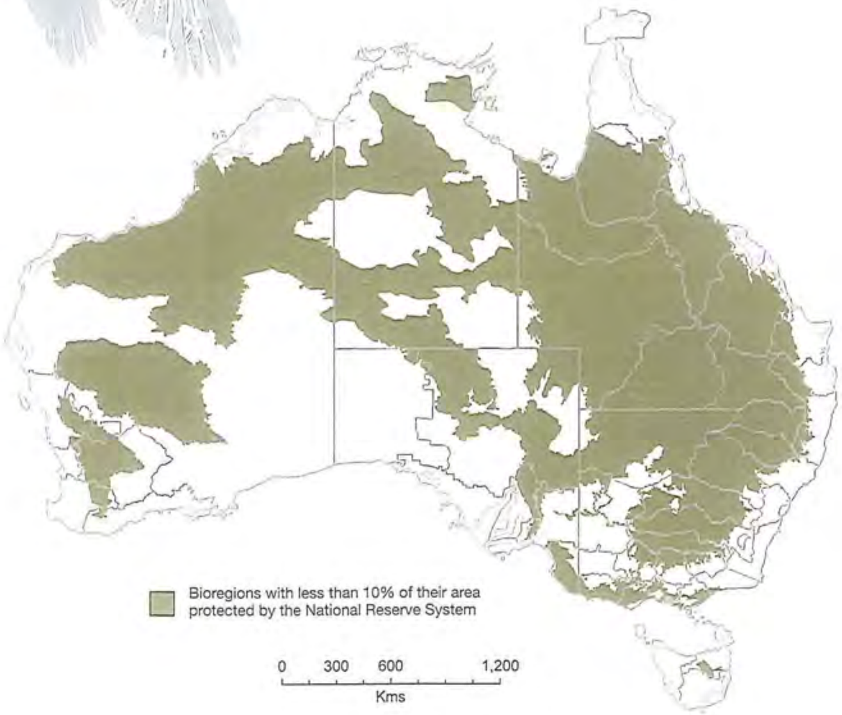
Australia's National Reserve System

Five-year Outcomes:

By 2013, Caring for our Country will:

- Expand the area that is protected within the National Reserve System to at least 125 million hectares (a 25 per cent increase), with priority to be given to increasing the area that is protected in under-represented bioregions.
- Expand the contribution of Indigenous Protected Areas to the National Reserve System by between 8 and 16 million hectares (an increase of at least 40 per cent).
- Increase from 70 per cent to 100 per cent the proportion of Australian Government-funded protected areas under the National Reserve System that are effectively implementing plans of management.

The threats to biodiversity posed by climate change and other pressures require us to accelerate our efforts to expand and better manage Australia's National Reserve System.



Source Data: National Reserve System based on Collaborative Australian Protected Area Database (CAPAD) to 30 June 2006 and Indigenous Protected Areas to 30 June 2008.
Bioregions are Interim Biogeographic Regionalisation of Australia (IBRA) version 6.1.
NRM regions supplied by state and territories to form a national dataset with consistent attributes based on Geosciences Australia 1:100,000 coastline.

Long Term (20 year) Projection:

A well managed, comprehensive, adequate and representative National Reserve System has been established to protect in perpetuity examples of at least 80 per cent of the extant native ecosystems present in Australia.[1]

This mature network of protected areas will provide an essential safety net for Australian biodiversity in a changing climate.

It will complement other efforts (in particular actions to improve vegetation, habitat and water quality) by the Australian Government and its investment partners to conserve biodiversity and meet Australia's international obligations to protect our native species and their habitats.

1 Native ecosystems identified in each Interim Bio-geographic Regionalisation of Australia (IBRA) region. Further information can be found in the National Reserve System Directions Statement available at: www.environment.gov.au/parks/publications/nrs/directions.html

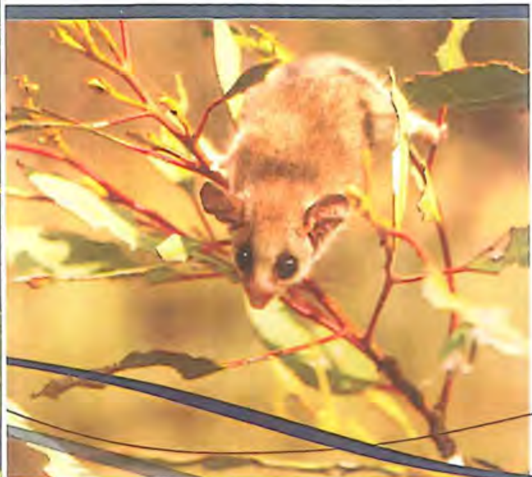
Strategies To Achieve The Five-Year Outcomes:

Expand the National Reserve System

- Purchase land, or use voluntary covenants to expand the National Reserve System, including the Indigenous Protected Areas.

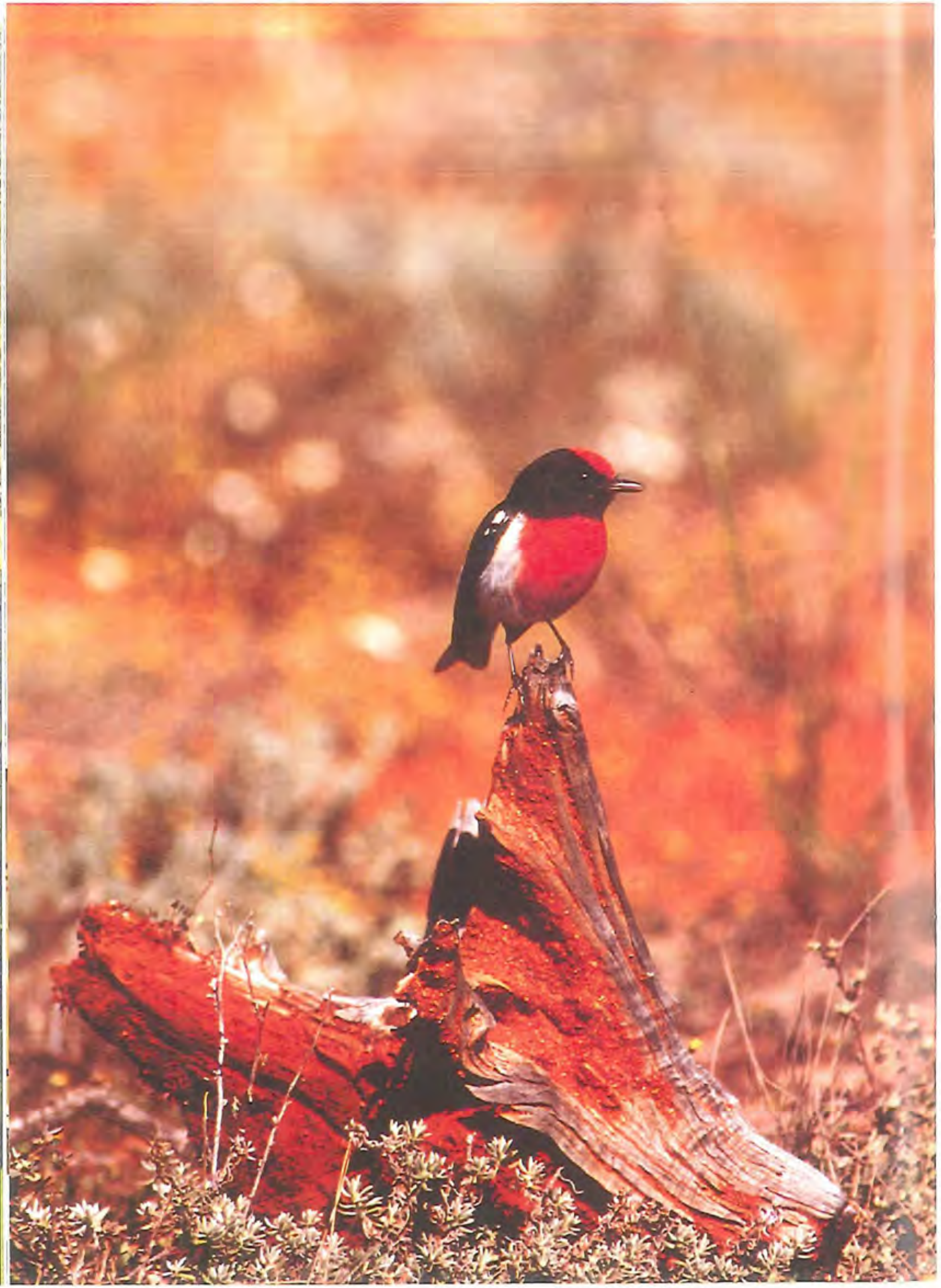
Improve the management of the National Reserve System

- Assess the management of areas within the National Reserve System against consistent standards, and ensure management actions are focused on protecting biodiversity values and improving resilience in the face of climate change and other pressures.
- Employ additional Indigenous Rangers to assist in the management of selected Indigenous Protected Areas.



Plan for the future of the National Reserve System in the face of threats such as climate change

- Identify key climatic refugia in bioregions, and identify priorities for landscape scale biodiversity conservation, and prioritise the purchase of land to include these areas in the National Reserve System.
- Enhance existing partnerships with Indigenous communities, farmers, and local governments in building the National Reserve System. For example, where there is a priority to include habitats on private land within the System, we will work with and support farmers in establishing conservation covenants to protect and maintain these habitats.
- Establish a standard monitoring and reporting system across all protected areas funded by the Australian Government to better track the on-ground outcomes of investments, and trends in the condition of areas within Australia's protected area estate.



Biodiversity and Natural Icons

Five-year Outcomes:

By 2013, Caring for our Country will:

- Increase, by at least one million hectares, the area of native habitat and vegetation that is managed to reduce critical threats to biodiversity and to enhance the condition, connectivity and resilience of habitats and landscapes. This is additional to the 125 million hectares that is to be protected within the National Reserve System.
- Reduce the impact of invasive species:
  - rabbits and rodents on Macquarie Island (Tasmania)
  - the southern and westward migration of Cane Toads
  - Tramp Ants and camels in at least one priority area[2]
  - in at least four other priority areas to be defined through the annual Caring for our Country business plans.
- Secure management arrangements for all World Heritage areas that meet the requirements of the World Heritage Convention.
- Improve the protection and management of Ningaloo Reef.
- Maintain viable Tasmanian Devil populations.

2 The priority area or areas will be identified through the annual Caring for our Country business plans.

Australia's unique biodiversity underpins the functioning of our natural and productive landscapes, but faces threats from habitat destruction, invasive species, pollution and climate change. These threats need to be systematically addressed.

Our World Heritage and National Heritage sites include places with very high environmental, social and economic values. Effective protection of these natural icons is needed to preserve them.

Long Term (20 year) Projection:

The declining trend of Australia's biodiversity has been reduced and our native flora, fauna and ecosystems have the best protection possible, especially given their vulnerability to climate change and other pressures.

Activities to conserve and manage Australia's biodiversity and natural icons will:

» be integrated across the Australian landscape—maximising the conservation benefits that can be drawn from Australia's protected area estate (including the National Reserve System), and World Heritage and National Heritage places, and complementary land uses on both public and private lands.

» include the most effective actions to protect threatened species and ecological communities, enhance habitat condition and connectivity, minimise threats to biodiversity, and strengthen ecological resilience[3] and productive capacity.

3 Ecological resilience represents the capacity of the natural environment to maintain critical ecological functions over time when exposed to disturbances and other shocks, such as fires and the impacts of invasive species and climate change. Further research will be needed to develop approaches to describe and monitor ecological resilience.

Strategies To Achieve The Five-Year Outcomes:

Enhance the connectivity of native habitats and ecological communities across the Australian landscape

» Identify and implement cost-effective conservation measures tailored to national and regional needs, including measures such as the retention of refugia that are needed to adapt to climate change.

» Apply market-based approaches, financial incentives, the use of voluntary covenants, and other voluntary measures to protect and improve biodiversity on both private and public land.

» Provide land managers with the information, skills and incentives to adopt sustainable land management practices that support biodiversity conservation.

Support the systematic appraisal of biodiversity in regions

» Use the best available information to assess biodiversity values, conditions and trends, and threatening processes.

» Ensure, through appropriate landscape scale planning, that investments in the conservation and management of private land complement the National Reserve System.

Improve the management of Australia's protected area estate

- Support actions that complement the conservation objectives of Australia's protected area estate, such as developing native vegetation buffers on private land around National Reserve areas.
- Invest in actions to reduce critical threats, improve, restore or enhance the outstanding universal values of World Heritage places, and the national values of National Heritage places.

Reduce the impact of invasive species

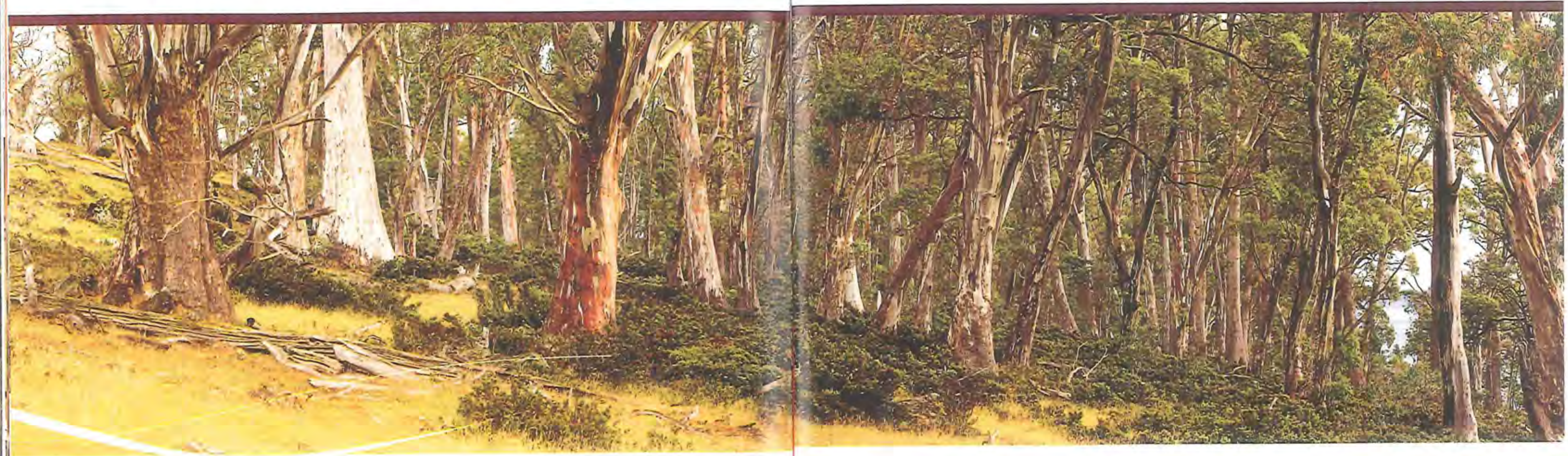
- Invest in activities to eradicate rabbits and rodents from Macquarie Island.
- Invest in actions to eradicate Tramp Ants in at least one priority area.
- Invest in actions to significantly reduce the impact of camels in at least one priority area.
- Develop a threat abatement plan to identify strategies for curbing the western and southward movement of the Cane Toad.
- Invest in activities to find methods for containing or eradicating nationally significant weed species.

Protect nationally threatened and iconic species

- Invest in research to find a solution to the Tasmanian Devil facial tumour disease and assist in establishing a disease-free Devil population.
- Focus on protecting the habitats and communities of nationally threatened and endangered species and endangered ecological communities (including through engaging private landholders and expanding the National Reserve System).

Expand Australia's protected area estate

- Nominate Ningaloo Reef and at least one other iconic area[4] for inclusion in the World Heritage List.



4 To be identified following consultation and assessment of areas with values that have a high potential to meet World Heritage listing criteria; and included in future Caring for our Country business plans.

Coastal Environments and Critical Aquatic Habitats

Five-year Outcomes:

By 2013, Caring for our Country will:

» Reduce the discharge of dissolved nutrients and chemicals from agricultural lands to the Great Barrier Reef lagoon by 25 per cent.

» Reduce the discharge of sediment and nutrients from agricultural lands to the Great Barrier Reef lagoon by 10 per cent.

