A REPORT ON THE STUDY OF LAND-SOURCED POLLUTANTS AND THEIR IMPACTS ON WATER QUALITY IN AND ADJACENT TO THE GREAT BARRIER REEF

AN ASSESSMENT TO GUIDE THE DEVELOPMENT OF MANAGEMENT PLANS TO HALT ANY DECLINE IN THE WATER QUALITY OF RIVER CATCHMENTS DRAINING TO THE REEF, AS A RESULT OF LAND-BASED POLLUTION, AND TO ACHIEVE THE LONG-TERM GOAL OF REVERSING ANY TREND IN DECLINING WATER QUALITY

LETTER OF TRANSMISSION

The Chairman,
Intergovernmental Steering Committee,
GBR Water Quality Action Plan,
C/- Premier's Dept,
Executive Building,
George Street,
Brisbane, Queensland, 4000

10/01/2003

Dear Chairman,

Attention:- Mr Terry Wall

Reference: A Report on the Study of Land-Sourced Pollutants and Their Impacts on Water Quality In and Adjacent to the Great Barrier Reef.

I submit this Report on behalf of the Panel of Scientists who participated in the Assessment.

The Report covers most issues required by the Terms of Reference, but I seek your permission to submit a Supplementary Report on the topics related to research activities, capabilities, gaps and priorities to full address Term of Reference 7.

You may wish to consider the following quote from Section 5.2.1 as a useful summary statement:

"The evidence that we now have for the GBR is as follows:

a. Land-sourced pollutants such as chemicals used by humans in current urban and rural activities are reaching the GBR. These include chemicals used in agricultural and veterinary applications (AgVet Chemicals)
b. Excess nutrients that are transported by rivers in peak floods, reach the GBR
c. Some areas of the coastal GBR, most affected by river run-off, appear to be degraded and/or slow to recover from natural events, such as cyclones. In this regard, we note the experiences documented overseas that the first major signs (that is, hard proof of adverse impact) appear when the coral reef system fails to recover from other disturbance (including natural events such as cyclonic level events).

There has been recent media debate claiming that turbidity in the waters of the GBR has not increased, and therefore, that adverse impact on the reef can not have increased. Such claims overlook the facets of river run-off, other than turbidity alone and fail to recognise the importance of some components of the sediments; sediments, which cause turbidity, may today include very different adsorbed and absorbed chemicals from those present in previous decades, and the dissolved substances in the sediment-carrying waters may also modify the characteristics of the sediments. The evidence is clear that the levels of some chemicals (notably in nutrients containing nitrogen and phosphorous), in some rivers discharging to the GBR are increasing, and have increased over several years.

The Panel is of the view that the current declines in river water quality in several catchments that drain to the GBR, should not be allowed to worsen, and that, as soon as is practicable, the trends in worsening water quality should be reversed, to allow the GBR and its catchments the best possible opportunities to recover from disturbances. This view includes the consideration that other disturbances, such as the predicted 'global warming', are likely to adversely affect corals and coral reefs.

The evidence that we possess is admittedly incomplete, and some will say that the situation is 'circumstantial', from the most rigid scientific approach. We agree that the scientific evidence is incomplete, but we also believe that the measures we are suggesting to be put in place, to improve the quality of water entering the GBR, are fully justified on the scientific evidence to hand.

The Panel is also of the view that the changes necessary to achieve improvement in water quality can be best achieved by close collaboration among all sectors of the community, and that corrections should be sought at the source of the problem, not 'at the end of the river' entering GBR waters."

I wish to acknowledge the cooperation received from all sectors of the community, from whom we sought information, and, particularly want to acknowledge the commitment of the members of the science panel, of research contractor, Dr Peter Murphy, and of the secretarial assistance received from Ms Gaye Hill, Queensland Fisheries Service, DPI, Queensland.

I apologise for the delay in completion of this Assessment.

Yours faithfully,

Joe Baker, AO, OBE, FTSE, MSc, PhD, FRACI, C Chem
CHAIRMAN, Science panel,
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A REPORT ON THE STUDY OF THE ASPECTS OF LAND-SOURCE POLLUTANTS AND THEIR IMPACTS ON WATER QUALITY IN AND ADJACENT TO THE GREAT BARRIER REEF

1. TERMS OF REFERENCE

For the Reef Protection Plan, the government has set an initial goal of halting the decline in the water quality of catchments draining to the Reef caused by land-based pollution. It has set a long-term goal of reversing the trend in declining water quality.

In the context of these two goals, the Panel will:

1. Review existing evidence for any decline in water quality of catchments draining to the Reef.

2. Review existing scientific evidence of the presence of land-based pollutants in Reef waters and of the nature and extent of the existing and potential impacts of any such land-based pollution.

3. Advise on methodology for developing scientifically sound and effective end-of-river targets to achieve the goals.

4. Evaluate the methodology and data used to set end-of-river targets contained in the GBRMPA Water Quality Action Plan.

5. Assess whether these targets are valid and appropriate for the above goals.

6. Assess whether the catchment risk classification contained in the GBRMPA Water Quality Action Plan is valid and appropriate for the above goals

7. Evaluate current research, and advise 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; and
   - assess the effectiveness of actions to reduce pollution.

8. Advise on the most practical options for improving catchment water quality.

9. Advise on the most practical options for reducing water quality impacts on the Reef.

2. SUMMARY

2.1 Overview

Through a Memorandum of Understanding announced on 13 August 2002, the Federal Government and the Queensland Government have undertaken to develop a Reef Water Quality Protection Plan with the goal of stabilising and reversing the decline in water quality entering the Great Barrier Reef as soon as practicable. The following statement summarises the report of a Panel of Scientists, (See Attachment 2, page 170, full report) which was established to provide advice to facilitate the development of that Plan. The Terms of Reference that the Panel was asked to address are noted throughout the document, and are included in full on page 6 above. Important terms used in this summary report are explained in **Section 3.2 and Attachment 5**

The Panel met on nine occasions and interviewed scientists, managers of Reef Agencies, representatives of major "User groups", and representatives of Non-Government Organisations. Written submissions were received, having been invited from all Queensland local government authorities adjacent to the Great Barrier Reef region, and from Australain Universities involved in Great Barrier Reef research. A total of 459 references was sighted or cited in the report.

As a group of scientists, the Panel is acutely aware of the changes that occur over various time frames from decades to thousands of years. For example, profound changes have occurred in the scales of thousands of years, with respect to the existence of the Great Barrier Reef, and the impact of a 40-metre sea level rise from about 18,000 years ago to about 8,000 years ago. We are not, however, reporting on the time scale of thousands of years.

In this report, we are concerned with what has happened over the very short time period of a maximum of about 200 years or so. Although humans have not been systematically monitoring events in the Reef for anything like the necessary length of time to be confident of fully understanding the impact of any changes in conditions (such as that of water quality), some of the Reef organisms (such as the hard corals), and some of the sediments in the Reef region, may well have retained "signals" or "indicators" of these recent events. These signals can now be accessed and evaluated using accepted scientific methodologies.

The Terms of Reference have set out that the Panel must focus on land-sourced pollutants, and it is recognised that these are not the only source of pressure on the Reef. Our aim has been to be as definitive about the level of these pollutants and the extent of their impact as is practicable, and to clearly describe the boundaries of uncertainty within which we have operated. This summary should be read with this in mind, and the full report should be read to understand the background to the summary statements.

The Panel also recognises that several other studies related to the issue of Reef water quality are planned or already in progress, and that these studies will further our knowledge beyond what we have at our disposal at this time. This, however, is the nature of science. If we wait for all the relevant research to be completed before making a decision on the level of risk then we run the risk of making those decisions too late.

The Panel considered nine terms of reference related to the evidence and impact of any decline in water quality entering the Reef from river catchments, advising on capabilities, gaps and priority research needs to achieve water quality improvements (including commenting on the *Great Barrier Reef Catchment Water Quality Action Plan* [GBRMPA Action Plan]), and on practical options for reducing adverse water quality impacts on the Reef.

The Panel found that there are clear indications that major land use practices in the river catchments, delivering waters to the Reef, have led to accelerated erosion and greatly increased the delivery of nutrients over pre-1850 levels. The reasons for this decline are varied but relate to activities within the river catchments, such as the extensive grazing practices in the drier catchments and overgrazing in general, urban development, agricultural (including horticultural) production, water use practices, extensive vegetation clearing and wetland drainage on coastal plains and development on acid sulphate soils (ASS) and on potentially acid sulphate soils (PASS).

The Panel found that there is clear evidence of the effect of these practices on some rivers, estuaries and inshore areas. Reefs at a number of inshore locations along the coast have been disturbed and have remained in a disturbed state. These reefs exhibit characteristics consistent with altered ecological function due to enhanced nutrient availability or sedimentation. Evidence of impacts on offshore areas of the Reef is not well understood, however information from overseas shows that by the time such effects are obvious the system would be almost irreparably damaged. In light of the above factors the Panel confirmed that there is a serious risk to the long-term future of at least the inshore reef area and that action is necessary to avoid such damage.

The Panel believes that an integrated resource management approach to dealing with the issue is the best way forward and supports the concepts of risk assessment and target setting. To this end the Panel found that the GBRMPA Action Plan has value on a broad basis, but requires significant refinement, particularly at a sub-catchment level. The future development of water quality targets and risk classification must include community input and would best be achieved through existing regional structures using specific local water quality data. The Panel proposes that such development should be initiated through a two day dedicated multi-disciplinary workshop providing a values-objectives-indicators-measurements decision tree for the Reef, involving representatives of all relevant stakeholders and experts in the field of water quality and taking account of State of the Environment reporting.

This Report identifies gaps in current knowledge and provides advice on tools and methods to improve water quality and how adverse water quality impacts on the Reef might be reduced. The Panel believes that its advice, which necessarily invokes the Precautionary Principle, should form an integral part in the development of an effective Reef Water Quality Protection Plan.

2.2 Summary responses to the Terms of Reference

The first two terms of Reference are considered together:

Term of Reference 1. *Review existing evidence for any decline in water quality of catchments draining to the Reef.*

Term of Reference 2. *Review existing scientific evidence of the presence of land-based pollutants in Reef waters and of the nature and extent of the existing and potential impacts of any such land-based pollution.*

The Panel has found that major land use practices in the Reef catchment have led to accelerated soil erosion, as well as increased fertiliser and pesticide application, with consequent increases of sediments, nutrients and pesticides in waterways flowing to the Reef. While these factors are known to have harmful effects on the health of tropical marine ecosystems, the spatial extent of impacts and the resilience of the Reef's systems to sediments, nutrients and pesticides is not as well understood.

Scientific measurements, calculations and predictive modelling of water quality conducted over the past 15 years consistently indicate that there has been at *least* a four-fold increase in sediment and nutrient delivery to rivers discharging to the Reef.

Current estimates of average annual sediment runoff into rivers draining to the Reef range between 10 and 15 million tonnes per year, while estimates of pre-1850 inputs fall between 1 and 5 million tonnes per year. Sediment increase factors of 4, 15 and 4 for rangelands, cropping lands and urban areas respectively, may often be conservative. Current estimates suggest that annual nitrogen (N) exports from catchments bordering the Reef have increased at least 2-fold (22,000 to 43,000 tonnes per year) since 1850. Annual phosphorus (P) exports have increased at least 3-fold (2,400 to 7,000 tonnes per year) since 1850.

Soil P levels in most sugar cane production lands and in soils used for vegetable production are nowadays well above those deemed as critical to achieve maximum yields indicating that improved fertiliser efficiencies are possible.

Inputs of fertilisers (chiefly N & P) and other chemicals for agricultural production in cropping systems of the Reef catchment have steadily risen.

Nitrogen budgets for cropping lands consistently indicate that a significant proportion (ca. 30-50%) of the N input is lost to the surroundings through gaseous transformations, surface runoff and leaching to groundwater. Between 80 and 90% of the P lost to waterways and the sea is attached to suspended sediments derived from eroded soil.

Because of the large area of land use involved, most of the sediments, N and P that move from catchments to the Reef are sourced from extensive grazing lands in the drier catchments (Burdekin and Fitzroy Rivers). However, there is evidence from a number of catchments (Haughton, Johnstone, Herbert and Tully Rivers) that nitrate-N concentrations in river waters increase as water passes through intensive sugarcane growing areas. For example, in the Johnstone Catchment, sugarcane occupies around 12% of the catchment yet contributes close to 50% of the nitrate exported. In contrast, rain forest, which occupies >50% of the catchment, contributes little more than 10% of the nitrate load. Sugar cane farming also contributes a disproportionate percentage of the total P transported from the catchment to the sea (>30%).

Time series sampling of nutrients in the perennially flowing lower Tully River show evidence for a steady increase in dissolved nitrate and phosphate concentrations and more frequent episodes of enhanced suspended sediment concentrations due to up-catchment erosion. This upward trend began in the early 1990's when a significant change in land use occurred within the Tully River catchment.

There is evidence from Bassett Basin (Pioneer Catchment) of elevated levels of ammonia/ammonium and oxides of N in water and pore-water, suggestive of point-source pollution from the nearby sewage treatment plant.

There is evidence of a significant buildup of nitrate below the root zone in highly weathered soils, particularly under sugarcane at Tully, Johnstone and Burnett catchments. A change in land management or cropping regime that changes soil pH is likely to release large quantities of this nitrate, which will then move to groundwater and appear as baseflow in streams. At present, there is no certainty when and to what extent this "sink" will overflow into adjacent waterways.

Livestock numbers in Queensland are as high as they have ever been, resulting in considerable and increasing pressure on grazing lands where grass/tree cover is <25-30%.

Human population and land use pressures in Reef catchments vary widely, with population density unrelated to catchment size. Extensive grazing is the major land use and occupies around 83% of the Reef catchment area between Cape York and the Mary River (94% of land use in the Dry Tropics; 52% of land use in the Wet Tropics). Urban [sub-urban and semi-rural] areas occupy 1.6% of the catchment, cropping 1.13% (dominated by sugarcane), while protected (pristine or minimally disturbed) areas (includes military lands) and forestry occupy the remainder. Land use pressure (impact per unit area) is highest in catchments where sugarcane is grown.

Construction of dams and weirs, development of extensive surface drainage networks and increasing extraction of water for irrigation and urban use have significantly altered the flow regime of some of the Reef rivers (eg. Burnett, Fitzroy, Pioneer, Burdekin, Barron), in some instances reducing overall flow or resulting in changes from seasonal flow to perennial flow and the transformation of ephemeral wetlands in irrigation drainage areas of the Lower Burdekin into permanent wetlands. This probably has (and definitely will have) effects on ecosystem health and water quality that as yet have not been fully quantified.

Extensive vegetation clearing and drainage works on coastal plains have significantly reduced the extent of riparian vegetation and wetlands (permanent and seasonal) and significantly degraded remnant habitats through weed infestations and loss of fringing vegetation.

Drainage and Land developments and drainage schemes on low lying coastal lands comprising a high proportion of acid sulphate soils (ASS), or potential acid sulphate soils (PASS) such as those at Trinity Inlet, have locally resulted in strong acidity, causing the mobilisation of aluminium and iron, increasing chemical demand for dissolved oxygen (DO) in waterways, and consequent harm to local aquatic biota. Although in open waters the acid is diluted when good mixing occurs, and slowly neutralised by seawater, the release of acid may occur over many years, effectively continuously, if only slowly. The extent of any indirect effects on coral reefs, fish and other biota is uncertain. However this is one specific example where the adage for chemical contamination should be heeded - that is, "dilution is not the solution".

Sugar cane juice and billets lost during mechanical cane-harvesting operations can contribute to very low DO in nearby waterways when the sugars and other soluble organics move off-site in runoff or in irrigation tail water. Contemporary research has confirmed that five-day biochemical oxygen demand (BOD_5) levels many times higher than the upper limit of 20 mg O_2/L permitted in municipal effluent can develop under wet field conditions. Mechanical removal of aquatic weeds can also lower DO concentrations for several weeks. While implications for local fish stocks are obvious (there are many floodplain waterways that are essentially fish-free), detailed information on the effects on fish that interact between coastal waterways and "reef" waters is lacking.

Episodically depleted concentrations of dissolved oxygen (DO) to levels unhealthy to fish have been recorded in coastal waterways of the Lower Herbert following runoff events and for several weeks in a lagoon in the Lower Burdekin after mechanical removal of aquatic weeds.

Comprehensive audits of pesticide applications are lacking for uses other than for sugarcane, which is a prominent user of herbicides such as atrazine, diuron, 2,4-D, glyphosate, ametryn, and paraquat, and an emerging user of new products such as Flame (imazapic), Confidor (imidacloprid), and Balance (isoxaflotol).

There are several reports of detections of atrazine, 2,4-D, ametryn and diuron in coastal waterways, including atrazine in groundwaters of the Burdekin Delta. For example, diuron residues have been detected in the Johnstone River, in agricultural drains in the Lower Burdekin, upstream of Mackay in the Pioneer River, in sediments of Bassett Basin in the Pioneer River estuary, and in downstream locations of the Mary River.

There is a recent Pioneer Catchment Report ("River Water Quality in the Pioneer Catchment on February 14-15, 2002", DNRM, July 2002) that states that 470 kg of diuron entered the Dumbleton Weir during this single flood event. This is a substantial and significant amount.

In summary, all of the above factors are very strong indicators of a decline in water quality in Reef catchments. In some catchments (Herbert, Tully, Johnstone) such changes are clearly demonstrated by the results of various extensive water quality monitoring programs in river networks. In many catchments, trends in water quality and nutrient exports are obscured by very high natural seasonal and inter-annual variations in river flow and nutrient concentrations. In such catchments we infer from the well-studied catchments and the factors listed above that there is a high likelihood of similar decline. This general pattern is also corroborated by the findings of the National Land and Water Resources Audit.

The second part of ToR 2 requires the Panel to *"Review existing scientific evidence .... on the nature and extent of the existing and potential impacts of any such land based pollution"*.

This is a very broad challenge, and the Panel advises that:-

1. Reefs at a number of locations along the coast have been disturbed and have remained in a disturbed state. These reefs exhibit characteristics consistent with altered ecological

function due to enhanced nutrient availability or sedimentation. These effects include: local reductions in biodiversity, reduced or failed coral recruitment, enhanced mortality of juvenile corals, reduced photosynthetic performance of corals and the replacement of reef-building hard corals by space-occupying algal communities.

2. Nearshore coral reefs in the Reef are influenced by increased sediment and nutrients in runoff from catchments with significant land clearing and fertiliser utilisation on a recurrent basis ranging from intervals of a decade or longer in the southern Reef to near-annually in sections of the central Reef (16°-19°S) coast bordering the wet tropics

3. River plumes following periods of heavy rainfall are observed well into the Reef lagoon. Apart from the mass of fresh water entering the coastal waters, turbidity has a major impact on available light and coral photosynthesis and coral death has been observed in a range of experimental conditions. Concentrations of nutrients in river runoff plumes reflect increased concentrations in river waters due to land use in catchments. This level of concentrated nutrients gives potential for harm.

4. Detectable concentrations of herbicides (principally diuron) have been found in coastal and intertidal sediments and seagrasses at a number of sites along the coast in close proximity to catchments with substantial sugarcane farming.

5. Elevated concentrations of fat-soluble pesticide residues have been found in dugongs and other marine mammals within the Reef, suggesting that land-based pollutants are finding their way into the food chain of biota associated with the Reef.

6. There is a significant body of well- documented evidence regarding coral reef systems outside of Australia demonstrating harmful effects of excess nutrient availability (eutrophication) and excess sedimentation. The principal effects of excess sedimentation and/or nutrient availability are through disruptions to normal ecological processes in reef systems, especially the capacity of coral-dominated reef communities to recover from natural disturbance events and to maintain naturally biodiverse communities.

Term of Reference 3. *Advise on methodology for developing scientifically sound, effective and measurable end-of-river targets to achieve the goals.*

An adaptive management framework that provides processes for participatory determination of water quality objectives and targets, catchment objectives and targets across social, economic and environmental indicators is needed. Such a process provides effective multi-stakeholder and multi-objective decision making as part of the plan making phase, and for these decisions to be based on a scientific conceptual understanding of the processes and drivers. Capacity and skills would be identified following a process to build a common understanding of the threats and consequences of various actions. The process recommended follows the National Water Quality Management Strategy but with specific science inputs.

End-of-catchment objectives and targets need to be translated to upstream reaches and associated properties, so that there are measurable targets at the point where land use change can be observed and measured and consequent changes in water quality measured over a shorter time period than end of catchment targets.

Steps in the methodology to set effective targets includes: set water quality values and objectives, set targets, set indicators of water quality, assess appropriate measurements and technologies and techniques to identify progress towards the targets, set time periods for expected response of the system, set interpretive tools to account for episodic events and impacts of multiple stressors. That is, a hierarchy of indicators is required from the individual parameter level to the more ecologically integrated indicators, so that multiple factors can be separated and adverse trends in selected indicators directly related to causal mechanisms.

This process should be facilitated by a multi-disciplinary Workshop providing a values-objectives-indicators-measurements decision tree for the Reef.

The methodology proposed is one that involves ”user groups” from the outset, and builds on systems already adopted by "user groups", such as the COMPASS concept of sugar cane growers, which would be adaptable to other users.

Measures warranting serious consideration to resolve environmental concerns are not restricted to end-of-river targets and should continue to include existing measures imposed on the industrial sector (including sugar mills and the mining sector) to limit point-source pollution and free rider behaviour. The measures to control diffuse sources of pollution should embrace enhanced management and monitoring of inputs, improved management of waterways and riparian vegetation, soundly based physico-chemical performance targets; fiscal controls; economic instruments; incentive structures; standards and voluntary agreements; and information and awareness campaigns.

Recalling that the MOU states "an initial goal for a Reef Protection Plan to halt the decline in the water quality of catchments draining to the Reef caused by land-based pollution and a long-term goal of reversing the trend in declining water quality", and noting that environmental systems represent complex networks of interactions amongst physical, biological and social entities making it difficult to fully define damage functions and assimilatory capacities, while simultaneously isolating background sources of the same pollutants, the Panel recognises that any measures introduced will only succeed if they lead to a net reduction in the pollution risk.

Reduction of the pollution risk may take many years as the environmental response to a lowering of some fertiliser application rates or the withdrawal of a herbicide such as diuron will be slow. Those measures "owned" or respected by the landholder or land manager are the most likely to be effective. Ideally, the benefits should not be outweighed by the costs imposed on businesses, the public or individuals. Typically, tradeoffs may need to be negotiated between resource managers and resource users, taking account of benefits, costs and risks.

In recognition of the complexity of the source and of the fate of catchment waters, including groundwater, and floodplain interactions during peak rainfall events, the Panel suggests that a two day Workshop be conducted at the earliest practicable time to review the most relevant measurements that should be made in catchment, in-river, end-of-river and in-reef waters to allow assessment over time of any changes in water quality, and of the sources of any materials associated with any change in water quality.

In determining the measurements to be made, recognition should be given to the Indicators used in National and Queensland State of the Environment (SoE) reports, to ensure compatibility and comparability with other floodplain and coastal aquatic systems, and to facilitate incorporation of Reef water quality results into State and National SoE reports in the future.

Consideration should also be given to the application of the Condition-Pressure-Response model (or similar model) to allow future recommendations to be made on modification of human behaviour to minimise adverse impacts on river, estuary and reef waters.

The Workshop should take into account the draft document "National Framework for Natural Resource Management Standards and Targets" (2001) which has been prepared as part of the Inter-government Agreement for the National Action Plan (NAP). The framework sets aspirational targets - a vision by the community for a region, achievable resource condition targets, the desired outcomes in the medium term of 10-20 years and management action targets for the short term of 1-5 years.