» Deliver actions that sustain the environmental values of:

- priority sites in the Ramsar estate[5], particularly sites in northern and remote Australia
- an additional 25 per cent of (non-Ramsar) priority coastal and inland high conservation value aquatic ecosystems including, as a priority, sites in the Murray—Darling Basin.[6]

» Improve the water quality management in the Gippsland Lakes in Victoria, the Tuggerah Lakes Estuary in New South Wales and in all priority coastal hotspots[7].

» Increase the community's participation in protecting and rehabilitating coastal environments and critical aquatic habitats.

5 The priority sites will be progressively identified in the annual Caring for our Country business plans.

6 A schedule of priority high conservation value critical aquatic ecosystems will be included in the annual Caring for our Country business plans and updated/revised as new information becomes available. The priority areas identified in this schedule will be the rivers, wetlands, floodplains, lakes, inland saline ecosystems, groundwater dependent ecosystems and estuaries that have been identified by the Australian Government as priorities for management. These aquatic ecosystems include ecosystems in coastal areas, but not the marine environment.

7 A preliminary list of Priority Coastal Hotspots which significantly contribute to the quality of Ramsar wetlands and other high conservation value aquatic ecosystems has been developed in consultation with jurisdictions (see www.nrm.gov.au). This list will be further developed throughout the first five years of Caring for our Country.

Australia's coasts and critical aquatic habitats are significant environmental assets which are also fundamentally important to the Australian lifestyle and economy. These assets face significant pressures including declining water quality (and quantity), climate change, dune erosion, habitat loss from urban development, land clearing and increasing traffic in our ports and marinas. Our coasts and aquatic habitats require better management and protection to ensure they are sustained into the future. The Great Barrier Reef is an internationally significant symbol of Australia and requires special protection.

Long Term (20 Year) Projection:

The impact of threats to the Great Barrier Reef from sediments and nutrients has been reversed, and water quality and aquatic health has been improved. Management arrangements are established in Reef catchments to prevent further deterioration, especially given the Reef's vulnerability to climate change.

The impact of threats to Australia's coastal environments, Ramsar wetlands, and other high value aquatic environments has been reversed. High value aquatic environments in poor condition have been restored and the decline in the fragmentation of coastal habitats has been arrested.

Australian communities have the information and social and institutional structures to effectively address local threats to coastal environments and critical aquatic habitats. These local capacities are integrated with broader national efforts to maintain and improve the quality, protection and management of coastal and aquatic environments.

Strategies To Achieve The Five- Year Outcomes:

Further reduce sediment and nutrient discharge from agricultural lands:

a) into the Great Barrier Reef lagoon

b) into Ramsar sites and priority coastal hotspots

- In Reef catchments, provide incentives to increase the adoption of improved land management practices by at least 30 per cent of agricultural land managers.

- In priority coastal hotspot areas, and areas surrounding Ramsar sites, provide incentives to achieve the adoption of improved land management practices by at least 30 per cent of agricultural land managers. Improved land management practices include techniques such as:
  - Protecting high conservation value areas of vegetation through stewardship arrangements
  - Establishing buffer zones and strategic fencing activities such as off-stream watering points for stock management and pasture/stock monitoring
  - Improving chemical use, particularly fertiliser efficiency and developing and applying alternatives to, or using herbicides more efficiently
  - Reducing and managing acid sulphate soils and salinity
  - Restoring wetlands
  - Revegetating and managing weeds in major waterways and remnant bushland.

Rehabilitate and protect nationally significant coastal and aquatic environments

- Invest in planning and on-ground actions that protect the conservation values of coastal and inland high conservation value aquatic ecosystems, including priority Ramsar wetlands, the Tuggerah Lakes Estuary and the Gippsland Lakes.

- Work in partnership with other Australian Government programs, such as Water for the Future, to identify, manage and protect high conservation value ecosystems in the Murray—Darling Basin.

Build the capacity of the community and land managers, including Indigenous communities, to support and undertake actions to improve coastal and aquatic environments

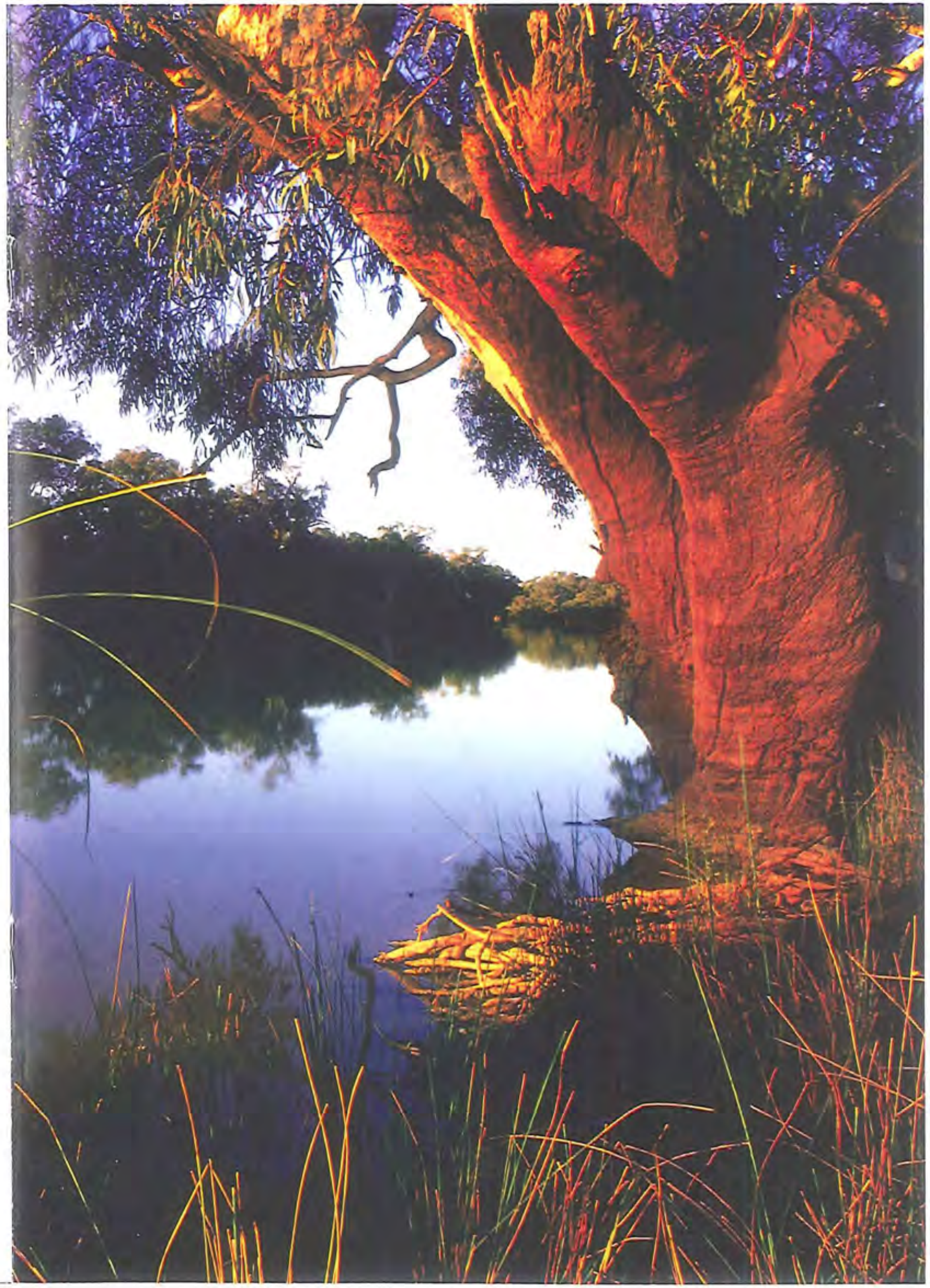
- Through training measures and providing better access to knowledge, enhance the capacity and skills of the community to undertake actions that will protect and rehabilitate coastal waterways and wetlands, prevent coastal erosion, and protect important migratory bird sites.

- Developing Indigenous land and sea country management projects.

- Work with Indigenous communities to record and pass on Traditional Knowledge, and protect Indigenous cultural landscapes and culturally sensitive sites that are related to coasts and critical aquatic habitats.

Understand and measure water quality and environmental change

- Invest in research and development to:
  - Improve understanding of the link between land management practices and environmental impacts
  - Trial new technologies or land management techniques which may improve water quality in Reef catchments, Ramsar sites and priority coastal hotspot areas
  - Develop and apply new water quality monitoring techniques for nutrients, chemicals and sediments.
- Continue and expand the existing Reef water quality monitoring program, including through implementing a coordinated catchment-wide water quality monitoring and measurement program.
- Measure improvements in the water quality of rivers and streams flowing into high conservation value aquatic ecosystems, and use this information to better target further investments.



Sustainable Farm Practices

Five-year Outcomes:

By 2013, Caring for our Country will:

» Assist at least 30 per cent of farmers to increase their uptake of sustainable farm and land management practices that deliver improved ecosystem services.

» Increase the number of farmers who adopt stewardship, covenanting, property management plans or other arrangements to improve the environment both on-farm and off-farm.

» Improve the knowledge, skills and engagement of at least 30 per cent of land managers and farmers in managing our natural resources and the environment.

Sixty per cent of Australia's landscapes are privately owned or leased for agricultural production. The practices adopted by land managers of these landscapes can contribute to environmental sustainability, and further improve the long-term security of food and fibre production. Equally, the long-term viability and health of our natural resources is critical to maintaining and building the productive capacity of Australia's agricultural industries.

Long Term (20 Year) Projection:

Australia's agricultural lands will support and maintain clean water, biodiversity and healthy soils, while continuously improving food and fibre productivity. The agricultural sector will be based on the sustainable management of natural resources and be better able to respond to the threats and opportunities created by changing circumstances, particularly a changing climate.

Strategies To Achieve The Five-Year Outcomes:

Improve the environmental outcomes from farm management while maintaining or improving productivity

- Support on-farm actions and investments that improve natural assets (including soil, water and biodiversity) and reduce the impact of invasive species.
- Support the use of flexible, innovative and cost-effective approaches, including market-based incentives, to deliver sustainable on-farm natural resources management and improve our natural assets.

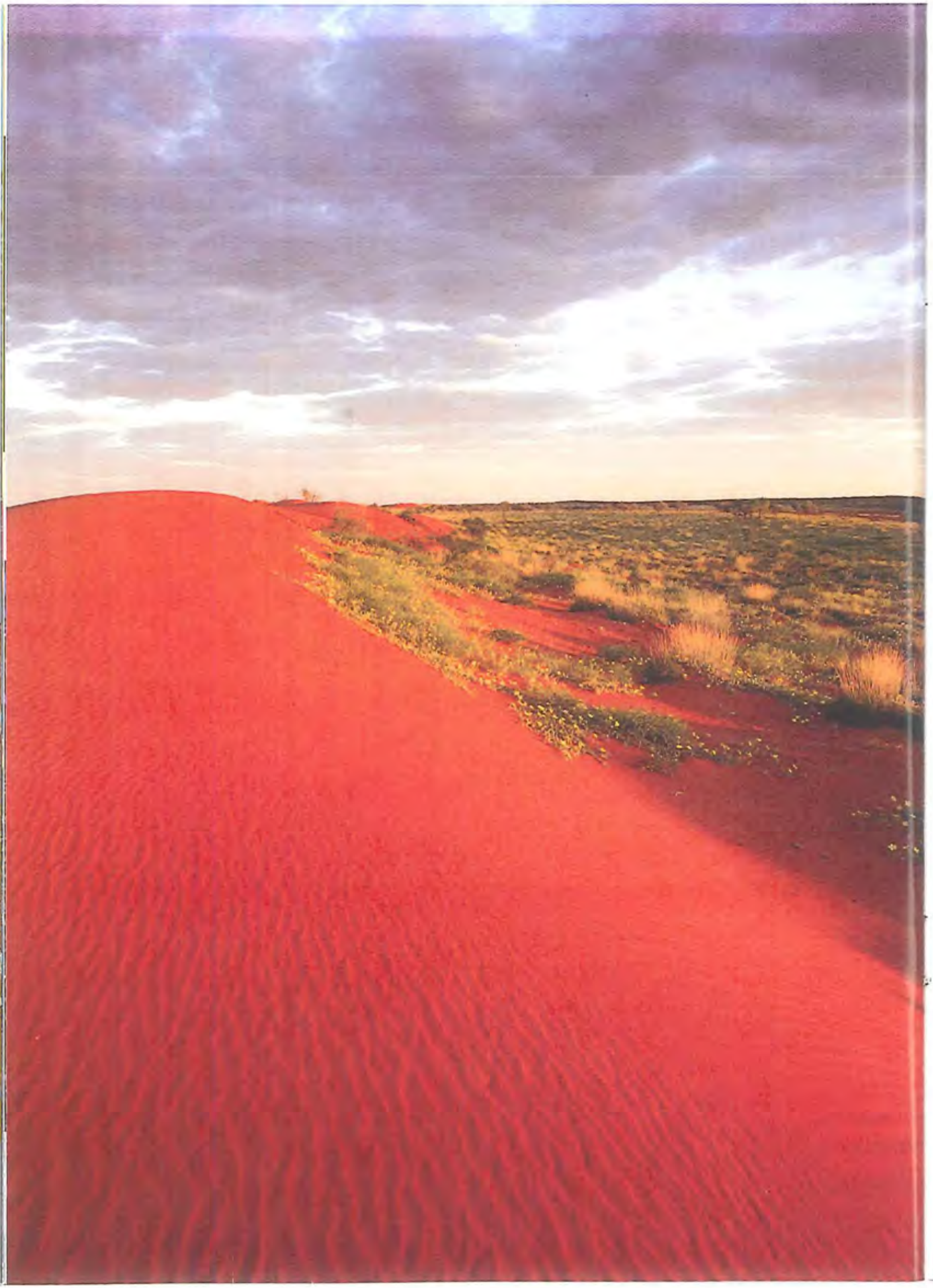
Provide information to allow farmers to make better decisions in a changing climate

- Support the uptake of sustainable farming techniques and technology by providing information and advice on:
  - new technologies, sustainable farm practices, and ecosystems services
  - the management of emerging threats to sustainable food and fibre production, including weeds, salinisation and pest animals.

Work with community and industry organisations, including landcare, to accelerate the adoption of more sustainable farm management

» Support the work of voluntary groups, including landcare groups, to build the skills and capacity of land managers and farmers to deal with emerging threats and opportunities relating to sustainable production and land management.

» Encourage effective partnerships between key stakeholders, including industry, regional, community and landcare groups, research and teaching organisations and governments which will drive on-ground practice change.



Northern and Remote Australia

Five-year Outcomes:

By 2013, Caring for our Country will:

» Protect important natural assets in northern and remote Australia, particularly the National Reserve System (and Indigenous Protected Areas within it).

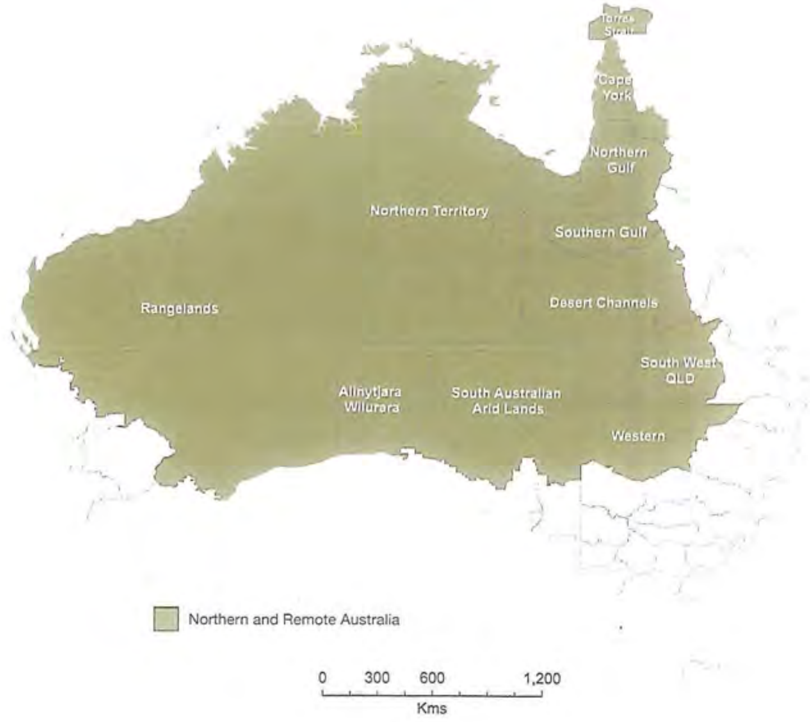
» Assist at least 30 per cent of land managers in northern and remote Australia to increase their uptake of sustainable grazing and land management practices.