For NAP, targets should be:
· Based on best available science;
· Benchmarked against current natural resource condition and trend;
· Capable of being linked to management actions;
· Defined at appropriate scales and set in specific locations;
· Able to take account of cumulative impacts of actions and the dynamic nature of natural systems;
· Clearly achievable, reflecting the agreed natural resource outcomes sought;
· Measurable, so that outcomes can be quantified;
· Time-bound, with targets moving progressively towards agreed outcomes.

Term of Reference 4. *Evaluate the methodology and data used to set end-of-river targets contained in the GBRMPA Water Quality Action Plan*; and
Term of Reference 5. *Assess whether these targets are valid and appropriate for the above goals.*

The Panel supports the concept of target setting to achieve the goal of stabilizing and reversing the decline in water quality entering the Reef. The Panel is aware that the 2001 *GBR Catchment Water Quality Action Plan* (the Action Plan) was the first step in a proposed staged approach at setting priorities and targets for addressing water quality issues and defining requirements for water quality monitoring and reporting. The Panel is also aware that the Action Plan did not involve public consultation and underwent only limited peer-review, in the short time allocated to its production

The Panel also considers that the Action Plan has value on a broad basis, but requires significant refinement at a sub-catchment level. It will be essential for the development of water quality targets to include community input in order to foster community ownership. The use of the most contemporary water quality data available is also fundamental to the broad acceptance of such targets. These aims can effectively be achieved through the involvement of existing regional structures and seeking specific local information and input.

These, and other points can be captured through the Workshop we have suggested in response to ToR 3, above. The Panel also suggests that end-of-river targets are not the only targets that should be considered in the holistic management of river catchments draining to the Reef.

Term of Reference 6. *Assess whether the catchment risk classification contained in the GBRMPA Water Quality Action Plan is valid and appropriate for the above goals*

The Panel believes that the Commonwealth and the State Governments should accept the concept of risk assessment and work to refine the classification procedure, in collaboration with regional NRM bodies, by jointly engaging a recognised risk analysis specialist(s) to review and assist in updating the proposed end-of-river sediment and nutrient and AgVet chemicals reduction targets, and to achieve desired water quality goals, as part of a process of continuous improvement.

The specific issues could be further addressed at the proposed Workshop.

Term of Reference 7. *Evaluate current research, and advise 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; and*
- *assess the effectiveness of actions to reduce pollution.*

The Panel believes that:-

1. A water quality and sediment pore-water survey should be commissioned in Reef catchments, targeting the discharge zone in coastal estuaries of municipal sewage treatment plants, with an emphasis on nutrients, including the levels of ammonia/ammonium, nitrate and total N, primarily to independently ascertain the "quality" of the discharge and its potential to promote or damage nearby aquatic fauna and flora.

2. Appropriate bio-physical, social and economic research should be undertaken to identify opportunities for improvement and barriers to the adoption and implementation of land and water management practices beneficial to catchment water quality. For example, measures to minimize the mobilization of sediments can be expected to include the avoidance of overgrazing, maintenance of around 75% ground cover across grazing lands, and attention to roadways, headlands and stream-banks in cropping areas where improved soil conservation measures have already been implemented. Collection/removal of cane trash as a possible green power fuel source, particularly in erosion prone areas, will need to be monitored carefully for impact.

3. All current fertiliser recommendations applicable in "reef" catchments (particularly those for sugarcane, vegetables, bananas and dairy pastures) should be reviewed, modified as necessary, and implemented as a matter of priority, with the goal of optimising for the lowest possible application rate to just achieve the maximum yield or production plateau. This may require a new series of experiments containing sufficient fertiliser rates to fit multiple parameter linear-plateau yield models. Alternatively and expeditiously, the data for sugarcane might be generated from modeled simulations. Moreover, soil test recommendations should be discontinued that encourage additional fertiliser input when specified soil test levels exceed values known to be sufficient for maximum yield. This will, for example, require a change to Table 1 of Schedule 1 of the *Code of Practice for*

Sustainable Cane Growing in Queensland, which presently specifies the use of 20 kg P/ha for plant cane at all soil P fertility levels above 40 mg/kg of air dry soil.

4. Research and development should be undertaken to produce and implement cost-effective monitoring technologies to ensure autonomous, wide-spread, long-term and consistent monitoring of key or proxy water quality parameters in the Reef and waterways of the Reef catchment. (This monitoring and the application of the results from the research would also be expected to provide methods to detect the origin of specific contaminants and pollutants transferred to streams and rivers, and/or to the Reef). In addition, the State and Commonwealth governments should establish a joint working group of experts to review and audit the outcomes and effectiveness of water quality monitoring programs on a regular and ongoing basis.

5. Technical (whole-of-system), institutional and social mechanisms for improving water quality in the Reef catchment and reducing contaminated runoff to the Reef should be trialed and demonstrated with a suitable level of support in a number of key or representative catchments (e.g. Fitzroy, Pioneer, Burdekin, Johnstone, Daintree) as a mechanism for encouraging wider adoption of effective approaches to improving water quality and reducing runoff to the Reef.

6. A concerted R&D effort should be undertaken to develop robust and effective modelling tools to support target setting processes and trade-off analysis of land management options in support of planning, policy formulation and implementation of improved land use. This would need to include:
    - Targeted data acquisition to validate and make the current sediment and nutrient delivery models more robust and scaled to information available in the various Reef catchments;
    - Additional process studies to improve our understanding of water quality effects and habitat modification on health of freshwater ecosystems in Reef catchments, and the resulting flow-on effects for marine environments;
    - Application of the refined modelling tools to determine the benefit of targeted intervention within key sediment and nutrient source areas in Reef catchments;
    - Application of the refined modelling tools to assist in options analysis at sub-catchment to local scales to identify priority actions for communities and industry.

7. While accepting that the sugar industry should move as quickly as possible to minimize or prevent the movement to waterways of sugars and other forms of highly labile carbon during and soon after mechanical cane harvesting operations, the Panel believes research is needed to assess the effects of acute and sustained levels of low DO in fresh waters on fish and crustaceans that interact between coastal waterways and reef waters, particularly to assess the consequences for biodiversity and population dynamics.

Term of Reference 8. *Advise on the most practical options for improving catchment water quality*
Term of Reference 9. *Advise on the most practical options for reducing water quality impacts on the Reef.*

The Panel has grouped these two Terms of Reference, because so many of the considerations will relate both to catchment water quality and to water quality impacts on the reef.

The Panel believes that Governments, and where appropriate industry and the general community engaged in the process of developing the Reef Water Quality Protection Plan, should consider the following options to improve water quality and ecosystem health in relevant wetlands, rivers and the GBR:

1. Undertaking a review of policies (including NRM policy) and legislation in 2002-2003 with a view to removing, by 30 June 2005, perverse incentives for activities or environmental outcomes contrary to the goal of improving water quality within the Reef and Reef river catchments.
2. Federal and State agencies jointly endorsing the 6 key principles in designing incentives to address water quality in Reef catchments. (*user pays; polluter pays; cost sharing; sense of community, ownership, and stewardship; adaptive systems; ecosystem approach*).
3. Federal and Queensland governments enhancing their support, including incentives, for industry-specific initiatives aimed at improving water quality performance, and to industries promoting development and adoption of codes of practice and guidelines for all operations and industries within Reef catchments, and to consider legislation to ensure adherence, where necessary.
4. Commissioning an independent review of options for implementation of enhanced incentives for improving water quality in Reef catchments.
5. Undertaking an urgent review of current legislation and commissioning an intergovernmental working party to explore options for legislative reform aimed at integrating and streamlining legislation relevant to water quality issues in Reef catchments.
6. Recommending on ways that industry and regional communities can be assisted in accessing key R&D resource products to assist in the implementation of water quality objectives.
7. Recommending on ways that Commonwealth and State agencies can develop strategic alliances with industry, regional communities and R&D providers to establish "demonstration sites" in the Fitzroy, Pioneer, Burdekin, Johnstone and Daintree (Douglas Shire) catchments to provide a focus for innovation in water quality management in Reef catchments.
8. Implementation of an ongoing system to assist industry and regional communities in data collection, data collation and analysis data integration, information access and use of the outputs of current/future R&D.
9. Investigation of the options, costs and benefits of establishing a Reef Catchments Commission based on the successful NSW Healthy Rivers Commission model, such investigation to include an analysis of whether any existing Agency, Ministerial Council or other body could assume this function.
10. At a whole-of-Reef level, developing a policy and planning framework to enable a whole-of-government approach to improve water quality. A core element should be the development of a whole-of-government service delivery model based on strong regional arrangements underpinned by meaningful and functional partnerships with industry and the wider community, with a panel to monitor and correlate performance across regions.

11. Putting in place adaptive management processes, consistent with best practice Integrated Resources Management (INRM) and at the scale of individual catchments draining into the Reef, to enable government, industry and community participation and partnerships.

12. Formal endorsement of INRM as the conceptual underpinning for water quality management in Reef catchments by industry, regional community and Government organisations and their representatives.

13. Explicit consideration of INRM principles and practices when evaluating the acceptability of policy, planning and management actions that are proposed and developed to address water quality objectives and targets in Reef catchments.

14. With respect to pesticides, intensify efforts to:

    (i) continue to accredit, reaccredit and further train primary producers on responsible and environmentally sound use of AgVet chemicals;

    (ii) develop and train people in the use of a spatially-referenced decision support tool to assess local risk of off-site pesticide movement in "reef" catchments and to provide guidance on appropriate strategies and practices to lessen risks of pesticide loss at the individual farmer level; and

    (iii) conduct research into alternatives to pesticides or on pesticides less prone to contaminate aquatic environments.

15. With respect to fertilisers, all intensively farmed coastal catchments draining to the Reef being classified as Nutrient Sensitive Zones (NSZs) with the following requirements:

    (i) purchase of fertiliser permitted only if there is a Nutrient Management Plan (NMP) for the block or property as part of an accredited Property Management Plan;

    (ii) NMPs supported by contemporary soil and/or plant testing of the area/farm in question, using approved sampling and analytical methods and undertaken by providers deemed to be proficient by the Australian Soil and Plant Analysis Council Incorporated; and

    (iii) records of all fertiliser inputs, including other materials used as an alternative to commercial fertiliser (eg. mill mud, biosolids) being maintained for a minimum of five years, and made available for annual collation by an authorised department or agency.

16. Federal and State agencies, with relevant Local Government involvement, developing a joint service delivery model for water quality management in Reef catchments, where service delivery is achieved in a way that supports community and industry networks, partnership and capacity.

17. Relevant personnel in Federal, State and Local government agencies responsible for water quality management in Reef catchments:

    (i) receiving adequate formal training in participatory processes, relationship management, service delivery and ethics; and

    (ii) when trained, be "accredited", to an appropriate national standard, to deliver participatory processes in regional communities.

18. Governments introducing accountability for the processes by which relevant personnel in Federal, State and Local government agencies responsible for water quality management

in Reef catchments interact with communities and ensure Agency accountability for community capacity building with respect to improving water quality outcomes.

19. Federal and State agencies jointly supporting programs in each Reef catchment to:
    (i) provide information to and engage stakeholders in consultations over water quality management, with an emphasis on regional and industry-by-industry approaches;
    (ii) undertake economic and socio-economic assessment of catchment water quality management options;
    (iii) develop tools and methods to enable the assessment of the benefits and costs of specific water quality management actions;
    (iv) ensure cooperation in the assessment of options for short, medium and long-term actions to address water quality issues, including the environmental, social and economic benefits and costs of those actions, and implementation through the regional NRM planning processes;
    (v) enable negotiation and implementation of local water quality improvement actions that are accredited in regional NRM plans;
    (vi) provide financial, policy and project management assistance to implement priority actions co-operatively with regional communities;
    (vii) provide assistance to industry to refine and encourage industry adoption of current recommended best practice in the use of AgVet chemicals;
    (viii) develop an independently assessable water quality audit system for each Reef catchment, that includes audits of inputs (eg. people, land uses, sediments, fertilisers, pesticides, heavy metals, and persistent organics).

20. Amending the State Coastal Management Plan to require any approvals under the Coastal Protection and Management Act 1995 to include the submission of an accredited Property Management Plan, including a Nutrient Management Plan (NMP).

21. Regional Coastal Management Plans (RCMPs) spatially identifying constraints to development so that these are comparable with basic land information. (This information to be incorporated into Local Government plans)

22. Federal and State Government agencies jointly providing financial, technical and project management assistance to Local Government, industry and the community in the support of Reef Catchment Plans and RCMPs to implement priority actions for water quality management co-operatively, including a whole-of-system approach (eg. soil types/fertility, inputs, riparian and in-stream condition, land and water management, etc.).

2.3 Conclusions

The Panel has recognised that the science related to the extent and impact of increases in the level of sediments, nutrients and pesticides is incomplete. Indeed the Panel has identified a range of monitoring, as well as biophysical, social and economic research, that should be undertaken to improve this knowledge. These suggestions range from ways to improve the identification of pollutant sources and of monitoring their impacts, to reviewing recommended fertiliser application rates and identifying barriers to the adoption of land and water management practices beneficial to water quality.

The Panel recognises that the Reef is spatially and temporally complex with various regional feedback mechanisms, such that a pressure in one part may not be evident in another part. In short, the Reef is not a homogeneous feature and it is subject to multiple and often coincident pressures making the clear identification of contributing factors and their relative importance difficult to quantify. This complicates interpreting pressure and risk.

This notwithstanding, there are very strong indicators of a decline in the water quality in Reef catchments. In some catchments this change is clearly demonstrated by the results of extensive water quality monitoring programs. In many catchments, however, trends are obscured by very high natural seasonal and inter-annual variations in river flow and nutrient concentrations. In such catchments we infer from the well-studied catchments and other relevant factors that there is a high likelihood of similar decline. This general pattern is also corroborated by the findings of the National Land and Water Resources Audit.

The Panel found that there is clear evidence that land practices are impacting some rivers, estuaries and inshore areas. Coral reefs at a number of inshore locations along the coast have been disturbed and have remained in a disturbed state. These reefs exhibit characteristics consistent with altered ecological function due to enhanced nutrient availability or sedimentation. The precise causes of adverse impacts on offshore areas of the Reef are not well understood; however, information from overseas shows that by the time such adverse impacts are obvious the system may well be almost irreparably damaged, in time frames of decades. In light of the above factors the Panel confirmed that there is a serious risk to the long term sustainable functioning of at least the inshore reef area, and that action is necessary to avoid such long-term adverse impact.

The Panel believes that an integrated resource management approach to dealing with the issue is the best approach and supports the concepts of risk assessment and target setting. To this end the Panel found that the GBRMPA Action Plan has value on a broad basis, but requires significant refinement, particularly at a sub-catchment level. The future development of water quality targets and risk classification must include community input and are best achieved through existing regional structures using specific local water quality data.

In summary the Panel believes that a precautionary approach needs to be used. The Precautionary Principle should be applied to both the Reef and to human activities in the catchments so that the major impacts of human disturbance are identified. From this, changed management practices can be implemented that will make a substantial improvement to water quality of streams discharging to the reef, rather than changes which will have limited impact on the reef but may significantly affect the livelihoods of many people and industries.

The Panel believes that the report sets forward a suitable process that sets ecological health and water quality objectives for both terrestrial activities and for the Reef based on scientific knowledge that is ‘socially robust’, and whose production can be seen by society to be both transparent and participative. This process utilises a multi-disciplinary workshop providing a values-objectives-indicators-measurements decision tree for the Reef, involving representatives of all relevant stakeholders and experts in the field of water quality and taking account of State of the Environment reporting. The Panel has also set out a number of practical options for improving water quality and reducing water quality impacts on the Reef that can be considered by Governments, industry and the general community as they are engaged in the development of the Reef Water Quality Protection Plan.

3. OBJECTIVES OF THE REPORT

3.1 Overview

In order to address the many issues involved in improving water quality in Great Barrier Reef (GBR) catchments, decision-makers need access to current scientific knowledge, to social and economic models, and to estimates of the likely impacts of any actions taken. They also need effective means of collating, interpreting and using the information with which they are provided. Policy and planning cannot be expected to achieve society's goals in the absence of adequate and readily accessible data relating to the biological, chemical, physical, economic and social factors that impinge on resource use.

Much information, however, remains unknown. This report identifies gaps in our understanding of physical, chemical and biological processes. Clearly, research is required to fill these gaps, and to improve our understanding of the social and economic systems in which resource use occurs. Research is also needed in the organisation of that information and its derived knowledge to provide an effective basis for decision-making. Fortunately, several other studies are planned or are in progress.

Geological changes have occurred naturally in the GBR over thousands of years; particularly important was a rise in sea level by about 100 metres that occurred between 18 000 and 8 000 years ago. However, we are primarily concerned with what has happened over the last 200 years, and although humans have not been systematically monitoring events in the Reef for anything like the necessary length of time to be confident of fully understanding the impact of any changes in conditions (such as that of water quality), some of the Reef organisms (such as the hard corals), and some of the sediments in the Reef region, have retained "signals" or "indicators" of past events, which can now be accessed and evaluated.

As well as understanding the behaviour of the Reef system over time, and how it is affected by river catchment processes in those rivers which drain into the Great Barrier Reef, (the "GBR catchments"} we also need to know how we can ameliorate problems caused by deleterious practices on the land, in those catchments. Attempts to do this – by establishing a comprehensive set of procedures and practices to improve water quality in GBR catchments – will pose very significant challenges for communities, government and industry. This report identifies several opportunities to address these challenges.

3.2 Limitations and Explanations

(a) This report is based on the best scientific information available, and is derived from the specific Terms of Reference formulated by an Interdeparmental Committee (IDC), which was itself established to ensure that the intent of the Memorandum of Understanding (MoU) (Attachment 1) between the Commonwealth Government and the Government of the State of Queensland was achieved. The MoU was designed to facilitate cooperation between the parties to protect the Great Barrier Reef from land-sourced pollutants.

The report does not attempt to go beyond its Terms of Reference (TOR). Terms 7, 8 and 9 allow scope for recommendations beyond the knowledge base derived directly from research in the natural and physical sciences, and can build on the collective experience of the Panel, as well as on information provided in meetings with and oral and written presentations from experts in different disciplines, to include recommendations of an organisational nature.

The constraints of this report must be acknowledged. It aims to assist the Federal and Queensland Governments to achieve the initial- and long-term goals for the "Reef Water Quality Protection (RWQP) Plan", the initial goal being "to halt the decline in water quality of catchments draining to the Reef caused by land-based pollution," and the long-term goal "of reversing the trend in declining water quality."

In accepting the responsibility of undertaking the preparation of this report, the Scientific Panel received approval to modify Term 1 so that there was no pre-judgement that there had been a "decline in the water quality". Therefore the first term of reference was modified to read as follows: "review existing evidence for any (rather than "the", as implied in the MoU) decline in water quality of Catchments draining to the Reef".

The report also focuses on "land-sourced pollutants". It is dedicated to the objective of protecting the GBR from such pollutants.

The MoU specifically acknowledges (clauses 7 & 11) that there is "a range of other sources of pollutants", and that "there are other threats to the values of the Reef, for example impacts from fishing and tourism ventures, and that separate processes are under way to address these threats".

At some time, the results of all these studies must be brought together, to allow a holistic approach to the understanding of the impact of human activities on the Great Barrier Reef. However, that is not the brief to which this Panel was required to respond.

(b) Our aim has been to be as definitive as is practicable, and to remove uncertainty as to the boundaries within which we have operated.

Therefore we have defined some essential terms. These are:

Water Quality

Water quality is socially defined, and depends on the desired use of water. For example: uses such as drinking, recreation, fishing and habitat for aquatic organisms are normally associated with high levels of water quality; whereas water used for hydroelectric power generation, industrial purposes, and irrigation does not require such high standards.

Clean water is necessary for human health and the integrity of aquatic ecosystems. Ecosystems filter and cleanse water of materials regarded as pollutants. This ability, however, can be impaired by increased levels of pollution and habitat degradation in many rivers, lakes, estuaries, and near-shore marine areas around the world.

Altered water quality has the potential to change the structure and function of aquatic ecosystems, including those of the GBR.

For the practical purposes of this review, water quality should be taken to mean the physical, chemical and biological characteristics that sustain both aquatic ecosystems and desired water uses.

Pollutants
Pollution is defined as a deleterious change in the chemical, physical and biological qualities of an ecosystem due to human activity. Pollutants are the substances, structures and species (biological or chemical) that cause the pollution.

The Reef
The Reef refers to the Great Barrier Reef or GBR. Reef waters are those within the "Great Barrier Reef World Heritage Area" and intertidal waters adjoining the World Heritage Area (WHA). For the purposes of this document, the southern boundary of the GBR catchment is defined as the Mary River, and the northern boundary is the Torres Strait.

GBR catchments – catchments of rivers that drain into the GBR lagoon.

Catchment – the total area upstream of a particular location in a river or stream system which collects and directs water into and past that location.

Anion – an electrically charged molecule or atom with a negative charge (e.g. Cl^-, NO_3^-, $SO_4^=$)

Cation – an electrically charged molecule or atom with a positive charge (e.g. Na^+, H^+, NH_4^+, Fe^{3+})

Aspirational target – a vision by the community for a region

Management action targets – the desired outcomes for the short term of 1-5 years

Achievable resource condition targets – the desired outcomes in the medium term of 10-20 years

(c) The full Memorandum of Understanding (MoU) is reproduced at Attachment 1.
The Panel makes the following observations on its brief relative to the MoU.

The Panel could not accept any prejudgement on water quality (for example, the statements of Clauses 3 and 4*) and received approval to modify TOR 1.

The Panel is strongly of the opinion that a precautionary approach should be used to protect the values of the Reef and that a risk management approach should be taken to address matters posed by any "decline in water quality that might impact on the environmental, social and economic values of the Reef."(Clause 5)#. However, our report does not attempt to address these three values in any detail as it is concerned solely with changes in water quality. (Clauses 5 and 12 refer to "environmental, social and economic values of the Reef".)

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* Clause 3. The governments agreed that the decline in water quality entering the reef lagoon poses a significant threat to the natural, economic and social values of the Reef.
Clause 4. The governments agree that as a first stage in the protection of the reef a major goal is stabilising and reversing the decline in water quality entering the reef lagoon as soon as practicable.

\# Clause 5. The governments agree that the precautionary approach needs to be used to protect the values of the reef, and that a risk management approach should be taken to address matters posed by declining water quality that might impact on the environmental, social and economic values of the reef.

The Panel has not necessarily accepted the statement of Clause 6 that "the major source of pollutants entering the reef lagoon emanates from land use activities in the catchments" but has assessed the evidence for this statement. The members of the Panel believe that their task can be addressed by considering solutions to any cases where a decline in water quality is shown, through remedial actions and Integrated Catchment Management (ICM), which is a desirable mechanism to follow.

In this regard, the Panel noted that Clause 15 states, "It is expected that the Regional Natural Resources Management (RNRM) plans will be the primary vehicle for implementing the Reef Water Quality Protection Plan (RWQPP) at the catchment level." That statement implies that for any given GBR catchment there will be an over-riding RNRM Plan, a specific ICM Plan, and an over-riding RWQP Plan. Additionally there are likely to be local Integrated Planning Act requirements, Regional Coastal Management Plans based on Queensland legislation, and GBRMPA Plans. The Panel is aware of the complexities and difficulties associated with such diversity of plans and legislation and believes that to improve environmental conditions a simpler, unified approach is required.

The Review process

The Panel (See Attachment 2) convened on nine occasions, three of those times being by teleconference.