» In priority areas in northern and remote Australia, reduce the impact of invasive species including, in particular, Cane Toads, Tramp Ants and camels.

» Expand traditional fire management regimes, across at least 200,000 square kilometres of northern Australia's savannas, to reduce the incidence of unmanaged fires, and position Indigenous land managers for entry into emerging voluntary or other emissions trading markets.

Northern and remote Australia contains some of our most intact high conservation value landscapes and environmental assets, and valuable productive resources with a high potential for future development. These assets will therefore be a major focus for Australian environmental and natural resource management effort in coming years. The unique environmental, social and economic challenges faced by northern and remote Australia require a tailored approach to sustainable natural resources use and environmental protection.

For the purposes of Caring for our Country, northern and remote Australia includes the following Natural Resource Management Regions: Rangelands, Northern Territory, Alinytjara Wilurara, South Australian Arid Lands, Desert Channels, Southern Gulf, Northern Gulf, Cape York, Torres Strait, South West Queensland and Western New South Wales (see map right).



Source Data: © The Australian Government with the cooperation of state and territory government agencies
Topographic Data 1:10,000,000 © The Australian Government, Geoscience Australia
Map Produced by: Environmental Resource Information Network (ERIN), Department of the Environment, Water, Heritage and the Arts, 2008

Long Term (20 Year) Projection:

The environmental and productive prospects of northern and remote Australia will be enhanced by protecting the ecological processes that support the natural environments and sustainable development of these areas.

Australia's tropical and arid landscapes and ecosystems in northern and remote Australia protected and appropriately managed.

Effective partnerships between governments, communities, industry, Indigenous Australians, regional bodies and land managers help maintain the long-term environmental and productive sustainability of northern and remote Australia.

Strategies To Achieve The Five-Year Outcomes:

Ensure that other Caring for our Country priorities are being addressed in northern and remote Australia

» Protect key natural assets (including those of particular cultural relevance to Indigenous Australians) through Indigenous Protected Areas and the National Reserve System.

» Enhance the connectivity of native habitats and ecological communities.

» Implement strategies that reduce the impact and spread of invasive species, including the Cane Toad.

» Facilitate the uptake of sustainable farm practices.

» Protect coastal environments, Ramsar wetlands, and other high conservation value aquatic ecosystems.

» Consult with stakeholders to determine improved arrangements for achieving national priorities and outcomes in northern and remote Australia.

Build partnerships that support a more sustainable approach to land management across all land tenures

» Increase the number of northern and remote communities and land managers who are provided with information, training and other support, to manage natural resources sustainably and to deliver effective ecosystem services.

» Contribute to at least five major regional partnerships with industry and other stakeholders, and at least 30 enduring partnerships with Indigenous groups (from a total of 50 partnerships nationwide – see also the Indigenous partnership strategy under the Community skills, knowledge and engagement priority area). These partnerships will:

- align the plans, investments and actions of partners
- seek to leverage cross-tenure action to achieve the outcomes sought from Caring for our Country
- include engagement with:
  a. relevant Australian Government agencies on initiatives such as the Office of Northern Australia, the Northern Australia Water Futures Assessment and the Tropical Rivers and Coastal Knowledge research hub[8] to ensure investments and approaches are consistent and complement each other
  b. landholders on measures to improve agricultural and other land management practices
  c. Indigenous Australians, including through the employment of Indigenous Rangers, to help protect environmental values, maintain traditional ecological knowledge, and provide economic benefits to remote Indigenous communities
  d. relevant industry sectors (including the mining, pastoral, and agriculture sectors) on sustainable land management practices and to encourage the protection and maintenance of natural values and ecological processes.

Ensure Indigenous groups are consulted and engaged in on-ground activities to improve management of the environment

» Determine capacity and facilitate Indigenous participation in emerging emissions reduction markets.

» Establishing, in consultation with Indigenous groups, landscape-scale fire management projects covering at least 200,000 square kilometres across the savannas in northern Australia to reduce the incidence of uncontrolled wildfires in northern and remote Australia, and their impact on grazing land, natural environments and, potentially, greenhouse-gas emissions.[9]

8 For more information about the Northern Australia Land and Water Futures assessment and the Tropical Rivers and Coastal Research (TRACK) hub, please see: http://www.environment.gov.au/water/action/northern-australia/index.html and http://www.track.gov.au/

9 Those actions may be undertaken in conjunction with the Australian Government's commitment to facilitate the entry of Indigenous land managers into emerging carbon trading markets

Community Skills, Knowledge and Engagement

Five-year Outcomes:

By 2013, Caring for our Country will:

- Improve the access to knowledge and skills of urban and regional communities in managing natural resources sustainably and helping protect the environment.
- Increase the engagement and participation rates of urban and regional communities in activities to manage natural resources and to help protect the environment.
- Position all regional natural resource management organisations to deliver best-practice landscape conservation and sustainable land use planning to communities and land managers within their regions.
- Ensure the continued use, support, and reinvigoration of traditional ecological knowledge to underpin biodiversity conservation.

Australia's progress towards a healthier environment and the sustainable use of natural resources depends on the collective actions of many individuals, groups and communities. Their actions need to be strategically supported and resourced.

Long Term (20 Year) Projection:

An informed Australian community that supports, and is effectively and actively engaged in, activities to protect our environment and sustainably manage our natural resources.

Strategies To Achieve The Five-Year Outcomes:

Ensure the public has access to information about the environmental challenges faced by our nation, as well as the state of our natural resources into the future

- Make information more readily available on the state of Australia's natural resources, and the outcomes of Caring for our Country investments, through the facilitator network, website information, information available to regional bodies, publications and public information sessions.
- Invest in actions, in partnership with state, territory and local governments, that support the community's ability to apply this information.
- Provide support for targeted sustainability education in schools by building on work including the Australian Sustainable Schools Initiative, and contributing to the implementation of outcomes outlined in the National Action Plan for Environmental Education.[10]

Engage the community in actions under Caring for our Country

- Contribute to enduring partnerships between relevant partners and stakeholders to enhance their active engagement in natural and cultural resource management. These partnerships will aim to align plans, investments and actions, promote inter-dependence and cooperation, and leverage cross-tenure action to achieve the specific targets and outcomes sought from Caring for our Country.
- Develop at least 50 enduring community-government partnerships with existing Indigenous groups to enhance their active engagement in natural and cultural resource management.
- Provide more effective support to regional groups, landcare groups and community organisations in regional, urban and peri-urban areas, who are working to increase environmental protection and the sustainable management of Australia's natural resources.

10 For more information see: http://www.environment.gov.au/education/nap/index.html

Improve the skills of the Australian community to deal with natural resources challenges

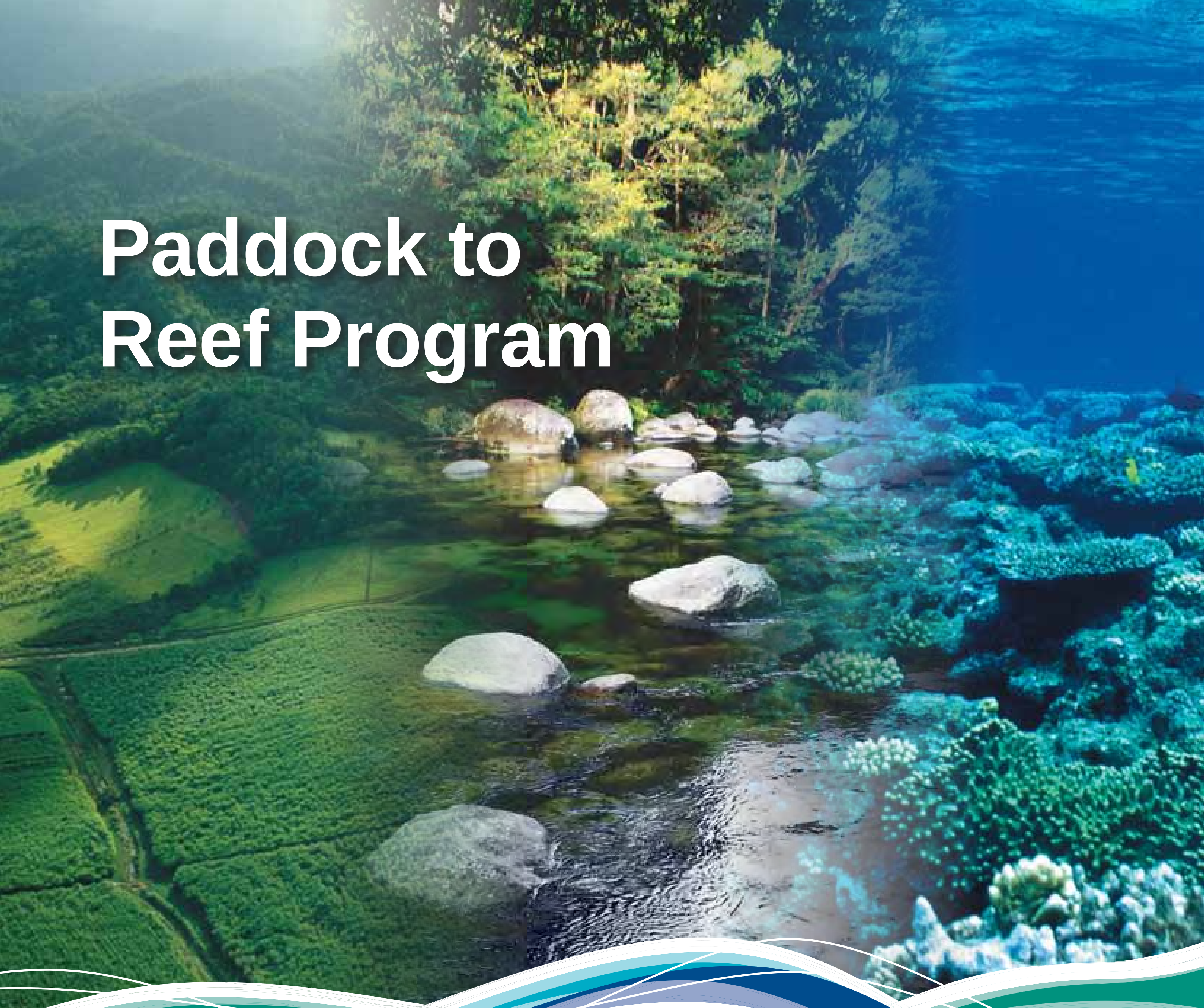
- Train and employ up to 300 Indigenous Rangers to manage and conserve the natural and cultural features of Indigenous lands and waters, including Indigenous Protected Areas.

- Provide information sessions on new technologies and sustainable farm practices to at least 30 per cent of land managers and farmers.

PHOTO CREDITS

PAGES 2, 11 Kerry Trapnell, Office of Minister Burke **PAGES 4-5, 6, 9, 10, 16-17, 32, 39, 42-43, 44** Nick Rains **PAGES 12, 25, 36, 37, 40** Andrew Tatnell **PAGES 14** Dave Watts **PAGE 15** Steve Strike **PAGE 18** Great Barrier Reef Marine Park Authority **PAGES 20-21, 38** Bruce Rose **PAGES 22, 24, 26, 28-29, 30, 31, 46** Department of Agriculture, Fisheries and Forestry **PAGES 23** Ian Oswald-Jacobs **PAGE 35** Mike Jensen **PAGE 45** Bureau of Rural Sciences

Paddock to Reef Program



Integrated monitoring, modelling and reporting

Reef Water Quality Protection Plan

Australian Government

CARING FOR OUR COUNTRY

Queensland Government

This program is supported by the Australian and Queensland governments with funding through the Australian Government Caring for our Country and Queensland Government Coasts and Country initiatives.

Published by the Queensland Government, November 2009, 100 George St, Brisbane Qld, 4000. Updated and reprinted March 2011.

Copies of this publication can be obtained by contacting (07) 3225 8050 or at www.reefplan.qld.gov.au

Objective

The long-term goal of the Reef Water Quality Protection Plan (Reef Plan) is to ensure that the quality of water entering the Great Barrier Reef (the Reef) from adjacent catchments has no detrimental impact on its health and resilience.

The objective of the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program is to measure and report on the progress towards the Reef Plan goals and targets.

Reef Plan 2009

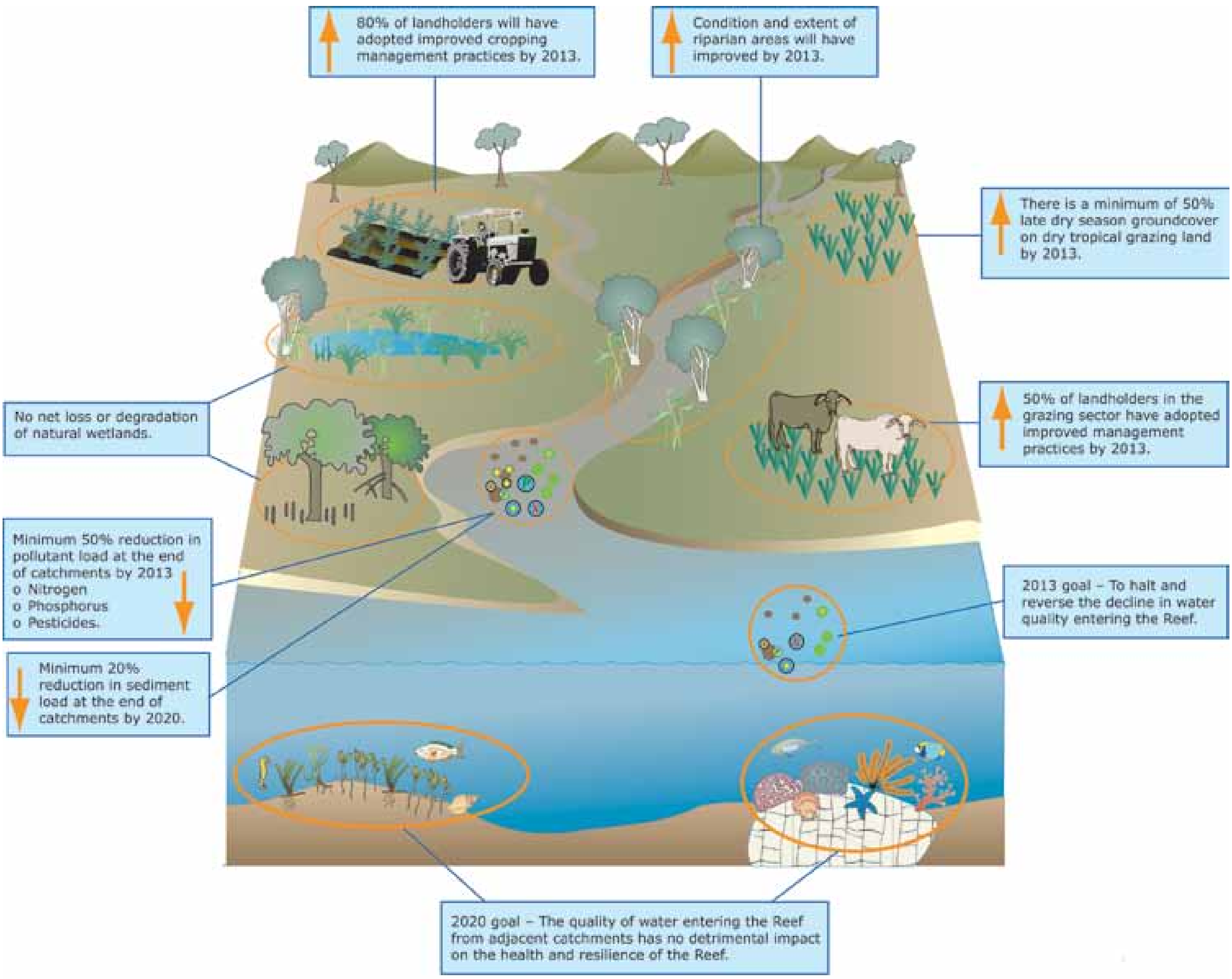
Reef Plan, first introduced in 2003, is a joint commitment of the Queensland and Australian governments to minimise the risk to the Reef ecosystem from a decline in the quality of water entering the Reef from the adjacent catchments. Reef Plan specifically focuses on non-point source pollution from broad-scale land use with other programs dealing with pollutant sources outside this scope.