- 27 March, teleconference
- 10 April, teleconference
- 16-17 April, at Department of Primary Industries, 80 Ann St, Brisbane
- 30-31 May, at CRC Reef Research Centre, Flinders Mall, Townsville
- 11 June, at Department of Primary Industries, 80 Ann St, Brisbane
- 18 June, at CRC Reef Research Centre, Flinders Mall, Townsville
- 9 July, at Department of Primary Industries, 80 Ann St, Brisbane
- 19 August, teleconference
- 2 October, at CRC Reef Research Centre, Flinders Mall, Townsville

The Panel interviewed a total of 37 scientists, managers of Reef Agencies, representatives of major "User groups", and representatives of Non-Government Organisations. Three written submissions were received. (See Attachment 3 for details)

Submissions were invited from all Local Government authorities and universities adjacent to and with operations in the Great Barrier Reef region.

Over 480 references were sighted and/or cited in the course of the panel's operation. The bibliography is listed in Section 7 of this report.

4. WATER QUALITY PROCESSES

4.1 Conceptual model – The Catchment to Reef Continuum

The Panel is strongly of the view that coastal ecosystems are closely linked to terrestrial and freshwater ecosystems, and that understanding of water quality issues in the coastal zone requires knowledge of processes on the land and in streams, rivers, estuaries and coastal freshwater and saline wetlands.

Linkages are not simply downstream, but also involve important migrations of many species (some of commercial value) between coastal marine habitats and inland waterways and wetlands. This concept of a continuum, through the catchment to coast, or "range to reef", is captured by a cross-section of the eastern Queensland landscape (Figure 1) and is underpinned by the connecting processes between two World Heritage Areas (WHAs), the Wet Tropics Rainforests and the Great Barrier Reef (GBR). These WHAs are major centres of terrestrial, freshwater and marine biodiversity in Australia, encompassing as much as 4% of the world's biodiversity. Together they sustain the most significant portion of the biodiversity of this megadiverse continent. The land-associated processes that are regarded as most significant in relation to the health of the GBR are:

- land-use change;
- the effects of land uses on nutrient, sediment and contaminant input to freshwater systems;
- processing of those materials in ground water, streams, rivers, estuaries and wetlands;
- delivery of sediments, enhanced nutrient loads and water-soluble and water-insoluble contaminants to coastal marine systems;
- movement of biota (e.g. fish, prawns) between inland and marine waterways as a necessary part of their life cycles.

Many biophysical variables influence these processes and their effects. These variables differ among GBR catchments, depending on climate, catchment size, topography, geology, soils, vegetation, etc. Important catchment variables that influence the health of marine systems include:

- natural levels of soluble and insoluble substances such as sediments and nutrients, to which the ecosystem has adapted – for example, erosion, transport and deposition of sediments are natural and vital processes that shape landscapes, determine aquatic habitat types and form floodplains; and leaching and transport of nutrients enhances productivity downstream;
- natural in-stream processes sustaining normal biodiversity, such as productivity, energy and materials pathways through food webs, dispersal, natural disturbance – these processes depend on natural rates of flow and materials transport, maintaining areal integrity of waterways and wetlands and their adjoining vegetation, and protecting ecosystems from damage, including invasion by weeds;
- land-use practices such as protecting waterways from contamination or stock access – stock may cause significant damage to banks, enhancing erosion and sedimentation, and may contaminate streams and waterholes, especially in the dry season; however, they may be useful as controllers of weeds in the riparian zones;

- agrochemical usage, including application rates and schedules with respect to weather – loss of nutrients to waterways enhances weed growth, eutrophication and oxygen reduction in waterways, and downstream contamination; loss of pesticides is likely to be detrimental to downstream biotic communities;
- climatic events such as floods, droughts, and baseflow characteristics (note that GBR catchments have intense climatic events and variable hydrographs by Australian standards) – ecosystems have changed with climate, and are sculpted by it; extreme events are a normal feature of the landscape and may lead to major temporal variation in water quality in inland and coastal waterways and wetlands;
- modification to flow volumes and patterns by dams, weirs, bund walls, culverts, diversions, vegetation type and cover, harvesting, irrigation tail water – despite the climatic variation of the GBR region, long-term flow regimes are predictable, and ecosystems are adapted to this predictability; major changes (such as reduced or supplemented flows) lead to major responses, including, variously, altered sediment dynamics and habitats, enhanced weed establishment, waterlogging of riparian vegetation and dieback, reduced flushing of waterholes, all of which have implications for downstream water quality;
- modification to groundwater levels and quality resulting from extraction or supplementation (e.g. by irrigation) – can lead to waterlogging, to maintenance of permanent surface water in otherwise ephemeral streams and wetlands (destroying important habitats), and salinity problems in some catchments;
- integrity of riparian vegetation as a bank stabiliser, contaminant filter/processor, habitat and in-stream habitat modifier – the condition of riparian vegetation through the catchment is one of the crucial determinants of in-stream conditions, and its broad-scale reinstatement would make a significant positive impact on water quality and habitat values of waterways and wetlands;
- integrity of in-stream and wetland ecosystems as contaminant filter/processors; as habitat and food for transient marine-freshwater species – streams and wetlands, in natural systems, are not inert channels and reservoirs, but are rich and active ecosystems that process materials within them, providing natural cleansing mechanisms for water through much of the year; and even in periods of major flooding, coastal floodplains and wetlands arrest water flow, facilitate sediment deposition and generally moderate impacts of the flood on coastal systems;
- barriers to movement (e.g. weirs, culverts and small flow control structures) – many fish and crustacean species move between coastal waterways, estuaries, streams and wetlands, but are thwarted by even the smallest water level control structures (such as drop boards); weirs and dams are normally complete barriers except to eels and some crustaceans which can bypass the structure; these barriers severely restrict the amount of habitat available to many species of interest to fishers (including barramundi, mangrove jack and jungle perch) and severely deplete the biodiversity of coastal waterways, and probably the population levels of such species along the coast.

Ultimately, any effects of freshwater systems and land use on the ecosystems of the GBRWHA are caused by materials (sediment, nutrients and other contaminants) which are introduced into the marine environment by streams and rivers in catchments, and by a complex of ecological processes. The effect of the processes listed above in GBR catchments is therefore of prime significance and relevance to the health of the GBR.

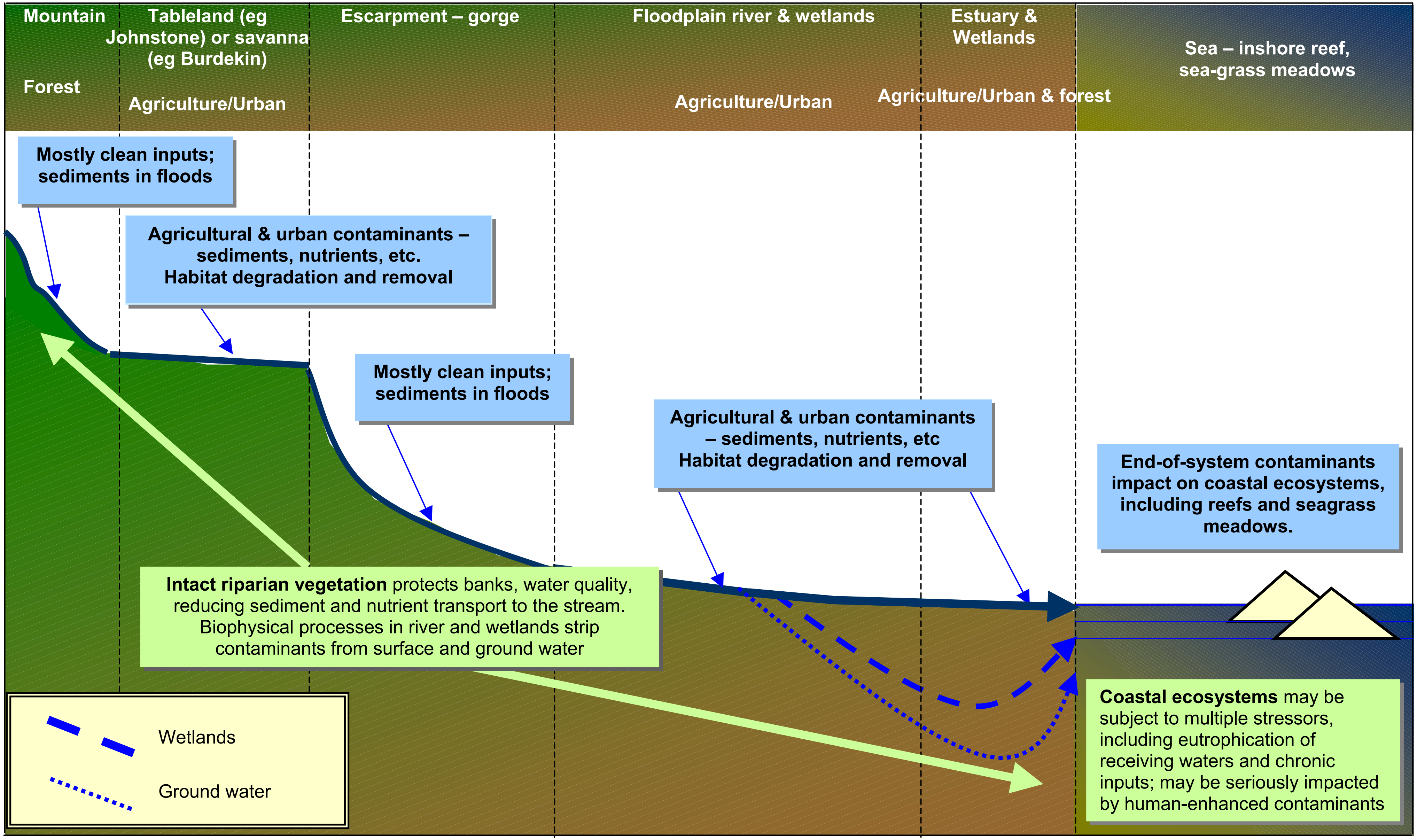
Major land uses that are known to influence these variables in catchments discharging to the GBR include agriculture (cattle grazing, cropping), urban development and aquaculture, forestry, mining and tourist activities. End-of-system values for water quality integrate these natural processes and variables, but do not equate to or indicate overall condition (e.g. habitat integrity). Flood-based monitoring quantifies material loads leaving the system but may miss periods of steady contaminant transport – chronic inputs to the inshore marine system may be just as important as acute flood pulses, as they supply readily accessible nutrients through the year.

Coastal marine systems, including coral reefs and seagrass beds within 20 km of the coast are influenced by these catchment processes, and changes to those processes present significant risk for undesirable or un-natural change in these coastal systems. These systems are naturally dynamic because they are subject to many stressors other than water quality, including floods, coral bleaching, cyclones, fishing, and crown-of-thorns starfish.

Evidence indicates that a range of processes, including land use, have materially increased the delivery of sediments and nutrients from river systems into the GBR lagoon. Human activities and practices have also altered the hydrology of many GBR catchments. It is acknowledged that bursts of excess sediment and nutrient transport occurred naturally in the past; however, changes in land use practice during the last 200 years may have altered the type, quantity and frequency of discharges to the GBR. Both the materials involved in the change and the rate and timing at which those materials are transported to the GBR may be significant.

Natural oceanographic processes (wind stress from SE tradewinds, Coriolis Force) typically move coastal waters to the north, as they are eventually mixed with more offshore waters. For this reason, coastal waters in Hervey Bay can influence the most southerly reefs of the GBR. Discharges from the Burnett, Burrum and Mary Rivers will tend to mix in the coastal zone. Coastal waters from south of the Mary River catchment are diverted offshore by Fraser Island and are unlikely to influence the southern GBR.

FIGURE 1. THE CATCHMENT TO REEF CONTINUUM – LAND→ RIVER→ (WETLAND)→ SEA: CHARACTERISTICS AND PROCESSES



5. REVIEW

5.1 Evidence for declining water quality in catchments draining to the Great Barrier Reef World Heritage Area

5.1.1 Introduction

In order to decide whether human activities within the GBR catchment are influencing water quality both there and in the adjoining ecosystems of the GBR, it is useful in the first instance to identify those factors that do or could influence water quality. Following that, we will present and evaluate evidence for changes in water quality and/or changes in nutrient and sediment delivery to the GBR, which could affect coastal water quality.

Basic statistics of mainland and larger-island drainage basins discharging into the GBRWHA are given in Table 1. These were compiled from data of the Queensland Department of Natural Resources and Mines (NR&M) and include the names and total capacities of significant storages (dams, weirs and barrages). There are 38 recognised catchments and 39 significant storages. Those storages are located in only 10 of the catchments. Total water storage volume represents 22% of the mean annual gauged discharge, as measured at the closest gauging station to the sea, noting there are no discharge data for 7 relatively small catchments.

Table 1. Selected summary statistics on eastern Queensland's reef catchments with particular emphasis on water resources.

Catchment number	Catchment name	Area of catchment (km^2)	Mean Annual Discharge from major river at closest AMTD[1] (ML)[2]	Significant water storage/s[3]	Capacity of significant water storage (ML)[3]	Total capacity of significant water storages per catchment (ML)	Total storage volume as percent of annual discharge	Catchment Area of water storage system (km^2)[2]	Number of surface water gauging stations 2002 [2]	Number of groundwater bore monitoring stations 2002[2]	Number of ground water quality monitoring bores 2002[2]	Number o surface wa ambient qua monitorin bores 200
101	Jacky Jacky	2,963	No Records									
102	Olive-Pascoe	4,179	1,320,698						2			
103	Lockhart	2,883	No Records									
104	Stewart	2,743	206,325						1			
105	Normanby	24,408	845,295						4			
106	Jeannie	3,637	137,251									
107	Endeavour	2,182	153,979						2			1
108	Daintree	2,107	988,953						4	9		3
109	Mossman	473	284,068						1	16	1	1
110	Barron	2,188	412,177	Tinaroo Falls Dam	438,900	438,900	106.5	545	10	66	3	2
111	Mulgrave-Russell	1,983	756,362						6	87	11	2
112	Johnstone	2,325	805,029						7	113	14	4
113	Tully	1,683	2,369	Tully Falls Dam					3	13	2	1
114	Murray	1,107	149,515						1	41	5	1
115	Hinchinbrook Is	396	No Records									
116	Herbert	9,843	3,591,976						12	97	7	5
117	Black	1,075	73,010						2	31	3	1
118	Ross	1,707	222,235	Ross River Dam Paluma Dam	214,000 11,800	225,800	101.6	750	5	14	1	1
119	Haughton	4,051	921						4	576	13	2
120	Burdekin	130,125	9,466,458	Burdekin Dam Clare Weir	1,860,000 15,900	1,875,900	19.8	114,654 129,712	24	472	7	14
121	Don	3,695	167,171						4	390	12	3
122	Proserpine	2,535	23,940	Peter Faust	491,400	491,400	2052.6	269	4	112	20	1

Catchment number	Catchment name	Area of catchment (km^2)	Mean Annual Discharge from major river at closest AMTD[1] (ML)[2]	Significant water storage/s[3]	Capacity of significant water storage (ML)[3]	Total capacity of significant water storages per catchment (ML)	Total storage volume as percent of annual discharge	Catchment Area of water storage system (km^2)[2]	Number of surface water gauging stations 2002[2]	Number of groundwater bore monitoring stations 2002[2]	Number of ground water quality monitoring bores 2002[2]	Number o surface wa ambient qua monitorin bores 200
				Dam								
123	Whitsunday Is.	162	No Record									
124	O'Connell	2,387	1,282						4	2		1
125	Pioneer	1,570	899,765	Eungella Dam	112,400	273,400	30.4	150	7	74	7	3
				Dumbleton Weir	8,840							
				Mirani Weir	4,660			1,211				
				Teemburra Dam	147,500			65				
126	Plane	2,535	58,681						2	200	13	1
127	Styx	3,005	No Records									
128	Shoalwater	3,607	No Records									
129	Waterpark	1,834	143,891						1	41	2	1
130	Fitzroy	142,541	4,893,483	Callide Dam	136,300	1,559,500	31.9	516	51	388	47	25
				Kroombit Dam	14,600			326				
				Glebe Weir	17,700			17,700				
				Gyranda Weir	16,400			22,097				
				Moura Weir	7,700			29,010				
				Neville Hewitt Weir	11,300			40,110				
				Orange Crk Weir	6,780							
				Theordore Weir	4,760			549				
				Bedford Weir	22,900			50,855				
				Bingegang Weir	8,060			16,173				
				Fairburn Dam	1,301,000			75,167				
				Tartrus Weir	12,000							
131	Curtis Island	567	No Records									
132	Calliope	2,236	155,579						2			1
133	Boyne	2,590	336,770	Awoonga Dam	270,000	474,200	140.8	2,261	3	14	6	1
				Boondooma Dam	204,200			4,039				
134	Baffle	3,996	246,340						1			1
135	Kolan	2,901	70,903	Bucca Weir	11,600	607,700	857.1	2,385	2	109	3	2

Catchment number	Catchment name	Area of catchment (km^2)	Mean Annual Discharge from major river at closest AMTD[1] (ML)[2]	Significant water storage/s[3]	Capacity of significant water storage (ML)[3]	Total capacity of significant water storages per catchment (ML)	Total storage volume as percent of annual discharge	Catchment Area of water storage system (km^2)[2]	Number of surface water gauging stations 2002[2]	Number of groundwater bore monitoring stations 2002[2]	Number of ground water quality monitoring bores 2002[2]	Number o surface wa ambient qua monitorin bores 200
				Fred Haigh Dam	562,000			1,300				
				Kolan Barrage	3,800			2,539				
135 (ctd)				Ben Anderson Barrage	30,300							
136	Burnett	33,247	1,428,658	Bjelke-Peterson Dam	134,900	436,510	30.6	1,664	29	349	32	15
				Walla Weir	29,500			32,595				
				Cania Dam	88,500			277				
				Claude Wharton Weir	12,800			23,304				
				John Goleby Weir	1,690			3,840				
				Jones Weir	3,720			21,700				
				Wuruma Dam	165,400			2,353				
137	Burrum	3,359	38,971						5	252	10	1
138	Mary	9,440	1,228,222	Borumba Dam	46,000	63,480	5.2	498	15	29	2	13
				Cedar Pocket Dam	730			18				
				Mary Barrage	12,000			7,333				
				Tinana Barrage	4,750			783				
	Totals:	***424,265***	***29,110,277***		***6,446,790***	***6,446,790***	***22.1***	***606,748***	***218***	***3,495***	***221***	***107***

1 AMTD - Adopted Middle Thread Distance measured upstream from the mouth. Dams and dam sites are fixed distances. (0.0km indicates not calculated).

2 One megalitre = 1,000,000 litres. Data sourced from Department of Natural Resources and Mines - Insite Website - Water Monitoring Summary Data.

3 Information sourced from SunWater (http://www.sunwater.com.au/current_storage_info/Water_Storage_Summary.pdf)

5.1.2 Evidence of factors leading to decline in water quality in GBR catchments

Materials in river discharges to the GBR include particles of eroded soil, re-mobilised stream sediments, nutrients such as nitrogen and phosphorus, pesticide residues, industrial chemicals, heavy metals and organic matter. Apart from pesticides, other manufactured substances and some substances formed during combustion, the listed materials occur naturally in the 424 265 km^2 of land drained by Queensland's east-coastal rivers from Cape York to the Mary River (See Map).

What, how much and how often "material" moves from land to the sea are functions of the river system, the weather, and how the catchments are utilised and managed. Nowadays, the Queensland Department of NR&M has a network of 207 surface water gauging stations and 3021 monitoring bores from east-Cape York to the Mary River to record the considerable spatial and temporal variations in water flows and groundwater resources that occur (Anon., 2002a). Catchment sizes and population density also vary widely (Figure 2). Population density is not necessarily related to catchment size, as some of the highest populations occur in relatively small catchments.

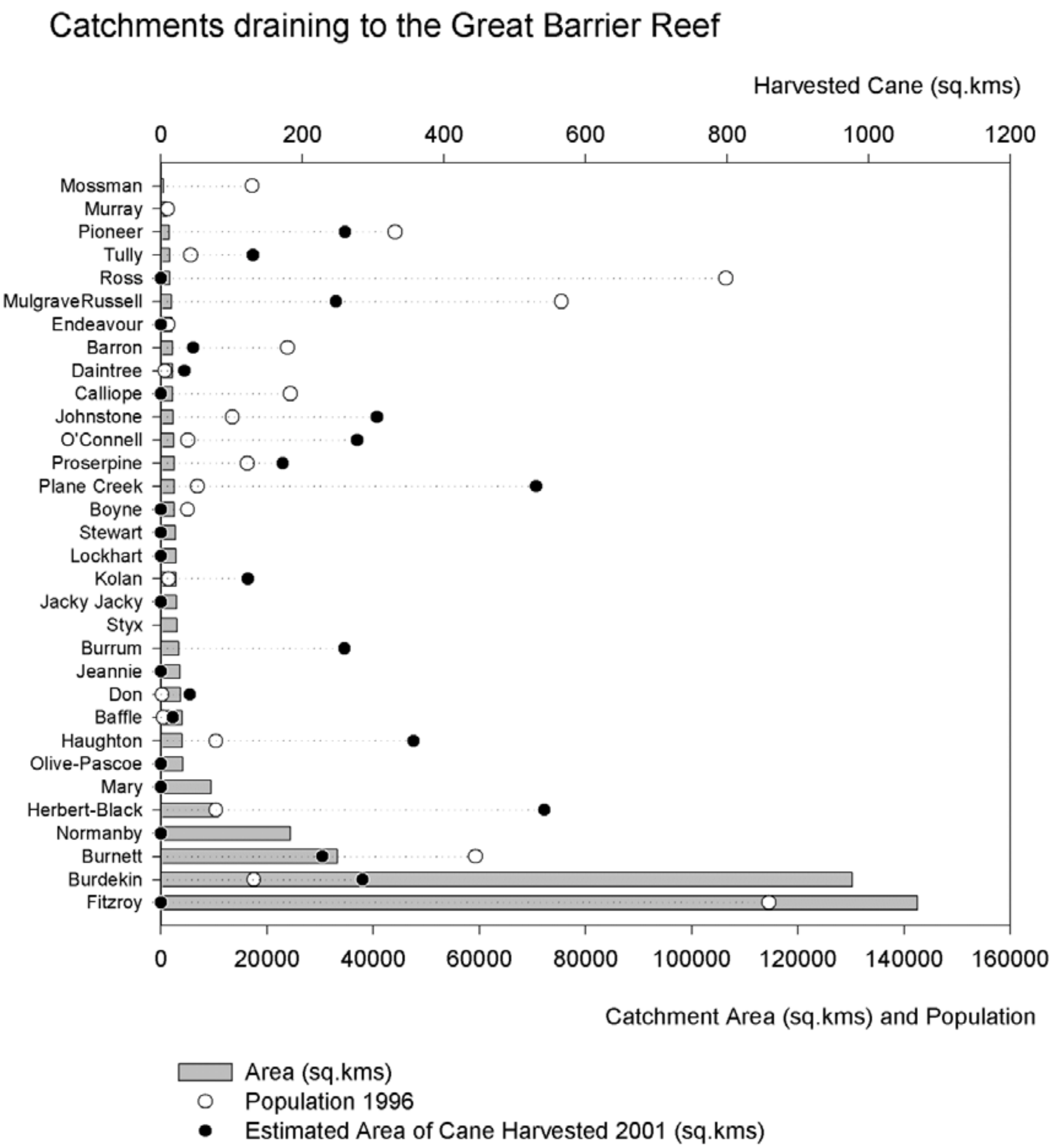


Figure 2. Catchments and demographics from Cape York to the Mary River in eastern Queensland, arranged by surface area from Mossman River drainage basin (472.4 km^2) to the combined Fitzroy River-Shoalwater drainage basins (146 148 km^2).