The plan was updated in 2009 (Reef Plan 2009) to ensure that reef water quality is improved and that the Reef has the resilience to cope with the stresses of a changing climate.

Reef Plan 2009 is underpinned by a suite of targets linking land management, water quality and ecosystem health from the paddock to the Reef. Achieving these targets will help achieve the long-term goal.

Reef Plan 2009 includes a robust monitoring and evaluation strategy to evaluate the efficiency and effectiveness of implementation and report on progress towards the Reef Plan (and Reef Rescue) goals and targets. A key action of Reef Plan 2009 is the development and implementation of the Paddock to Reef Integrated Monitoring, Modelling and Reporting program.

Reef Plan goals and targets - Paddock to Reef



Development approach

A collaborative approach was used to develop the program including a suite of Reef-wide and regional workshops and forums involving a broad range of expertise from the following areas:

- paddock scale land management practices and processes
- catchment water quality processes (including monitoring and modelling)
- marine water quality and ecosystem health processes
- remote sensing technologies
- program managers and policy officers.

More than 100 scientific and technical personnel from 18 organisations were involved in the program design and their contribution is acknowledged.

The program design built upon the knowledge generated since the commencement of Reef Plan in 2003 and utilised current research, development and innovation. This design minimised costs as it utilised, refocused and integrated existing monitoring and reporting programs.

Program components

The framework for the design involves monitoring and modelling a range of attributes at a range of scales including management practices, water quality at the paddock, sub catchment, catchment levels and in adjacent marine areas. This approach provides the ability to link the monitoring and modelling outputs at each scale and across scales.

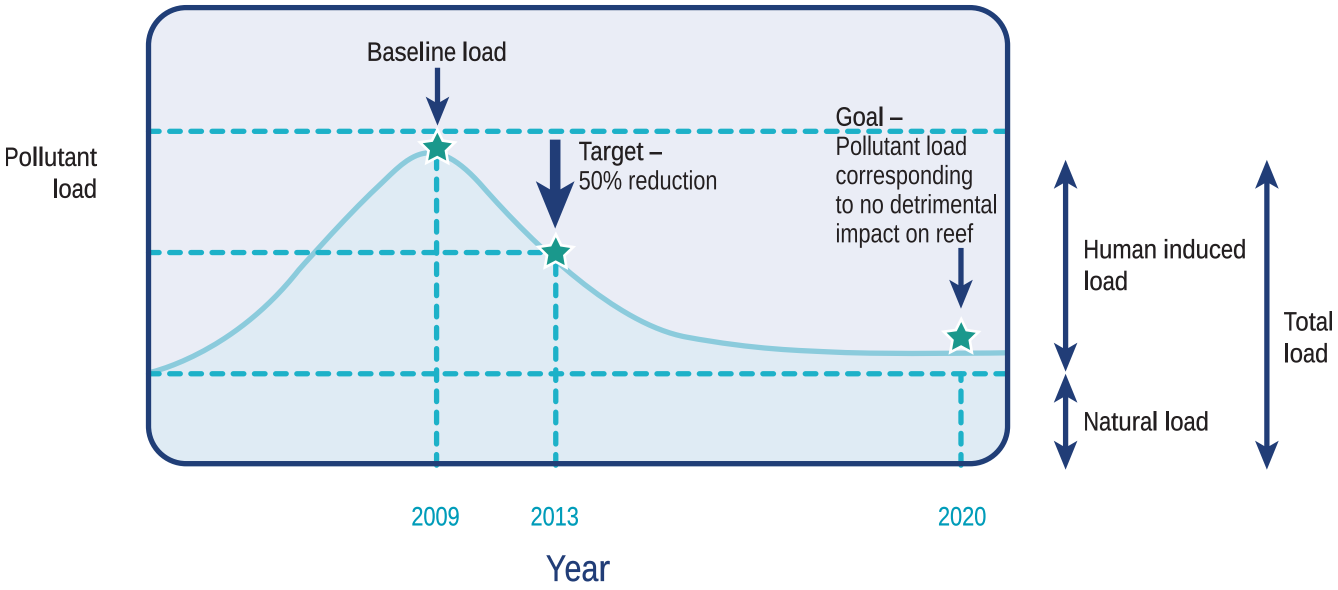
Monitoring involves recording changes as they happen and reporting them after the event. Modelling provides the opportunity to forecast changes prior to their occurrence and separate the management impacts upon water quality from other influencing factors such as climate change.

Combining monitoring and modelling provides a robust tool for measuring and predicting change and highlighting and forecasting trends in data.

The monitoring data will also be used to validate and improve the models at each scale, continuously improving the confidence in the estimates of water quality over time.

The program uses cutting edge monitoring and modelling tools across each of the scales (paddock, catchment, marine) to enable reporting against the Reef Plan goals and targets in the short to medium term.

Defining the pollutant load targets



The Paddock to Reef integrated monitoring, modelling and reporting program

Monitoring and modelling from the paddock to the reef allows us to measure and report on progress towards the Reef Plan goals and targets.

Management practice adoption

The objective of collecting management practice information for each industry and each region is to determine the extent of change in land management practices that lead to water quality improvement over time.

Management practice adoption information will be used to report against the Reef Plan targets and provides essential information for the paddock and catchment scale models which, in turn, predict water quality improvement.

Monitoring water quality leaving the paddock from improved sugarcane management practices.

Paddock monitoring and modelling

Paddock scale monitoring provides information on the water quality changes related to specific management practices. Paddock models such as Agricultural Production Systems Simulator (APSIM), HowLeaky and GRASP are used to corroborate this information.

Paddock scale rainfall simulation field trials in sugarcane.

The program consists of three monitoring and modelling activities:

1. **Paddock monitoring – collecting run-off during actual rainfall events from a uniform portion of a paddock. Over time, the paddock monitoring provides temporal data to capture variability in rainfall and other climatic factors, changes in management and changes in system responses.**
2. **Rainfall simulation – collecting run-off from a simulated rainfall event from a plot within a paddock. Over time, the rainfall simulation work progressively extends the spatial coverage by capturing the variation in response at sites with different soil or land type characteristics.**
3. **Paddock modelling – over time, the paddock modelling progressively develops spatial coverage across soil and land types with improved estimations from using paddock monitoring and rainfall simulation information.**

Catchment monitoring and modelling

The objective of catchment monitoring and modelling activities is to improve the ability to measure water quality change at sub catchment and end of catchment scales. Pollutant load monitoring is conducted at 27 sites across the Reef catchments. The catchment water quality monitoring objectives are to:

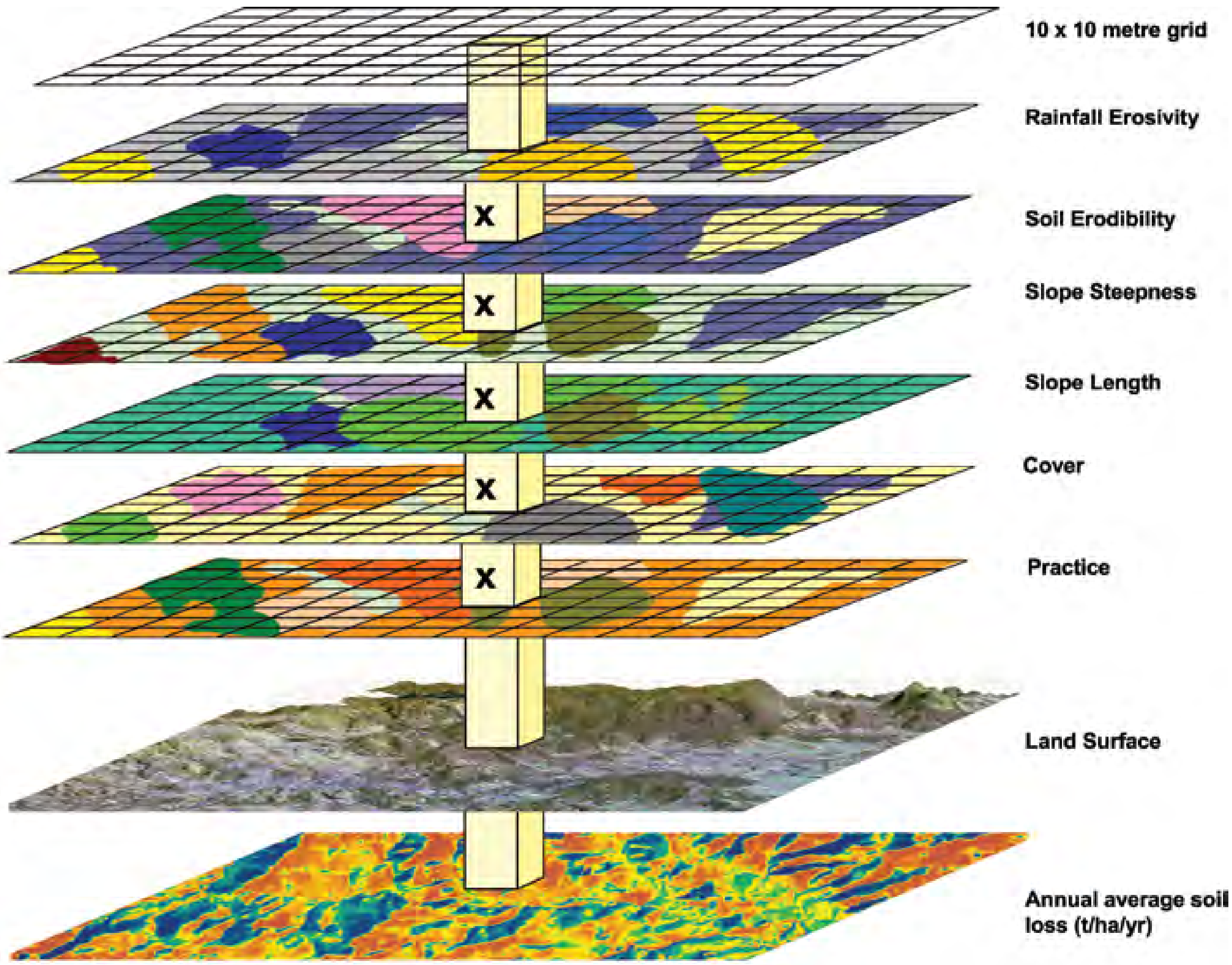
- Assess the water quality entering the Reef lagoon from catchments and determine trends in water quality over time.
- Identify potential source areas of contaminants.
- Link to paddock scale and marine monitoring and modelling.
- Validate and calibrate the catchment models.

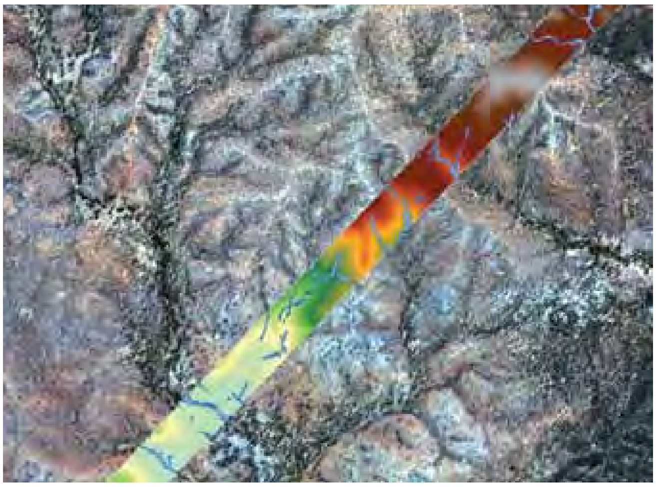
In order to assess the water quality improvements due to management practice change, models are required. In particular, water quality improvements measured in focus areas will need to be scaled up to the entire Reef catchment. Current catchment models have limitations that are being overcome by development and use of the (eWater Cooperative Research Centre) Source Catchments catchment modelling tool.

Source Catchments can produce annual loads due to its short time-step capabilities and is being developed to represent catchment trapping mechanisms and dissolved nutrients.

Information on the condition of the catchment will also be collected and reported including an assessment of ground cover in dry land grazing areas and the extent and condition of riparian areas. This information is used to report on progress towards the Reef Plan targets and provides useful input data for the catchment modelling.

Data layers used in catchment water quality modelling





Airborne laser technology is being used to improve our knowledge of gully erosion processes.

Monitoring the water quality at the end of the catchment.

Marine monitoring and modelling

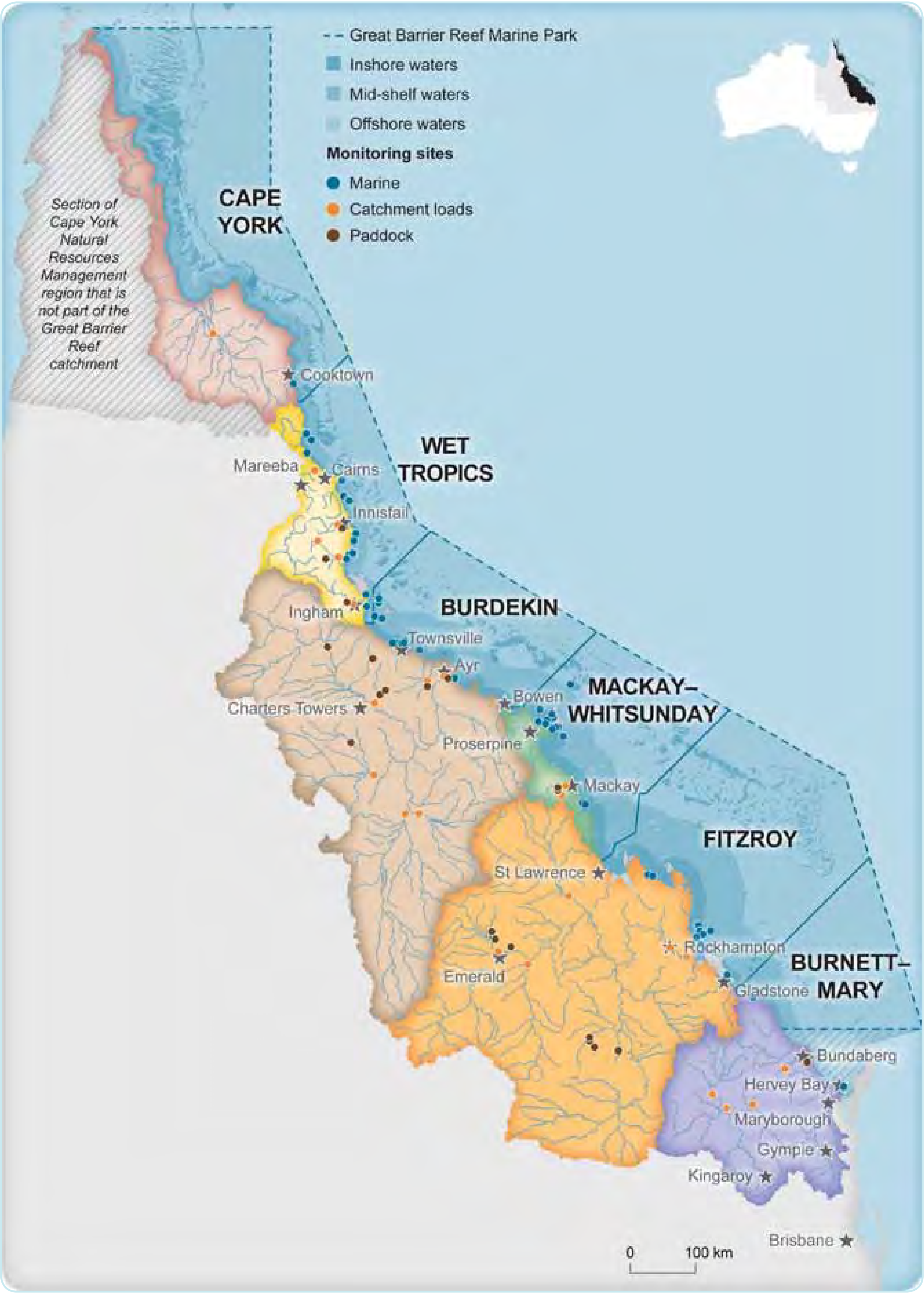
The Reef Water Quality Marine Monitoring Program, led by the Great Barrier Reef Marine Park Authority (GBRMPA), assesses the health of key marine ecosystems (inshore coral reefs and intertidal seagrasses) and the condition of water quality in the inshore Reef lagoon. The program is critical for the assessment of long-term improvement in water quality and marine ecosystem health associated with the adoption of improved land management practices in the Reef catchment.