Most of the river systems flowing into the GBR are relatively short (excepting the Fitzroy, Burdekin, Burnett, Normanby, Herbert and Mary River systems), descending rapidly in their upper reaches, often crossing a tableland before again rapidly descending the escarpment, then slowing as they approach the coast. Rivers in catchment areas of the Wet Tropics (eg. Daintree, Mossman, Barron, Mulgrave-Russell, North and South Johnstone, Tully-Murray) flow year round (Hausler, 1991). The rest largely cease flowing in dry seasons. In times of flood, flows in all rivers can increase for a comparatively short time by up to several hundred-fold of the long-term mean annual flow. Water storages including farm dams, barrages and major dams make important contributions to standing freshwater reserves and, in the case of the Tully River, to stream flows in dry seasons (Anon, 1993a,b,c; Anon, 1994; Anon, 1995a,b). The Mulgrave-Russell, Johnstone, and Tully river catchments have the highest mean area-specific annual run-off, each exceeding 2000 mm.

5.1.2.1 Soil Factors and Soil

The more important soils of the east Queensland coastal zone have been described and evaluated for their physical and chemical characteristics and land-use suitability. At the profile scale, surface layers almost always exhibit higher levels of total nitrogen (N) and phosphorus (P) than do corresponding sub-surface layers. The few soil fertility maps that are available show wide variations in the bicarbonate-extractable P status of surface soils from the Fitzroy and Burdekin catchments (Ahern, 1988; Ahern *et al*, 1994).

There is evidence of a net loss of P in products harvested (grains and meat) and in the erosion of soil particles from grain-growing and grazing lands (Rayment and Neil, 1996), as very little fertiliser is used in the region. In contrast, over 80% of all cane lands now contain considerably more P than the 40 mg/kg of acid-extractable soil P the sugarcane crop needs to achieve maximum yield (Rayment *et al*, 1998a). At present, the mean level of acid-extractable P in NorthQueensland canelands is four times higher than the mean level recorded in the mid-1930s (Rayment,1999; Rayment, 2002b). Soil P levels in caneland are lower on average than those in surface soils used for commercial vegetable production (see Table 2).

Table 2. The total and extractable P status [arithmetic means and ranges] of dry surface soils used for commercial vegetables and sugar cane in different parts of coastal Queensland [data of Rayment (1994) and Rayment *et al* (1998a)]

Location	Acid-extractable P* *(mg P/kg)*		Total P *(%)*	
	Mixed Vegetables *(0-100 mm)*	**Sugar cane** *(0-250 mm)*	**Mixed Vegetables** *(0-100 mm)*	**Sugar cane** *(0-100 mm)*
North Qld	246 15-1669	97 (2-360)	0.137 (0.04-0.43)	0.10 (0.01-0.77)
Ayr/Bowen	417 (79-834)	112 (17-494)	0.098 (0.04-0.14)	0.05 0.02-0.12)
Proserpine to Plane Creek		63 (2-200)		0.06 (0.02-0.18)
Bundaberg/Gympie	99 (21-190)	65 (13-125)	0.076 (0.05-0.11)	0.08 (0.01-0.29)

[1]Method of Kerr and von Stieglitz (1938)

The situation for N is less clear, although there is evidence that Ferresols in the Johnstone Catchment have quantities of nitrates (expressed as N) of ≥ 345 kg/ha below the root zone of cane. This compares with 75, 21 and close to zero kg nitrate-N/ha for bananas, rainforest and pasture, respectively (Rayment, 1999; Rayment, 2002a). Significant bulges (elevated concentrations) of nitrate-N at depths of 4-8 m exist under cane, but were not apparent under rainforest and pasture and were less distinct under bananas. Approximately 500 kg N/ha as nitrate is known to occur between 1 m and 3.5 m below a sugarcane field at Bundaberg, with little nitrate-N at the same soil depths in unfertilised land. Anion exchange capacity (AEC) in these sub-soils helps retain nitrate at depth in a form that resists leaching.

Soils in the Tully-Innisfail area of North Queensland divide into three groups on the basis of their surface charge characteristics (Gillman and Abel, 1987). River alluvium has relatively high cation exchange capacities (CEC) at soil pH, including a relatively high portion of permanent negative charge. Nutrient cations show resistance to leaching in such soils, even if soil acidification subsequently occurs. A large group, mainly soils formed from granitic and metamorphic rocks, have both low CECs and low AECs. In these soils both nutrient cations and anions are likely to leach. The third group, derived almost entirely from basaltic rock, has low CECs at soil pH, but also relatively high AECs [1.9 - 3.5 cmol (i^+)/kg], particularly at depth. These soil properties favour the leaching of cations (such as ammonium, potassium and calcium) and the retention of anions (such as nitrate and phosphate). If allowed to further acidify, the effective CEC of these soils would decline while AEC may increase. Clearly, soil colloids affect the behaviour and movement of nutrients on land but their nutrient-release behaviour in reef waters has not been studied.

Acid sulphate soils (ASS) and potentially acid sulphate soils (PASS) occur in many low-lying areas along the NE Queensland coast. In some ASS-prone areas, ASS are or have been cleared, drained and used for agriculture, chiefly sugarcane farming. When disturbed, ASS release sulphuric acid, aluminium and iron to low-salinity drainage and estuarine waters. This acid drainage water has a high level of chemical oxygen demand (COD) which can locally deplete dissolved oxygen in waterways. Upon mixing with seawater in open-water conditions, the acidity of ASS drainage waters is first diluted and then neutralised, and most of the dissolved metals are precipitated as insoluble oxides. As a result, drainage waters from ASS will have little short-term effect upon fully marine waters in adjacent coastal habitats. In low-salinity estuarine habitats and in places of restricted mixing, however, acidity and metals derived from ASS drainage can harm fish and other aquatic organisms.

The erosion of soils by water and the collapse of stream-banks during periods of high and receding stream flows are major pathways for the entry of materials to waterways. For example, annual soil losses in row-crop sugar cane from the Johnstone River Catchment near Innisfail of <50 to 500 t/ha (average of 150 t/ha) have occurred (Prove, 1988; Prove *et al*, 1995), whereas soil losses under lower rainfall conditions near Mackay were 42 to 227 t/ha (Sallaway, 1979). Large cumulative losses of topsoil had already occurred in Childers-area canelands by the early 1970s, but nowadays soil losses have been lowered to less significant rates (e.g. ≤ 13.5-15.1 t/ha/yr) by moving cane assignments to erosion-resistant lands, and by the adoption by canegrowers of modern soil conservation measures, particularly green-cane trash blanketing (Sullivan and Sallaway, 1994).

At Emerald, in the Central Queensland Highlands, an estimated 1440 tonnes of suspended sediments were mobilised in a drain immediately downstream of an irrigated cotton site following a storm that generated a total flow of 1200 ML (B. Simpson et al, unpublished data).

More recently, Visser (2002) has constructed a sediment budget for caneland in the Lower Herbert. The median net export of suspended sediments (particles <20 μm) measured for the wet seasons 99/00 and 00/01 was 1.7 t/ha. The main sources of erosion were identified as being plant-cane paddocks and water furrows (median unit area soil loss rates of 3.8 t/ha and 12 t/ha, respectively), while well-grassed headlands and farm drains tended to act as sediment sinks (median unit area deposition rates of 7.5 t/ha and 45 t/ha, respectively).

An estimated 0.3 t/ha/yr of soil is lost by erosion in the Burdekin River Catchment (Belperio, 1983a,b). In the same catchment near Charters Towers, soil losses measured as sedimentation in dams were positively correlated with the degree of gullying. Measurements (Ciesiolka, 1976) showed that 0.9, 1.6 and 27-30 t/ha/yr were moved from catchments with minor gully erosion, one active gully, and with severe gully erosion, respectively. Overseas data supports local observations that the maintenance of good ground cover (at least 40%) can markedly reduce soil losses. However, significantly higher levels of ground cover (>75%) are required to reduce runoff in high intensity rainstorms (McIvor *et al*, 1995; Roth, 2002). Areally weighted average soil erosion rates for Queensland grazing lands range from zero to 4.1 t/ha/yr (Elliott *et al*, 1996); the development of grazing lands for cultivated cropping is likely to add to soil erosion losses.

While soil erosion at the paddock scale is relatively easy to measure, its delivery to the coast is more complex. To understand this, we must examine in-stream sediment loads. These are more difficult to attribute to specific land uses than is the case for soil erosion. Crude estimates of the role of land use in determining in-stream sediment loads in the GBRWHA have been made using general relationships between stream water quality and catchment characteristics derived from the literature. If a value of one is taken to mean 'natural' sediment load, a conservative assumption (Rayment and Neil, 1996) is that grazing or urbanisation increase suspended sediment concentrations by a factor of 4, and cropping by a factor of 15.

Outputs from modelling (examples in Table 3) clearly suggest that rangelands are the major source of suspended sediments and nutrients transported to east Qld coastal waters (Moss *et al*, 1992; Neil and Yu, 1996). However, modelling has also pointed to cropping lands as the source of most suspended sediments and nutrients on a per hectare basis, suggesting room for improvement at paddock and farm scales. One estimate (Rayment, 1999; Rayment, 2002a) is that about 1.25 M tonnes of suspended sediment and 8800 and 1300 tonnes of N and P, respectively, are lost annually from canelands via Queensland's east-coastal rivers. In comparison, the same modelling process estimated that 47 100 t of N and 6700 t of P are lost annually on average to the sea from grazing lands via eastern rivers of Queensland. Prosser (2002) has calculated new and more refined estimates (given elsewhere in this report) as part of the National Land and Water Resources Audit.

Table 3. Estimates from simple models of mean annual exports of suspended sediments (million tonnes/y) from a selection of Queensland coastal catchments.

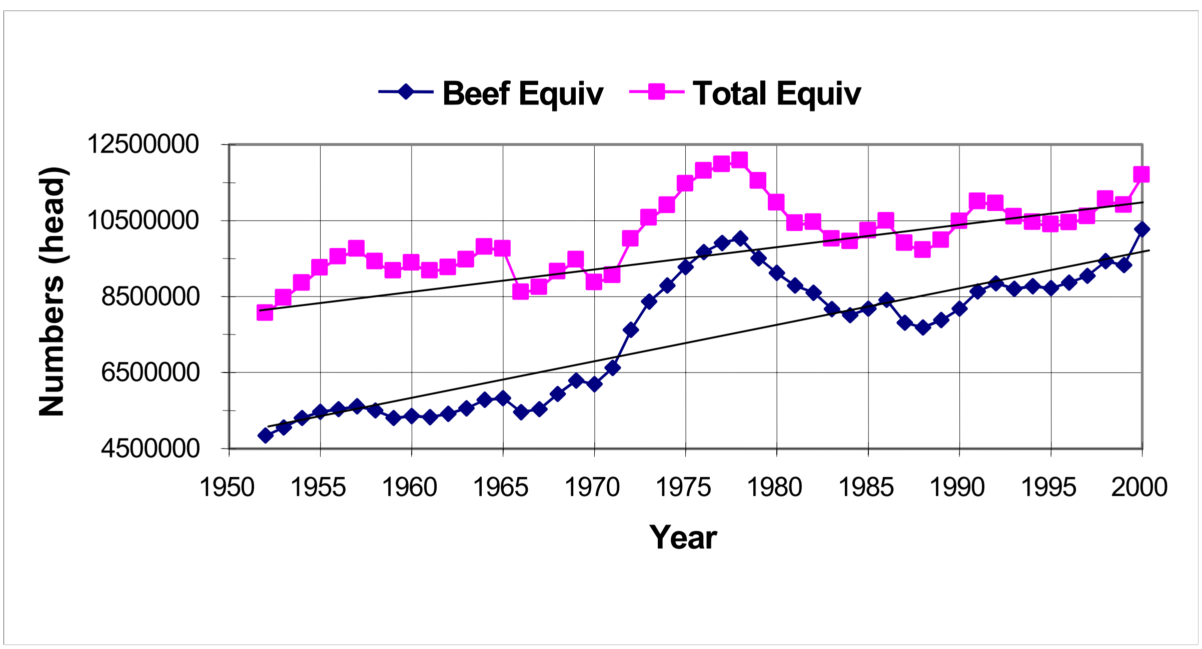
Catchment	Belperio (1983b)	Moss *et al* (1993)	Neil and Yu (1996)	Furnas (2002)
Johnstone	1.5	0.6	0.2	0.2
Burdekin/Haughton	3.5	2.7	8.4	4.0
Fitzroy	2.2	1.8	10.3	2.2
Burnett/Kolan	1.7	0.8	2.4	0.5

5.1.2.2 Changes in Land Use

Contemporary land uses reflect climatic conditions, topography, soil fertility, the presence of minerals, water quantity and quality, and proximity to or accessibility of processing facilities and markets.