Linking end-of-catchment loads with marine trigger values will also require a receiving water model to simulate the fate and impacts of these contaminants as they pass through estuaries and into the Reef lagoon and beyond.

Core programs	Sub-programs
Inshore biological monitoring	Inshore coral reef monitoring
	Intertidal seagrass monitoring
Water quality monitoring	Inshore marine water quality monitoring
	Flood plume water quality monitoring
	Inshore pesticide monitoring
	Remote sensing water quality in the Great Barrier Reef

Inshore coral reef monitoring as part of the marine monitoring program.

Map of monitoring locations for the Paddock to Reef Integrated Program



Reporting

The Reporting Framework for the program is driven by the Reef Plan goals and targets and the principles outlined in the Reef Plan Monitoring and Evaluation Strategy. The First Report Card covers monitoring up to 2009 and provides the baseline for key indicators. Subsequent report cards will measure progress towards goals and targets from the paddock to the reef.

Partners

The Paddock to Reef Program is funded jointly by the Australian and Queensland governments. Implementation of the program is a collaborative effort involving governments, key industry partners, research organisations, regional Natural Resource Management bodies and individuals.

Oversight of the Reef Plan Monitoring and Evaluation arrangements is provided through the Reef Plan Intergovernmental Operational Committee and a Partnership Committee made up of key stakeholders. Leadership and coordination is provided through a range of organisations including:

- **Queensland Department of the Premier and Cabinet**
- **Queensland Department of Environment and Resource Management**
- **Great Barrier Reef Marine Park Authority**
- **Australian Government Department of Sustainability, Environment, Water, Population and Communities**
- **Queensland Department of Employment, Economic Development and Innovation**
- **Regional Natural Resource Management Bodies**
- **agricultural industry groups**
- **research and development organisations.**

Water quality monitoring in the Reef lagoon as part of the marine monitoring program.

Australian Government

Queensland Government

DPC2291

Marine Pollution Bulletin xxx (2011) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Large-scale pesticide monitoring across Great Barrier Reef catchments – Paddock to Reef Integrated Monitoring, Modelling and Reporting Program

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A R T I C L E I N F O

Keywords:
Great Barrier Reef
Reef Plan
Pesticides
Mixtures
Toxic equivalent quotients

A B S T R A C T

The transport and potential toxicity of pesticides in Queensland (QLD) catchments from agricultural areas is a key concern for the Great Barrier Reef (GBR). In 2009, a pesticide monitoring program was established as part of the Australian and QLD Governments' Reef Plan (2009). Samples were collected at eight End of System sites (above the tidal zone) and three sub-catchment sites. At least two pesticides were detected at every site including insecticides, fungicides, herbicides, and the Reef Plan's (2009) five priority photosystem II (PSII) herbicides (diuron, atrazine, hexazinone, tebuthiuron and ametryn). Diuron, atrazine and metolachlor exceeded Australian and New Zealand water quality guideline trigger values (TVs) at eight sites. Accounting for PSII herbicide mixtures increased the estimated toxicity and led to larger exceedances of the TVs at more sites. This study demonstrates the widespread contamination of pesticides, particularly PSII herbicides, across the GBR catchment area which discharges to the GBR.

1. Introduction

The Great Barrier Reef World Heritage Area is not a closed system and therefore activities that occur in regions adjacent to the Great Barrier Reef (GBR) will influence the functioning of the GBR. The importance of maintaining the biodiversity, health and functional plasticity of the GBR is of national and international interest (United Nations Educational, Scientific and Cultural Organisation World Heritage Convention, 1981). Hence it is not surprising that human activities undertaken in these adjacent regions are under scrutiny for their potential impacts to the GBR.

A close relationship of the ecosystems along the Queensland coast exists with the GBR (see Haynes et al., 2007 for a conceptual model). The freshwater riverine systems, wetlands, mangroves and seagrasses support the reef through the provision of fisheries habitats, filtration of terrestrial runoff, nutrient cycling and key components of the foodweb (Costanza et al., 1997; Duke et al., 2005; Schaffelke et al., 2005; Waycott et al., 2007). The importance of the supporting services that these adjacent ecosystems provide has been highlighted by Stoeckl et al.'s (2011) report on the economic value of the GBR. They (Stoeckl et al., 2011) emphasised the critical nature of anthropogenic impacts on the "supporting services", without which, the ability of the reef to provide its services would deteriorate. With the GBR services valued at over AUS$5 billion (Access Economics, 2005), the decline of the adjacent ecosystems becomes not just an environmental issue, but an important economical issue as well.

Poor water quality in GBR catchments is problematic to the GBR in two ways (1) pollutants are transported to the GBR and cause direct impacts to reef biota; and (2) pollutants impact the biota within the freshwater and estuaries of the riverine systems and this affects the services that the river systems provide to the GBR. The poor water quality is principally a result of land clearing and agricultural land-use practices since European settlement that have introduced man-made chemicals (i.e. pesticides) and generated loads of sediment and nutrients above natural levels (Brodie et al., 2008).

Pesticides have been detected in the water (Shaw and Müller, 2005; Davis et al., 2008; Lewis et al., 2009; Packett et al., 2009), sediment (Duke et al., 2005) and biota (Haynes et al., 2000; Mortimer, 2000) of GBR catchments and these include insecticides, herbicides and fungicides (Haynes and Michalek-Wagner, 2000). These contaminants are transported in runoff from paddocks and enter creeks and rivers that feed into the GBR lagoon (Haynes and Michalek-Wagner, 2000). With agriculture occupying approximately 70% of land in the GBR catchment area (GBRCA) (Australian Bureau of Statistics, 2011) including grazing, sugar cane, horticulture, plantation forestry, pasture, cropping and cotton, there is concern that pesticides pose a direct threat to GBR biota. Currently, more than 200 pesticides (i.e. active ingredients) are registered for use with the Australian Pesticides and Veterinary Medicines Authority (Shaw et al., 2011), of which, it is the herbicides that inhibit photosystem II (called PSII herbicides) that have been most

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doi:10.1016/j.marpolbul.2011.08.010

frequently detected in the GBR lagoon (Shaw and Müller, 2005; Bainbridge et al., 2009; Lewis et al., 2009) and throughout the GBRCA (Davis et al., 2008; Mitchell et al., 2005; Packett et al., 2009).

PSII herbicides act by inhibiting photosynthesis and target a specific group of organisms, phototrophs. In the GBR, PSII herbicides have been detected in seagrasses which are an important food source for dugongs and provide nurseries for reef fish (Haynes et al., 2000). Studies have also proven that PSII herbicides can induce coral bleaching by impacting zooxanthellae (symbiotic dinoflagellates) which leads to their expulsion from the coral (Jones et al., 2003; Negri et al., 2005). In addition, benthic microalgae and crustose coralline algae have been shown to be sensitive to PSII herbicide inhibition (Magnusson et al., 2010; Harrington et al., 2005, respectively).

Pesticides are often found in mixtures, but to date, the potential threat of pesticides to the GBR has only been assessed for individual chemicals. The scientific consensus of water quality in the GBR indicated that the potential interactive effects of pesticide mixtures were a key uncertainty of the causal relationship between water quality and ecosystem health (Brodie et al., 2008). Therefore, assessing the potential impact of pesticides as a mixture is of high importance to ensure the ecological health of the GBR is maintained.

It is well established that chemicals that exhibit the same mode of action conform to the concentration addition model (Mumtaz et al., 1994). PSII herbicides, in combination, have been proven to conform to this model of mixture toxicity and to produce additive toxic effects to exposed organisms (Faust et al., 2001; Magnusson et al., 2010). Ma (2002) generated dose response curves for 30 herbicides including PSII herbicides. Thus, there exists a data set to derive toxic equivalent quotients (TEQs) for determining the toxicity of a mixture of PSII herbicides from the concentrations of the constituents.

In 2009, a large-scale pesticide monitoring program was funded as part of the Queensland Government's commitment to the joint Australian and Queensland Government "Paddock to Reef Integrated Monitoring, Modelling and Reporting Program". This was established in order to measure progress towards the Reef Plan (2009) water quality goals and targets. The pesticide monitoring program was developed as part of a coordinated effort to assess the success of agricultural management strategies in reducing the loads of five priority PSII herbicides (atrazine, diuron, hexazinone, tebuthiuron and ametryn) in riverine systems. This paper reports on the initial findings from the first year (2009/2010) of monitoring for the GBR pesticide monitoring program. The objectives for reporting these initial findings were to: (1) provide a spatial overview of pesticide inputs to the GBR lagoon and end-of-system aquatic habitats associated with GBR catchments; (2) assess the degree of contamination, i.e. the number and types of pesticides, the concentration of pesticides and duration of exposure; and (3) assess the potential toxicity of pesticides occurring as a mixture.

2. Materials and methods

2.1. Study area

The GBRCA is comprised of 35 coastal catchments situated in north-east and central Queensland, Australia, which drain into the GBR lagoon (Fig. 1). Eleven sites were monitored from eight catchments, with eight End of System sites (above the tidal influence) and three sub-catchment sites (Fig. 1) that all represented areas with high agricultural land use. The sites were selected based on a previous hazard assessment (Shaw et al., 2011) which identified these catchments as being the largest potential contributors to pesticide loads entering the GBR and therefore posing the greatest potential risk. The catchments were distributed across five of the six Natural Resource Management (NRM) regions that cover the GBRCA. All catchments drained directly into the GBR lagoon except for Barratta Creek, which drains firstly into Bowling Green Bay, a RAMSAR wetland.

2.2. Grab sampling

Manual grab samples (1 L) were collected at each site over at least two flow events from the 2009/2010 wet season. Samples were collected from approximately 0.3 m below the water surface in an area of high flow, in close proximity to deployed passive samplers. Samples were collected directly into solvent rinsed, 1 L glass bottles, transported on ice and stored in the dark at ~4 °C before analysis. The number of grab samples collected and the timing of collection was based on the occurrence of large flow events at each site. The objective was to sample at least two events such that approximately four samples were collected on the rise of an event and three samples were collected on the fall of an event, but more were collected if possible. This was not always possible at some sites as logistical issues (e.g. flooding) made it impossible to do so. A total of 268 grab samples were collected and chemically analysed across all sites.

All grab water samples were chemically analysed by Queensland Health Forensic and Scientific Services (QHFSS), a National Association of Testing Authorities (NATA) accredited laboratory. Water samples were analysed using a multi-residue method for the determination of organochlorine (OC, neurotoxins) and organophosphorus (OP, cholinesterase inhibitors) pesticides, acetylcholine agonists, synthetic pyrethroids pesticides, triazine herbicides (PSII herbicides) including atrazine, simazine and prometryn, bromacil (PSII herbicide), trifluralin (seedling growth inhibitor), substituted urea herbicides (PSII herbicides) and polychlorinated biphenyls (PCBs). A liquid/liquid extraction was performed on 1 L samples using 250 mL of dichloromethane. The filtered extracts were concentrated under nitrogen gas and low heat. For analysis by liquid chromatography tandem mass spectrometry (LC–MS/MS) only (substituted ureas, triazines, bromacil and imidacloprid), the extract was further prepared by the addition of 5 mL of hexane, followed by a second concentration stage and the addition of methanol.

All samples were analysed by high performance LC–MS/MS using an AB/Sciex API 300 mass spectrometer (Applied Biosystems, Concord, On, Canada) equipped with a heated nebuliser (chemical ionisation) interface coupled to a Shimadzu SCL-10A*vp* HPLC system (Shimadzu Corp., Kyoto, Japan). Selected samples were also analysed by gas chromatography mass spectrometry (GC–MS) for the determination of OC, OP, PCBs, synthetic pyrethroids and triazines. GC–MS analysis was performed on a Shimadzu QP5050A GC–MS.

Analysis of samples for phenoxy acid herbicides (synthetic auxins) was performed separately. Only selected samples from Sandy and Barratta Creeks were tested for phenoxy acid herbicides. Samples were first hydrolysed with sodium hydroxide to convert herbicide esters to the sodium salt form. Samples were then acidified, and the phenoxy acid herbicides were extracted by solid phase extraction using a polymeric cartridge (Oasis HLB, Waters Australia), and 2% NH_4OH/98% acetonitrile followed by dichloromethane solvent eluent. The extract was evaporated just to dryness and prepared in 10% methanol aqueous solution. The phenoxy acid herbicides were then analysed by high performance LC–MS/MS.

2.3. Passive sampling

Passive samplers were deployed at each site throughout the 2009/2010 wet season to measure the presence/absence of

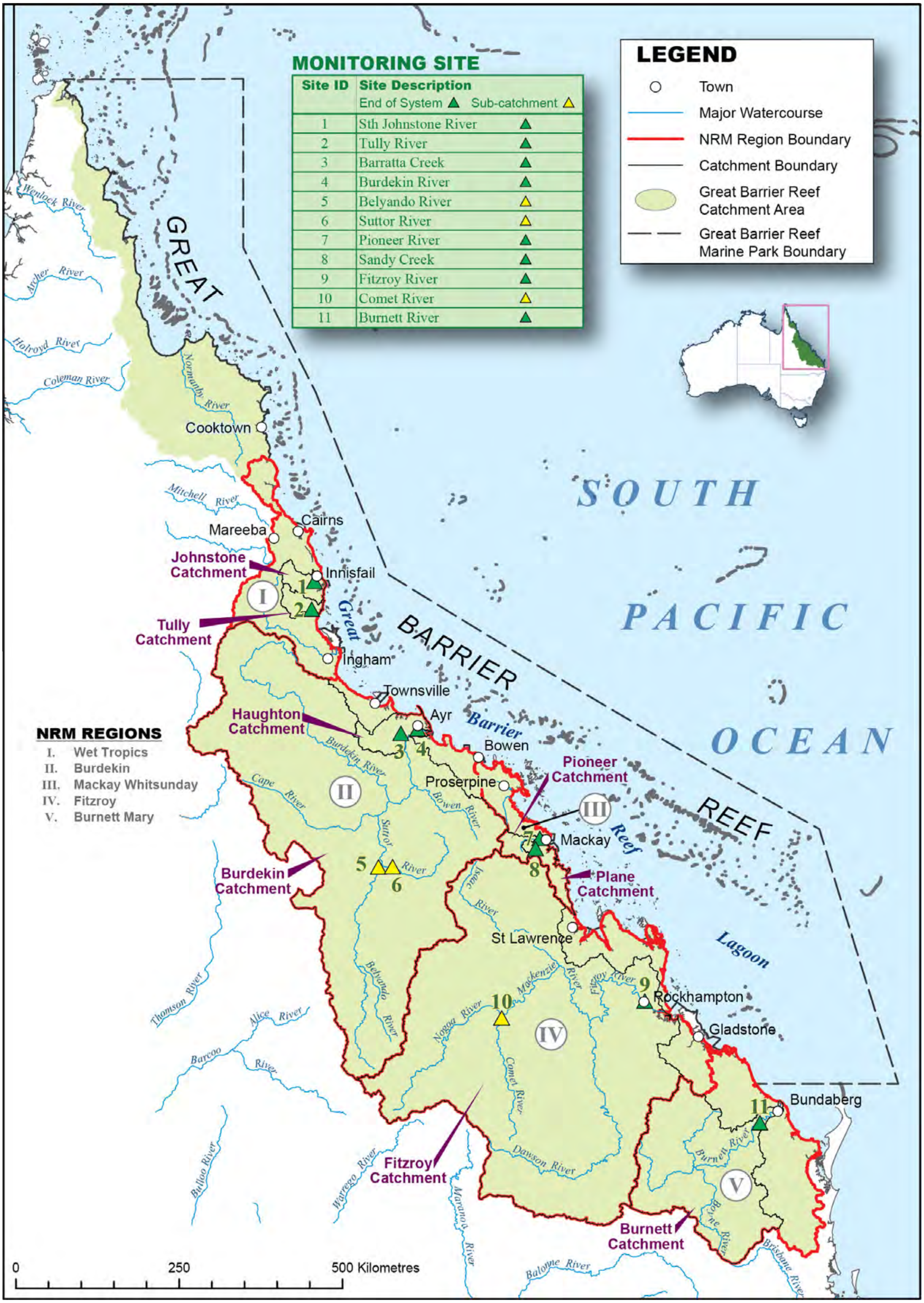

Fig. 1. End of System and sub-catchment pesticide monitoring sites of the Reef Plan (2009) Paddock to Reef Program for the 2009/2010 wet season.

pesticides over extended periods. A passive sampler unit consisted of three types of passive monitors; two SDB–RPS Empore™ disks (EDs), a semipermeable membrane device (SPMD) and a polydimethylsiloxane (PDMS) device. The EDs were mounted in Teflon

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Table 1
EC50 concentrations for *Scenedesmus obliquus* and *Chlorella pyrenoidosa* derived from Ma (2002) and calculated atrazine toxic equivalency factors (TEF).

Species	Units	Atrazine	Diuron	Ametryn	Simazine	Prometryn
Scenedesmus obliquus	EC50 μM	0.573	0.0175	0.0515	1.27	0.0069
	TEF atrazine	1.00	32.74	11.13	0.45	83.04
Chlorella pyrenoidosa	EC50 μM	0.6720	0.00559	0.00141	0.409	0.0493
	TEF atrazine	1.00	120.21	476.60	1.64	13.63

cases that hold the disks in position and allow the membrane to be exposed to the passing flow, as well as protecting the membranes from passing debris. The PDMS and SPMD were mounted in a stainless steel cage that allowed for the surrounding water to move through the cage and come into contact with the membranes.

The passive sampler membranes were prepared by the National Research Centre for Environmental Toxicology (EnTox), using an established method (Shaw et al., 2010). Passive sampler units were deployed in the flow of the stream for up to a month. However, if a large flow event occurred during deployment, the sampling unit was collected as soon as possible once flow had returned to base conditions/levels. Upon retrieval of a passive sampling unit from the field, the passive samplers were transported (on ice) to EnTox for extraction of the aggregated pesticides and analysis. Methods of extraction and analysis have previously been described (Shaw et al., 2010). A total of 50 passive samplers were deployed with 44 of these analysed for pesticide residues. Six passive samplers were lost or damaged during deployment and therefore could not be analysed.

2.4. Flow measurements

The Department of Environment and Resource Management (QLD State Government) gauging stations recorded river height in accordance with Water Resource Plans for the allocation and sustainable management of water as a requirement of the Water Act (2000) (DNRW, 2007). Discharge was then calculated from the river height and the flow velocity based on the cross-sectional area.

2.5. Toxic equivalency quotients

The toxic equivalent quotient (TEQ) was calculated to provide a measure of toxicity for PSII mixtures detected from grab samples. TEQ concentrations were calculated according to Safe (1998) using the following equation:

$$\mathrm{TEQ} = \sum C_i \times \mathrm{TEF}_i$$

where, C_i = the concentration of individual compounds, and TEF = -toxic equivalency factor of the individual compounds.

The TEFs were determined based on the study by Ma (2002), from which EC50 concentrations were calculated for five PSII herbicides: atrazine; diuron; ametryn; simazine; and prometryn (Table 1). Ma (2002) was used to calculate the TEFs as it provided EC50 concentrations from an acute 96 h growth bioassay of two species of freshwater microalgae, *Scenedesmus obliquus* and *Chlorella pyrenoidosa*, which can be found in tropical regions of Australia (Day et al., 1995). Furthermore, the test temperature conditions, 25 °C, were more relevant to GBR waters than what is typically used in ecotoxicity tests for temperate species (e.g. 20 or 21 °C). From the literature, the Ma (2002) study provided the most complete set of EC50 concentrations for PSII herbicides, conducted on multiple phototrophic species under the same test conditions. TEFs were derived based on the relative toxicity of diuron, ametryn, simazine and prometryn to atrazine. Atrazine was chosen to derive TEFs because the Australian and New Zealand Trigger Value (TV, ANZECC and ARMCANZ, 2000) for atrazine was of high reliability while the others were of lower reliability and because diuron (the most toxic of the measured PSII herbicides) is about to be banned in Australia. Trigger values are the numerical limits for contaminants in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ, 2000). For slightly to moderately modified waterbodies (that would apply to most catchments in agricultural areas) the TVs aim to protect 95% of species. Deriving such TVs was only possible when there were sufficient data to permit the use of the BurrliOZ species sensitivity distribution method (Campbell et al., 2000). In all other cases, the assessment factor method was used (i.e. lowest toxicity value was divided by an assessment factor); the resulting TVs do not correspond to protecting any percentage of species, but provide a generic level of protection. All TVs will henceforth be referred to simply as TVs.

2.6. Reporting pesticide concentrations

Pesticide concentrations were only reported for grab samples, passive sampler data were used for presence/absence reporting only. For presence/absence, frequency and TEQ calculations of grab samples, pesticides were only considered present when concentrations were equal to or above the limit of reporting (LOR).

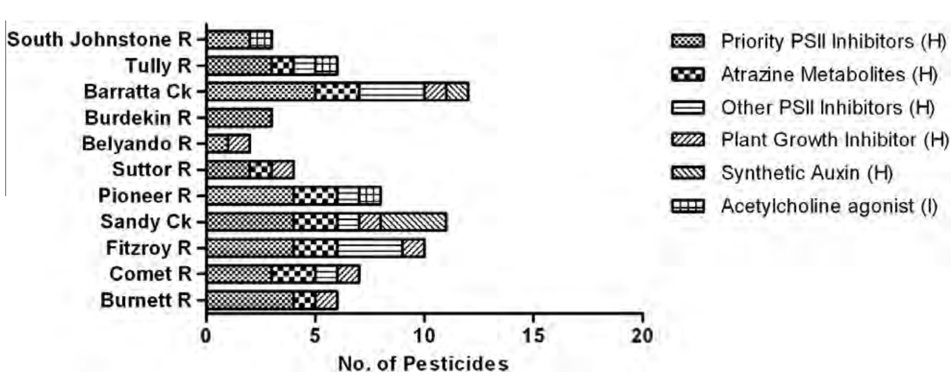

Fig. 2. Pesticide richness detected in grab samples at each site. Pesticides were grouped according to their mode of action and target organisms; H = herbicide, I = insecticide. Note that the synthetic auxins were only tested for at Barratta and Sandy creeks.

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The 95th percentiles of individual pesticide concentrations were calculated for each site and these values were compared to the appropriate TVs to determine if the TVs had been exceeded and therefore posed a potential risk. The 95th percentiles were calculated according to the following equation:

$$Cp = p \times \frac{n+1}{100}$$

where, Cp = concentration of the pth percentile, and n = the number of values in the data set (including all detections below the LOR).

Using the same methodology the 95th percentiles of the TEQ values were calculated for each site and these were compared to the atrazine TV.

3. Results

3.1. Presence/absence

The number of different pesticides detected was calculated for each site over the entire sampling period. Figs. 2 and 3 depict the total number of pesticides (grouped according to mode of action) at each site that were above the LOR, based on detections from grab and passive sampling, respectively. Barratta Creek had the greatest number of pesticides detected, but also had the greatest variety of pesticide types in both grab and passive samples. Sampling sites within the Burdekin catchment (the Burdekin, Belyando and Suttor rivers) had the least number of pesticides detected by both sampling methods and furthermore, only herbicides were detected.

In general, passive samplers detected a greater number of pesticides at each site than grab sampling (Figs. 2 and 3 and Table 2). Grab sampling (Fig. 2) detected only one type of insecticide, imidacloprid, whereas the passive samplers were able to additionally detect five OP insecticides (diazinon, chlorpyrifos, chlorfenvinphos, prothiophos and propiconazole), three OC insecticides (dieldrin, endosulfan beta and endosulfan sulphate), as well as a fungicide (tebuconazole).

One major difference noted in the two different sampling methods was the results from South Johnstone River (in the Johnstone River catchment). The grab samples detected only three different pesticides, indicating this site was one of the least contaminated sites surveyed (in terms of presence/absence). However, the results obtained from the passive samplers indicated that the South Johnstone River site had the second greatest number of pesticides present consisting of chemicals with five different modes of action.

The presence of PSII herbicides was consistent across all catchments surveyed. At least one of the five priority PSII herbicides (ametryn, atrazine, diuron, hexazinone and tebuthiuron) was detected at each site (Table 2), with all five priority PSII herbicides being detected at both Barratta Creek (Haughton River catchment) and the Fitzroy River (Fitzroy River catchment). Atrazine was detected at all sites by both sampling methods (Table 2), and at least one of its metabolites, desethyl atrazine and desisopropyl atrazine (Figs. 2 and 3), were also detected across all sites (but not consistently for both methods), demonstrating the widespread presence of atrazine. Hexazinone was also detected at all sites with passive samplers, but only seven sites with grab samples. Ametryn was detected at the least number of sites, i.e. three sites by grab samples and at five sites by passive samples, followed by diuron (eight sites for both types of samples) and tebuthiuron (seven sites for grabs and nine sites for passive samples).

Table 2
Presence/absence of the Reef Plan's (2009) five priority photosystem II herbicides at each of the monitoring sites. The presence of pesticides in each catchment was indicated by (■) for grab samples and (▨) for passive samples.

Site	Ametryn	Atrazine	Diuron	Hexazinone	Tebuthiuron
Sth Johnstone R		■ ▨	■ ▨	▨	▨
Tully R		■ ▨	■ ▨	■ ▨	▨
Barratta Ck	■ ▨	■ ▨	■ ▨	■ ▨	■ ▨
Burdekin R		■ ▨	■ ▨	▨	■ ▨
Belyando R		■ ▨		▨	■ ▨
Suttor R		■ ▨		▨	■ ▨
Pioneer R	■ ▨	■ ▨	■ ▨	■ ▨	
Sandy Ck	■ ▨	■ ▨	■ ▨	■ ▨	
Fitzroy R	▨	■ ▨	■ ▨	■ ▨	■ ▨
Comet R	▨	■ ▨		■ ▨	■ ▨
Burnett R		■ ▨	■ ▨	■ ▨	■ ▨

3.2. Frequency of detection

In order to assess the most common pesticides entering the GBR lagoon through catchment runoff, the frequency of pesticide detection was calculated for all samples analysed. From the 268 grab samples analysed using LC–MS (Fig. 4), seven different PSII herbicides were detected, with atrazine, hexazinone and tebuthiuron the most frequently detected pesticides (occurring in more than 50% of samples). Ametryn was detected the least of the five priority PSII herbicides, being detected in less than 20% of samples. Metolachor, a plant growth inhibitor, and the insecticide, imidacloprid, were also frequently detected, occurring in approximately 30% of samples.

Thirteen samples were analysed for phenoxy acid herbicides from two sites, Barratta Creek and Sandy Creek (Fig. 4). The synthetic auxins, 2,4-D and MCPA, were detected in more than 90% and 60% of these samples (respectively). Another synthetic auxin, fluroxypyr, was also detected but in less than 10% of samples.

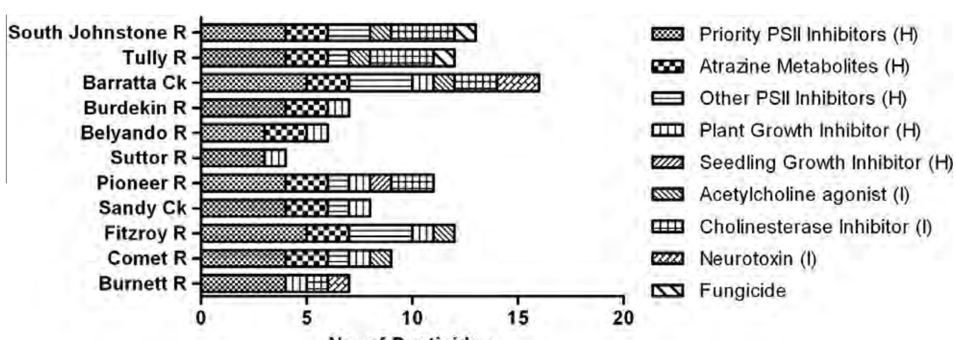

Fig. 3. Pesticide richness detected in passive samplers (ED, SPMD and PDMS) at each site. Pesticides were grouped according to their mode of action and target organisms; H = herbicide, I = insecticide.

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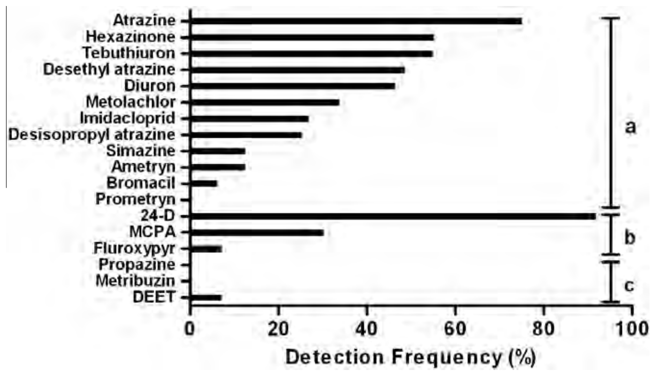

Fig. 4. Frequency of pesticides detection from grab samples collected across all sites. Frequency (%) was determined based on the number of samples that were analysed for (a) LC–MS, $n = 268$; (b) phenoxy herbicides $n = 13$; and (c) GC–MS, $n = 80$.

Samples analysed using GC–MS, which is able to detect chemicals such as OPs and OCs, only detected low frequencies (< 1%) of two herbicides, metribuzin and propazine, and DEET, an insect repellant.

3.3. Pesticide discharge characteristics

The five priority PSII herbicides were examined, along with flow data, to assess the potential exposure patterns of these herbicides on biota. Two examples of a catchment's pesticide discharge characteristics are presented here; Barratta Creek a small catchment of approximately 753 km^2 (Fig. 5), and the Fitzroy River the largest catchment sampled, with approximately 135,757 km^2 (Fig. 6).

Concentration trends at Barratta Creek (Fig. 5) demonstrated a typical first flush effect, i.e. high concentrations of pesticides (e.g. 16 μg L^{-1} of atrazine, 6.5 μg L^{-1} of diuron) in the first rain event of the wet season (December 2009) after which concentrations decreased as the wet season progressed interspersed with a spike in the concentrations during two events. Both pesticide concentration trends and flow trends were different for the Fitzroy River (Fig. 6) compared to Barratta Creek. Whereas the flow for Barratta Creek was composed of small, short-term events (a few days), Fitzroy River had a much larger volume of water that continued throughout the wet season. In terms of trends in pesticide discharge, concentrations in the Fitzroy River were generally lower than those reported at Barratta Creek (note the differences in scale on *y*-axis) and were less variable between events. In contrast to Barratta Creek, the pesticide trends for the Fitzroy River showed a general increase in concentration of tebuthiuron and atrazine at the start of the wet season (January and February) and then remained fairly stable for the rest of the wet season. It is important to also note that in both catchments (Figs. 5 and 6) pesticides remained present in samples throughout the wet season which lasted for two to three months.

3.4. Pesticide toxicity

Pesticide concentrations reported from grab sample monitoring were compared to the Australian and New Zealand WQG (ANZECC and ARMCANZ, 2000) TVs for the protection of aquatic ecosystems. The 95th percentile concentration was calculated for each pesticide from the distribution of samples collected at each site (Table 3). At Barratta Creek one sample could have been considered an outlier as no pesticides were detected in it, in contrast to all other samples collected from that site. Rather than omitting this potential outlier the 95th percentiles for atrazine and diuron at Barratta Creek were calculated both with and without this particular sample as these were the two chemicals where the 95th percentiles based on all the concentration data were closest to the TVs (Table 3). For both chemicals excluding the one potential outlier increased the 95th percentiles. In the case of atrazine the 95th percentile increased from 12.58 to 13.15 μg L^{-1}, the latter exceeding the TV. For diuron the 95th percentile increased from 5.63 to 5.78 μg L^{-1} but both exceeded the TV.

Of the 18 different pesticides that were detected from grab samples, only three pesticides exceeded TVs, i.e. atrazine (refer to previous paragraph), diuron and metolachlor. Nine of the detected pesticides did not have Australian and New Zealand TVs (Table 3) and therefore no comparisons could be made for these chemicals.

Of the 11 sampling sites, eight sites had at least one pesticide above the Australian and New Zealand (ANZECC and ARMCANZ, 2000) TVs. Metolachlor was the pesticide that most frequently exceeded its TV. Barratta Creek had the highest number of pesticides (three) that exceeded TVs and was the only site in which atrazine exceeded its TV. Barratta Creek also had the highest 95th percentile concentrations of atrazine (13.15 μg L^{-1}) and diuron (5.78 μg L^{-1}), compared to other sites. For the five priority PSII herbicides, only four sites exceeded TVs.

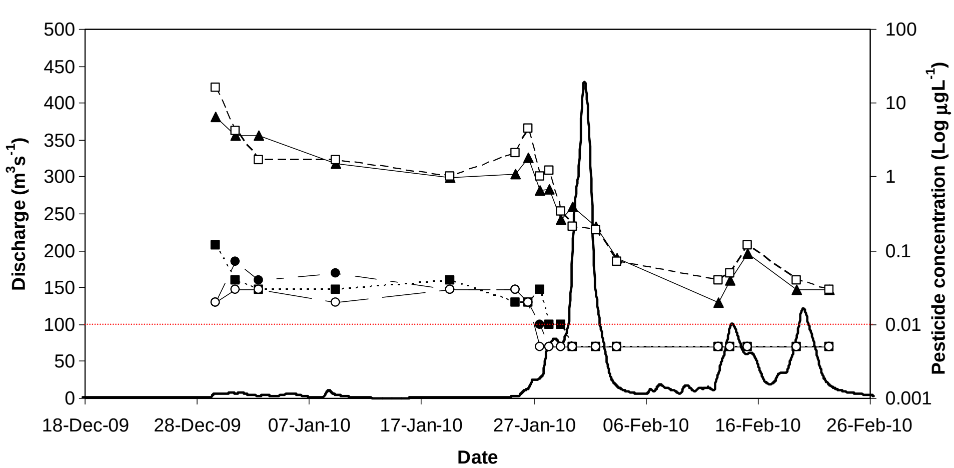

Fig. 5. Discharge (m^3 s^{-1}) and pesticide concentrations (μg L^{-1}) for Barratta Creek during the 2009/2010 wet season. Symbols represent the five priority PSII herbicides; diuron (▲), atrazine (□), hexazinone (■), ametryn (●) and tebuthiuron (○). Solid black line represents discharge (m^3 s^{-1}), red line represents the limit of reporting (LOR) (μg L^{-1}). Detections below the LOR were reported as half the value of the LOR. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this paper.)

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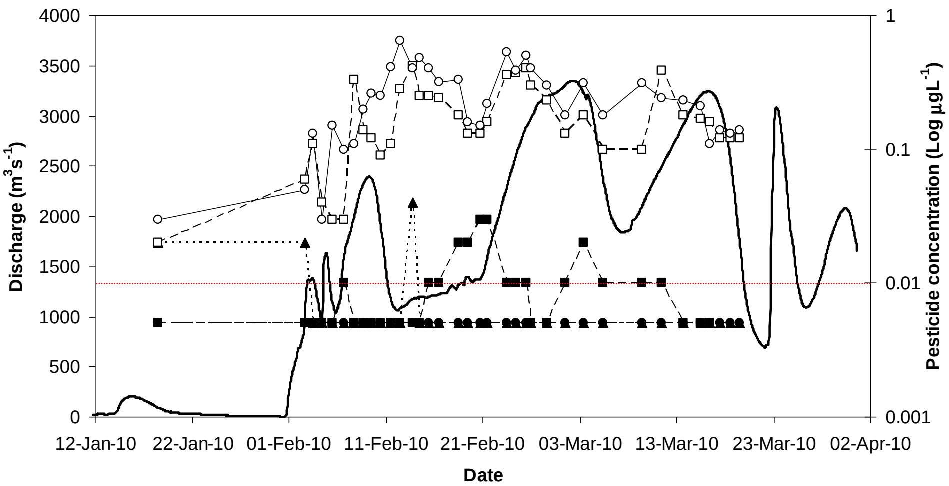

Fig. 6. Discharge ($m^3\ s^{-1}$) and pesticide concentrations ($\mu g\ L^{-1}$) for Fitzroy River during the 2009/2010 wet season. Symbols represent the five priority PSII herbicides; diuron (▲), atrazine (□), hexazinone (■), ametryn (●) and tebuthiuron (○). Solid black line represents discharge ($m^3\ s^{-1}$), red line represents the limit of reporting (LOR) ($\mu g\ L^{-1}$). Detection below the LOR were reported as half the value of the LOR. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this paper.)

Table 3
95th percentile pesticide concentrations calculated from 2009/2010 wet season (grab sampling only) from 11 sites within the Great Barrier Reef catchment area. Values were compared to ANZECC and ARMCANZ (2000) water quality guideline trigger values (TVs). Values in bold indicate concentrations that exceed ANZECC and ARMCANZ (2000) TVs, values in italics indicate concentrations that equal trigger values.

Pesticide	Trigger value[a] ($\mu g\ L^{-1}$)	Barratta Ck	Tully R	Suttor R	S. Johnstone R	Sandy Ck	Pioneer R	Burdekin R	Fitzroy R	Comet R	Burnett R	Belyando R
Ametryn	n/a	0.06	–	–	–	0.24	0.09	–	–	–	–	–
Atrazine	13	**12.58–13.15**[c]	0.32	0.20	0.03	2.58	1.90	0.03	0.40	3.10	0.08	0.02
Desethyl atrazine	n/a	0.89	0.03	0.02	–	0.18	0.27	–	0.04	0.14	0.01	–
Desisopropyl atrazine	n/a	0.28	–	–	–	0.06	0.12	–	0.03	0.06	–	–
Diuron	0.2[b]	**5.63–5.78**[c]	**0.58**	–	0.14	**4.70**	**3.40**	0.02	0.02		0.13	–
Hexazinone	75[b]	0.10	0.28	–	–	1.86	0.98	–	0.03	0.08	0.04	–
Prometryn	n/a	–	–	–	–	–	–	–	0.00	–	–	–
Simazine	3.2	0.04	0.03	–	–	0.01	0.03	–	0.02	0.04	–	–
Tebuthiuron	2.2	0.03	–	0.67	–	–	–	0.07	0.52	0.08	0.04	0.27
Bromacil	180[b]	–	–	–	–	0.03	–	–	0.02			
Metolachlor	0.02[b]	**0.05**	–	**0.42**	–	**0.05**	–	–	**0.18**	**0.31**	**0.06**	*0.02*
Imidacloprid	n/a	0.007	0.06	–	0.06	0.08	0.07	–	–	–	–	–
2,4-D	280	0.50	n/t	n/t	n/t	1.10	n/t	n/t	n/t	n/t	n/t	n/t
Fluroxypyr	n/a	–	n/t	n/t	n/t	0.20	n/t	n/t	n/t	n/t	n/t	n/t
MCPA	1.4[b]	–	n/t	n/t	n/t	0.50	n/t	n/t	n/t	n/t	n/t	n/t
Metribuzin	n/a	0.2	–	–	–	–	–	–	–	–	–	–
Propazine	n/a	0.2	–	–	–	–	–	–	–	–	–	–
DEET	n/a	–	–	–	–	–	–	–	–	0.63	–	–

n/a = Not available; n/t = not tested; dash (–) = below the limit of reporting.
[a] See Section 2 for a definition of the ANZECC and ARMCANZ (2000) TVs provided;
[b] Low reliability trigger value, i.e. an interim or indicative working level only due to the absence of a data set of sufficient quantity to derive the trigger value.
[c] Two 95th percentile values were calculated, refer to Section 3.4 for explanation.

To derive an estimation of the toxicity of PSII herbicides as a mixture, the 95th percentile for TEQ_{SO} (toxic equivalent quotient for *S. obliquus*) and TEQ_{CP} (toxic equivalent quotient for *C. pyrenoidosa*) were calculated for each site (Table 4). Atrazine equivalent concentrations far exceeded the detected atrazine concentrations, as would be expected, with the calculated 95th percentile TEQ concentration being more than 100 times the detected atrazine concentration for a number of sites. The highest atrazine equivalent concentration detected was 807 $\mu g\ L^{-1}$ at Barratta Creek (data not shown) with 672.3 $\mu g\ L^{-1}$ as the 95th percentile concentration (TEQ_{CP}). Such high atrazine equivalent concentrations for these samples at Barratta Creek were principally derived from the high diuron concentrations which accounted for 97% of the mixture toxicity (data not shown).

The number of sites that exceeded the atrazine TV (13 $\mu g\ L^{-1}$) increased to six for TEQ_{CP}, and remained at four for TEQ_{SO} (Table 4). The number of events where TEQ_{SO} and TEQ_{CP} exceeded the atrazine TV and which atrazine and diuron exceeded TVs on their own was recorded in Table 5. The number of events that exceeded TVs was greater for four sites (Barratta Creek, South Johnstone River, Sandy Creek and Burnett River) when PSII herbicide concentrations were combined using TEQ_{CP} compared to atrazine or diuron concentrations on their own. On the other hand, at two sites (Tully River and Sandy Creek), the number of events that exceeded TVs using TEQ_{SO} was less than the number of events in which diuron concentrations exceeded the TVs. When TEQ concentrations were graphed over time (days), the duration of atrazine TV exceedances was demonstrated (Figs. 7 and 8). At Barratta Creek, the atrazine TV was exceeded for approximately 30 consecutive days when calculated with both TEQ_{SO} and TEQ_{CP}. At Sandy Creek TEQ_{CP} and TEQ_{SO} were above the atrazine TV for more than 30 and 18 consecutive days (data not shown). For the Pioneer and Tully rivers,

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Table 4
The 95th percentile of atrazine toxic equivalent (TEQ) concentrations calculated from the toxic equivalency factors (TEFs) of the PSII herbicides; atrazine, diuron, ametryn, simazine and prometryn. Atrazine TEQs were determined from Ma (2002) for the freshwater microalgal species, *Scenedesmus obliquus* (TEQ_{SO}) and *Chlorella pyrenoidosa* (TEQ_{CP}). Values are compared to the ANZECC and ARMCANZ (2000) trigger value (TV) for atrazine.

Site	TEQ_{SO} (μg L^{-1})	TEQ_{CP} (μg L^{-1})
Barratta Ck	**186.6**	**672.3**
Tully R	**19.14**	**69.7**
Suttor R	0.23	0.23
Sth Johnstone R	4.58	**16.83**
Sandy Ck	**157.4**	**664.0**
Pioneer R	**112.6**	**438.0**
Burdekin R	0.59	2.16
Fitzroy R	0.71	2.46
Comet R	3.11	3.15
Burnett R	4.33	**15.7**
Belyando R	0.02	0.02
Atrazine trigger value[a]	13	13

[a] See Section 2 for a definition of the ANZECC and ARMCANZ (2000) TVs provided.

concentrations of TEQ_{CP} and TEQ_{SO} above the atrazine TV were of shorter duration, up to eight and two consecutive days (respectively). Although atrazine TV exceedances were short-term at Tully, there were pulses of high concentrations (i.e. >13 μg L^{-1}) for multiple events (Fig. 8).

4. Discussion

The results from this study are in agreement with the scientific consensus (Brodie et al., 2008) that there is a widespread problem of pesticide contamination in catchments draining into the GBR. Although the Reef Plan (2009) pesticide monitoring program is in its early stages, the data collected thus far is already providing valuable information on the extent of the pesticide contamination in the GBR catchments, and the potential threat it poses to biota.

The contamination was prevalent on both a spatial and temporal scale with pesticide detections recorded at all 11 sites (i.e. across eight catchments) throughout the 2009–2010 wet season. However, the extent of contamination extended further than just their presence on a temporal and spatial scale. The degree of contamination was truly realised in the number of different pesticides that were recorded at each site, the classes of pesticides that were detected, the commonality of mixtures in a sample, and the concentrations that were present.

Between 2 and 16 different pesticides were recorded at each site, with PSII herbicides detected at all sites (Figs. 2 and 3). The PSII herbicides were the most frequently detected pesticides across all eight catchments (Figs. 2 and 3), occurring in up to 80% of samples (Fig. 4). This result was not surprising based on the recurrent reporting of the presence of PSII herbicides in the GBR lagoon and GBR catchments (e.g. Lewis et al., 2009; Davis et al., 2008; Packett et al., 2009; Shaw and Müller, 2005). Each of the Reef Plan's (2009) five priority PSII herbicides were detected (Table 2) as well as other PSII herbicides, i.e. simazine, bromacil, propazine, prometryn and metribuzin. The five priority pesticides were not equally spread throughout the GBRCA; diuron, ametryn and tebuthiuron were confined to particular catchments, whereas atrazine and hexazinone were present at every site (Table 2). Barratta Creek and Fitzroy River were 'hot spots' for the priority PSII herbicides, with all five detected. It was also found that PSII herbicides were often detected together in a sample; for example, individual samples from Barratta Creek were composed of up to seven PSII herbicides (data not shown for individual samples). Along with the PSII inhibitors, other types of pesticides known to exhibit toxic effects on aquatic biota were detected including other classes of herbicides, insecticides and a fungicide.

The herbicides (other than PSII herbicides) detected included metolachlor, a plant growth inhibitor, which was recorded at nine sites (Fig. 3) in more than 30% of samples (Fig. 4). Metolachlor has been shown to be toxic to aquatic organisms, impacting the growth of phototrophs such as microalgae and macrophytes (Fairchild et al., 1998). The degradation products of atrazine, desethyl atrazine and desisopropyl atrazine, were also frequently detected at most sites. Additionally, the phenoxy acid herbicide 2,4-D was detected in over 90% of samples ($n = 13$) while MCPA and fluroxypyr were detected regularly (10–30% of samples) at the two sites they were monitored – Barratta and Sandy Creeks (Fig. 4). As previously discussed, herbicides pose a real threat to aquatic phototrophs which play a key role in freshwater, estuarine and coastal marine ecosystems, providing vital services to the GBR, such as nutrient cycling, food resources and habitats (Schaffelke et al., 2005; Waycott et al., 2007).

Insecticides (OPs, OCs and an acetylcholine agonist) were also detected across the majority of the monitoring sites. Over the 2009–2010 wet season, the presence of the acetylcholine agonist, imidacloprid, was widespread, occurring in six of the eleven sites: Barratta Creek and the Comet, Johnstone, Tully, Pioneer and Fitzroy rivers (Figs. 2 and 3). Imidacloprid was detected in more than 20% of grab samples (Fig. 4) as well as passive samplers and has been shown to be toxic to aquatic invertebrates (Stoughton et al., 2008). The organophosphate and organochlorine insecticides were only detected with passive samplers and therefore only presence/absence data were available. Organophosphates were detected at

Table 5
Number of events in which the 95th percentile concentration for atrazine, diuron, TEQ_{SO} and TEQ_{CP}, exceeded ANZECC and ARMCANZ (2000) TVs.

Site	Total no. of events sampled	No. of events exceeding trigger values[a]			
		Atrazine	DCMU	TEQ_{SO}	TEQ_{CP}
Barratta Ck	6	1	2	2	3
Tully R	6	0	3	2	3
Suttor R	3	0	0	0	0
Sth Johnstone R	4	0	0	0	1
Sandy Ck	7	0	6	4	7
Pioneer R	2	0	2	2	2
Burdekin R	1	0	0	0	0
Fitzroy R	5	0	0	0	0
Comet R	3	0	0	0	0
Burnett R	1	0	0	0	1
Belyando R	3	0	0	0	0
Trigger value[a] (μg L^{-1})	–	13	0.2	13	13

[a] See Section 2 for a definition of the ANZECC and ARMCANZ (2000) trigger values provided.

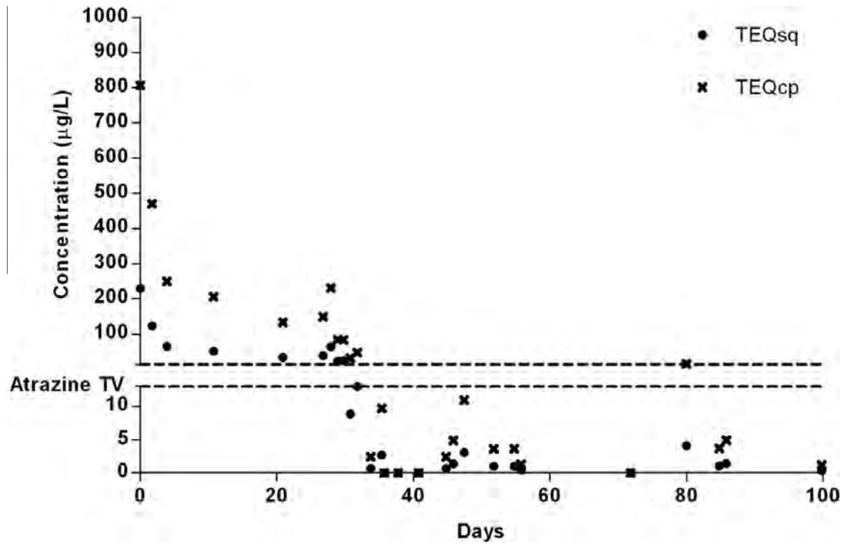

Fig. 7. Atrazine toxic equivalent quotients (TEQs) for the freshwater microalgal species, *Scenedesmus obliquus* (TEQ_{SO}) and *Chlorella pyrenoidosa* (TEQ_{CP}) at Barratta Creek over the 2009–2010 wet season. Time (days) was calculated from the date the first sample was collected. Dotted line indicates the atrazine trigger value for 95% protection of species (13 µg L^{-1}). Note that the scale changes on the *y*-axis after the segment break.

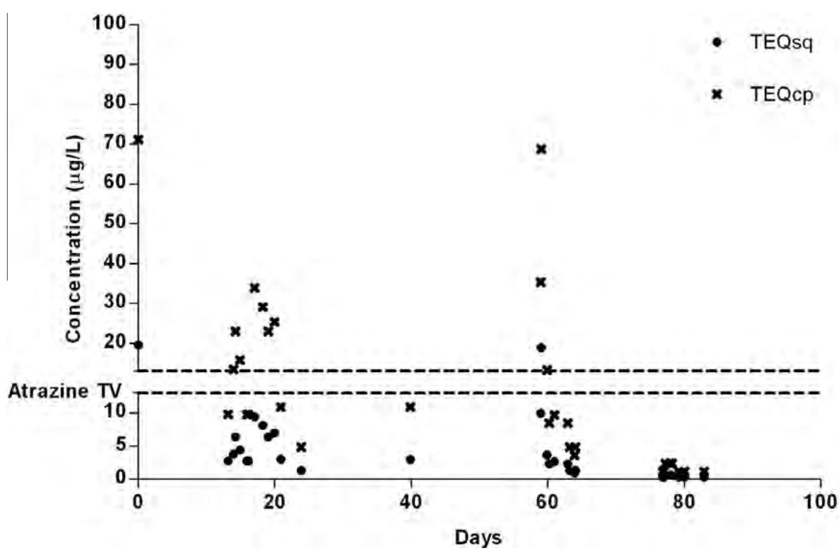

Fig. 8. Atrazine toxic equivalent quotients (TEQs) for the freshwater microalgal species, *Scenedesmus obliquus* (TEQ_{SO}) and *Chlorella pyrenoidosa* (TEQ_{CP}) at Tully River over the 2009–2010 wet season. Time (days) was calculated from the date the first sample was collected. Dotted line indicates the atrazine trigger value for 95% protection of species (13 µg L^{-1}). Note that the scale changes on the *y*-axis after the segment break.

five sites (cholinesterase inhibitors in Fig. 3) and OCs, including the recently banned endosulfan, were detected at two sites (neurotoxins in Fig. 3). The presence of OPs and OCs in catchments draining into the GBR is of concern due to their ability to bioaccumulate, their persistence in aquatic environments and their endocrine disrupting properties (Mortimer, 2000; Kojima et al., 2004).

The threat to aquatic biota from individual pesticides was assessed by comparing concentration data (grab samples only) to the Australian and New Zealand TVs (ANZECC and ARMCANZ, 2000). As recommended by the Australian and New Zealand WQGs (ANZECC and ARMCANZ, 2000) if the 95th percentile of concentrations exceed the TV for a chemical at a site, then there is a moderate to high probability of toxicological effects occurring and further investigation is warranted to determine the potential risk of that chemical to the biota in that ecosystem. In this study, exceedances of the TV occurred at eight sites by three different chemicals: atrazine, diuron and metolachlor (Table 3). However, this assessment may in fact be an underestimation as no TVs were available for nine of the detected pesticides. Of those that did have a TV for comparison, only half of these again had values that were of high reliability. This is a crucial knowledge gap that should be addressed in order to permit a more comprehensive and reliable estimate of the hazard posed by pesticides.

When PSII herbicides were combined using the TEQ approach the toxicity of samples was far greater than the toxicity of the pesticides on their own (compare values in Tables 3 and 4). For example, the 95th percentiles of atrazine TEQ_{CP} at Barratta Creek (the site with the highest pesticide contamination) were approximately 50 times larger than the atrazine TV (Table 4), compared to being approximately equal for atrazine acting individually (Table 3). Furthermore, atrazine TEQs exceeded the Australian and New Zealand TVs (ANZECC and ARMCANZ, 2000) at more sites and more often when compared to the exceedances of the individual chemicals (Table 5).

The mixtures observed in samples were not just restricted to PSII herbicides. The grab samples often consisted of multiple herbicide classes as well as the insecticide imidacloprid. Additionally, the passive samplers adsorbed an even greater number of chemicals during their deployment. The presence of such complex mixtures with chemicals having different modes of action would provide opportunity for interactive effects (including synergism and antagonism) on biota. For instance, it has been demonstrated that atrazine in combination with its metabolites can produce additive and synergistic effects on phototrophic microorganisms (Stratton, 1984). In addition, there is evidence that, when in combination, atrazine and organophosphates (e.g. chlorpyrifos) can produce synergistic effects (Pape-Lindstrom and Lydy, 1997). However, determining the toxicity of a complex mixture consisting of chemicals with many modes of action becomes difficult to derive without conducting whole effluent toxicity tests.

The TEQ results demonstrate the severe underestimation of the true toxicity of a sample if mixtures are not taken into consideration. Even the TEQ concentrations reported here are likely to be an underestimation of toxicity, as only half of the PSII herbicides that were detected in the GBR catchments were accounted for, and the herbicides, insecticides and fungicide with a different mode of action were not included in the TEQ calculations. Furthermore, to be more accurate in using the toxic equivalency approach for GBR catchments, a greater number of species from different trophic orders representative of the GBR catchments should be used to derive TEFs.

There is also debate as to how representative the Australian and New Zealand WQGs (ANZECC and ARMCANZ, 2000) are for tropical species (van Dam et al., 2008) and this was one reason for deriving Water Quality Guidelines for the Great Barrier Reef (Great Barrier Reef Marine Park Authority, 2008). The current Australian and New Zealand WQGs (ANZECC and ARMCANZ, 2000) are predominantly derived from temperate and cool-temperate species, which have been proven to vary in sensitivity to tropical species (Kwok et al., 2007). The results, though, do highlight a pressing need for further investigations of the risk to biota in the catchments monitored in this study.

The potential risks to biota may be further exacerbated by the nature of the exposure patterns. Some catchments showed that highly variable, first flush and pulsed exposure characteristics would be likely to occur, e.g. Barratta Creek and Tully River (Figs. 5 and 8). Whereas other catchments showed that a more low level, chronic exposure would be likely, e.g. Fitzroy River (Fig. 6). Again when assessing the TEQ results, biota were potentially exposed at Barratta Creek and the Tully River, to concentrations greater than the TVs for up to 30 days and to low level concentrations for more than 70 days (Figs. 7 and 8).

PSII herbicides may cause damage or stress to phototrophs in either of two ways. Firstly, high concentrations of PSII herbicides with relatively high light levels can lead to photoinhibition and the formation of reactive oxygen species causing protein damage (Beligni and Lamattina, 2002; Fufezan et al., 2002). In this instance, damage will occur in the short-term, but if exposure was long term this type of damage can become irreparable (Falkowski et al., 2007). Secondly, the impact of PSII herbicides on the photosynthetic apparatus occurs together with shading caused by high total suspended solids concentrations (Haynes and Michalek-Wagner, 2000) that may reduce the phototroph's ability to produce carbohydrates. Reduced electron transport due to PSII binding and shading will ultimately lead to stress and reduced growth in the organism if these conditions are sustained for long periods of time (Harrington et al., 2005).

The second scenario involves the occurrence of multiple stressors in flood plumes, a circumstance that needs to be taken into account when assessing the impact of pesticides on GBR biota. For instance, high concentrations of sediment and suspended solids are ubiquitous with the freshwater flood plumes entering the GBR lagoon (Devlin et al., 2001; Furnas, 2003). Large sediment loads from flood plumes have previously been linked with impacts to seagrasses (Preen et al., 1995; Longstaff and Dennison, 1999). Furthermore, a synergistic interaction between sediment and a PSII inhibitor to coralline algae has been reported (Harrington et al., 2005).

The impact of pesticides to biota in these catchments is likely to have been occurring for many years. PSII herbicides were detected in the mouths of the Tully and Johnstone Rivers in 2004 and 2005 (Shaw et al., 2010). Similarly to this study, diuron concentrations in samples collected at Sandy Creek and Pioneer River were reported to exceed Australian and New Zealand TVs (ANZECC and ARMCANZ, 2000) in 2002 (Mitchell et al., 2005). Monitoring conducted between 2005 and 2008 in the Burdekin and Haughton catchments reported diuron and atrazine in exceedance of the Australian and New Zealand (ANZECC and ARMCANZ, 2000) TVs. Metolachlor was also previously recorded to have exceeded its TV in the Burdekin-Townsville region (Davis et al., 2008; Lewis et al., 2009). Diuron was found in sediments of subtidal regions of the Johnstone and Fitzroy rivers in 1997, in addition to lindane, dieldrin and DDE in the Johnstone River and DDE in the Fitroy and Burdekin rivers (Haynes et al., 2000). Additionally, insecticides such as OPs, OCs and ACh agonists have previously been detected in the Haughton, Burdekin and Fitzroy catchments (Davis et al., 2008; Lewis et al., 2009; Packett et al., 2009).

It is also likely that the extent of pesticide contamination covers a large area over the GBRCA, particularly if the very reasonable assumption is made that other catchments with agricultural land use are also transporting pesticides. Large-scale contamination could pose major problems for reef communities in their ability to recover from natural disturbances such as cyclones, bleaching events or crown-of-thorns starfish (Nyström et al., 2000).

5. Conclusions

This study has found that there is widespread pesticide contamination across the GBR catchments that discharge to the GBR lagoon. The contamination is characterised by frequent and widespread occurrences of pesticides including PSII herbicides and the presence of complex pesticide mixtures. Concentrations of individual pesticides and mixtures of PSII herbicides exceeded the Australian and New Zealand TVs (ANZECC and ARMCANZ, 2000) at a number of sites in the 2009–2010 wet season. These exceedances and the potential transport of these pesticides into the GBR lagoon are concerning for the health and resilience of the reef. The evaluation of potential environmental harm was not fully characterised due a lack of high reliability TVs and toxic equivalence factors. In addition, ecotoxicological research of tropical species representative of north Queensland aquatic ecosystems needs to be thoroughly examined, such that laboratory bioassays can be conducted to indicate the toxicity of End of System waters sampled from rivers transporting agricultural runoff. Bioassays of this nature would provide insight into the concomitant effects of multiple stressors to tropical freshwater, estuarine and marine systems.

Acknowledgements

We are very grateful to a number of people who helped with the collection of flow data, grab samples and deployment of passive samplers in the regional areas. This included the Queensland regional hydrographic staff, Hydrographic Support Unit, The Australian Centre for Tropical Freshwater Research, and Regional NRM bodies.

The study was funded by the QLD State Government as part of Reef Plan (2009).

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Methods for Loads Calculations - Fitzroy River at Rockhampton

Flood Events during November 2010 - January 2011

The extreme weather events that occurred at Rockhampton covered a period of two months, with moderate flooding occurring during December followed by major flooding in January. The total suspended solid (TSS) load that passed through the End of Catchment monitoring site (Fitzroy River at Rockhampton; Department of Resource Management (DERM) SITE 1300000) between 23 November, 2010 and 1 February, 2011 was estimated as being approximately 6 302 000 tonnes. The total nitrogen (TN) load was estimated as being approximately 31,000 tonnes and the total phosphorus (TP) load was estimated as being approximately 14,000 tonnes.

The methods used to calculate the loads passing through this monitoring point are described below.

The Department of Environment and Resources Management (DERM) recorded flow at Fitzroy River at The Gap (Guaging Station 130005A) and a correction factor of 14.5 hours was applied to this data to estimate flow at Fitzroy River at Rockhampton. **NOTE: Flow data from Fitzroy River at the Gap was unvalidated at the time of the loads estimations.** Samples were collected manually throughout the flood period by DERM staff, with good coverage being obtained throughout the entire event (Figure 1). Samples were transported to the NATA accredited Environmental Resources Sciences Chemistry Centre (ERSCC) at Dutton Park, Brisbane and analysed.

To derive load estimations at Rockhampton, flow and concentrations of TN, TP and TSS were imported into the Water Quality Analyser program (developed under the eWater CRC). As good coverage of the event had been obtained, the loads were estimated using the linear regression method, and were checked by repeating the estimation using the Beale ratio method. Load estimations obtained using both methods were within 15% of each other.

The loads estimated were then compared with the total loads reported by Kroon et al. (2010). The 'total load' for each analyte defined by Kroon et al. (2010) was flow corrected to normalise for seasonal variation as well as area corrected for diffuse sources of contaminants from below each gauging station site. The loads calculated for the flood period and reported here did not include a correction for land use down stream of the monitoring sites.

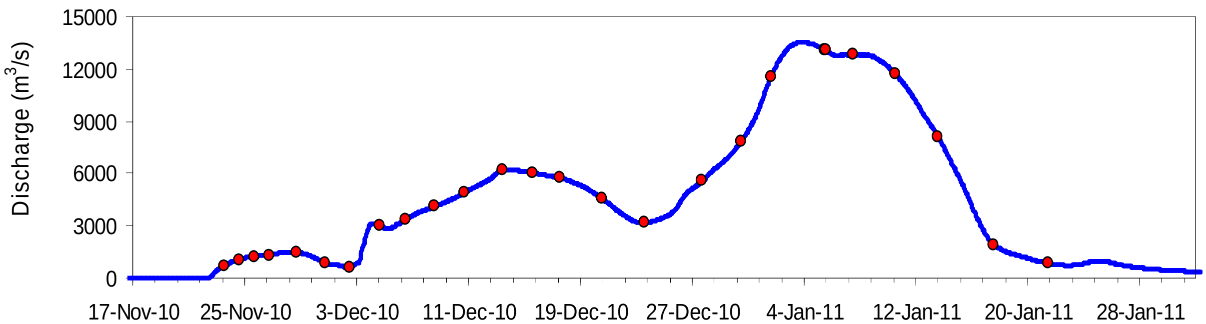

Figure 1 - Unvalidated hydrograph at from the Fitzroy River at Rockhampton during the November 2010 to January 2011 Events. Note: Red circle indicates sample collected.

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