Records (Pringle, 1991) for the periods 1897, 1944-45, and 1983-84, show progressive increases in total areas being utilised for cropping and cattle grazing. For example, there was a trebling in the area under sugar cane during the period 1951 to 1988 (Pulsford, 1991). 'Waves' of land development for sugarcane from 1931 to 1958 were estimated to increase stream sediment yields by 31% in the Tully River Catchment (Rayment and Neil, 1996) with subsequent developments for pastures (1958 to 1967) and sugarcane/bananas (1967 to 1990) contributing a further 26% and 13%. Neil (1995) suggests there were negligible increases in sediment yields from 1866 to 1931 at Tully.

Figure 3. Time trends in Queensland's domestic animal numbers (source NR&M: G. McKeon *et al*, 2002).



By 1928, cattle were well distributed across the extensive grazing lands of Queensland (Hancock, 1964) and still are. Indeed, livestock numbers in Queensland are as high as they have ever been (Figure 3), the majority in catchments draining to the GBRWHA, exerting considerable and increasing land use pressure. Not only have beef numbers doubled in the last 50 years, but "tougher" *Bos indicus* breeds have significantly replaced drought-sensitive and heat-sensitive British breeds.

Nowadays, extensive grazing by cattle (along with some by native fauna) is overwhelmingly the major land use in the GBR catchment (83% of the total area). About 6% of the GBR catchment remains in a pristine protected status, while forestry accounts for 7%. Although important economically, urban, sub-urban and rural-residential areas collectively occupy only 1.6% and cropping only 1.13%, including just over 400 000 ha for sugar cane. Approximate land use percentages by catchment region are summarised in Table 4.

Table 4. Approximate land use distribution as a percentage of total areas of catchment-regions draining into or near to the Great Barrier Reef World Heritage Area east of Queensland (Anon (1993a), Moss *et al* (1993), Rayment and Neil (1996); NR&M, unpublished data).

Catchment region	**Pristine** %	**Timber** %	**Grazing** %	**Crops (sugar)** %	**Urban** %
Cape York	34	4.3	62	0.05	0.05
Wet Tropics	13	23	52	7.76 (7.4)	3.6
Dry Tropics	1.7	1.1	94	0.52 (0.5)	2.1
Proserpine to Fitzroy	2.4	6.9	86	0.86 (0.85)	0.49
Baffle to Mary	1.1	17	75	1.64 (1.56)	3.9
Weighted average	6	7	83	1.13 (1.1)	1.6

Land-use change is continuing, based on findings from Queensland Statewide Landcover and Tree Study (QDNR, 1999a,b). There is measurable evidence over the last decade of clearing of woody vegetation cover (≈ 12% projective foliage cover or greater) for pastures, cropping, urban use and for forestry at rates greater than the rate of re-vegetation. Prominent in this regard are Baffle Creek and the Burdekin, Don, Fitzroy and Proserpine catchments. Clearing for cropping in the early 1990s has been most noticeable in the Herbert, Murray, Haughton, Plane Creek and Fitzroy catchments.
For example, 18.5 km^2/yr of natural vegetation was lost in the Herbert Catchment between 1991 and 1995 for cropping. A further 1.35 and 0.33 km^2/yr was removed for pasture and urban uses, respectively, while new re-growth was only 0.54 km^2/yr. The low international price for sugar may see further land use change as cane lands that are only

marginally productive are forced by economics into other uses. Contemporary basal tree cover across Australia is shown in Figure 4 (Danaher *et al*, 1992).

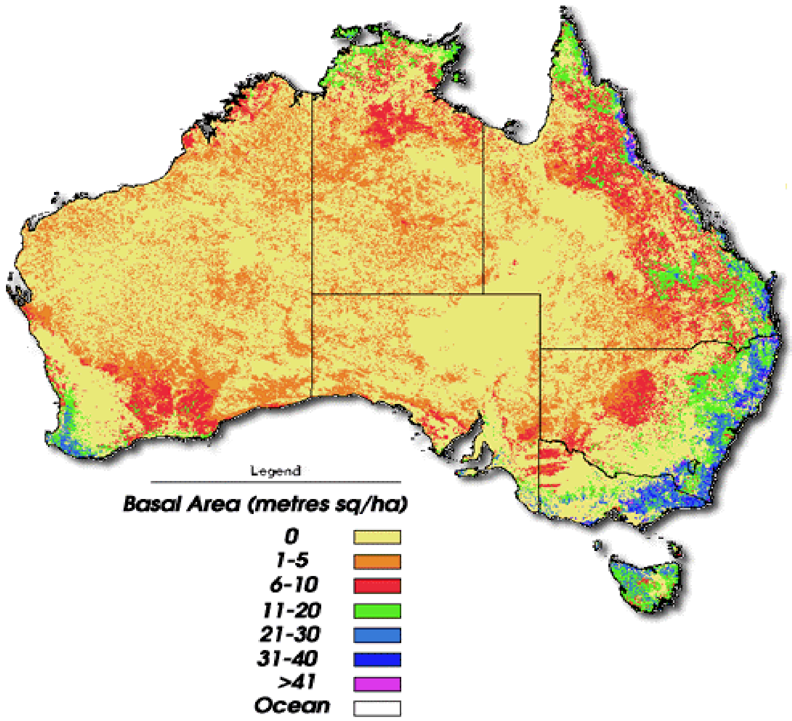


Figure 4. Contemporary basal tree area in Australia, showing tree densities of 11-20 m^2/ha or less prevails in much of coastal Queensland (source G. McKeon, NR&M).

Land use areas are not the sole issue; location and the extent of land use change are also important. For example, in the cropping areas, sugarcane (the main crop) is predominantly located adjacent to waterways on fertile coastal floodplains. Moreover, the natural vegetation of many of the river catchments adjoining the GBRWHA has been extensively cleared (Russell and Hales, 1993), mostly since the mid-20th century. Freshwater wetlands and riparian forests that once covered large areas of the coastal floodplains have been drained and cleared for agriculture and urban living (Tait, 1994; Johnson *et al*, 1999). Nowadays, only remnants of these biologically rich and diverse ecosystems remain (Anon, 1993a; Arthington and Hegerl, 1988; Arthington *et al*, 1997; Blackman *et al*, 1996; Russell *et al*, 1996a), while present day coastal wetlands and riparian forests are frequently narrow and sparsely vegetated and have been invaded by exotic weeds (Johnson *et al*, 2001). Eight of the 19 Queensland wetlands identified as having national importance are located adjacent to or within the GBRWHA (Blackman *et al*, 1996).

As a consequence of changed land use, many of the GBR catchments have experienced considerable change to flow regimes, due to the level of impoundments used for the provision of irrigation and urban water supplies (Table 1). In addition to the resultant abstraction of water for the above purposes, dams and weirs significantly alter flow patterns, for instance by reducing overall flow, but also by changing flow patterns from formerly seasonal flows to perrennial flow patterns. The precise impact of these changes on aquatic eceosystems is poorly quantified.

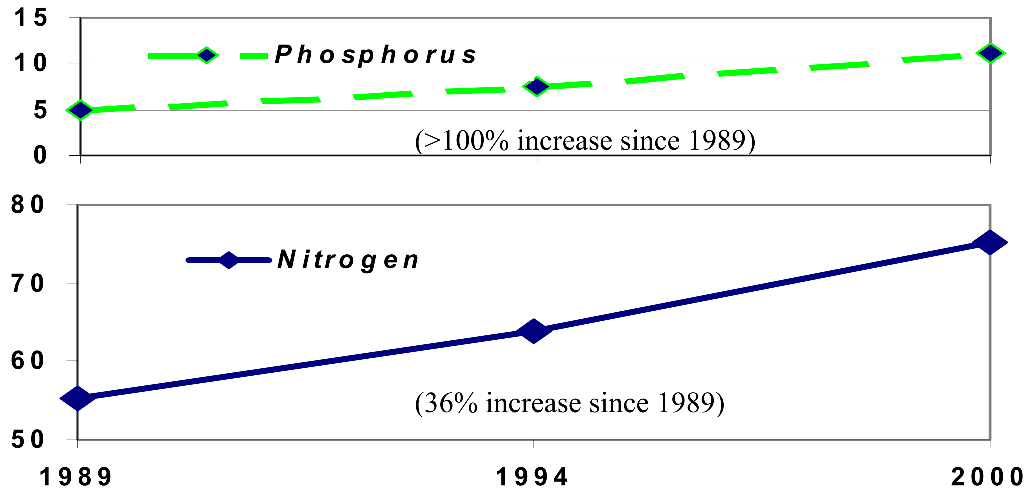
In addition to impoundments, there are other interventions on river systems themselves, such as changes to river channels, construction of levees and removal of riparian vegetation, leading to changes in flood frequency and intensity, and increased bank erosion. These impacts are further exacerbated by loss of floodplain function in many coastal areas through the development of drainage systems and removal (infilling) of wetlands (see also section 5.1.3.1), which have led to reduced residence times of flow (Post et al., 2001).

5.1.2.3 Inputs of Fertilisers Recycled Products and Pesticides

Fertiliser usage in coastal Queensland is dominated by the sugar industry (Pulsford, 1991; Pulsford, 1996). In 1990, for example, some 59 000, 3300, 3000, 11 200 and 6600 tonnes of fertiliser N were used on sugarcane, fruits, vegetables, field crops and pastures, respectively, in coastal catchments from the Mary to the Daintree Rivers. Corresponding quantities of P were 7400, 650, 1000, 1800, and 2600 tonnes. Across all catchments, the average fertiliser N to fertiliser P mass ratio was 6.2:1, whereas the average ratio for the top 12 catchments (Mulgrave/Russell, Johnstone, Herbert, Haughton, Burdekin, Proserpine, O'Connell, Pioneer, Plane, Fitzroy, Burnett, Burrum) on an N-supplied basis was 7.8:1 (Rayment and Neil, 1996).

By 1994, fertiliser N and P use on cane in coastal Qld had increased to 63 945 and 7745 tonnes p.a., and there have been further increases since then due in part to growth in the area under cultivation (Figure 5).

Figure 5. Recent trends in fertiliser use (in thousands of tonnes) for Queensland sugar



Application rates and N:P input ratios in year 2000 for different sugarcane regions are given in Table 5. In addition, about 2 million tonnes of mill mud (mean concentration of N and P of 1.48% and 0.91%, respectively, which approximate to 30,000 and 18,200 tonnes of these nutrients annually) are recycled annually, currently at rates well above immediate sugar cane crop requirements. A typical application of 150 wet tonnes/ha of mill mud adds about 560 kg N/ha and 340 kg P/ha (Barry *et al*, 2000). There is only limited redistribution to soil of an estimated 250 000 t/yr of municipal biosolids produced in coastal areas. Detailed public statistics for non-cane uses of fertilisers since 1990 are lacking.

Assuming that, in the GBR catchment, the proportion of total fertiliser that is applied to sugarcane crops has remained relatively constant, annual fertiliser N and P applications in the catchment would be not less than about 100 000 tonnes and 20 000 tonnes, respectively (Furnas, 2002).

Table 5. Fertiliser use in "reef canelands" – 2000 (adapted from Rosecom Fertiliser Industry Market Share Report – Rosecom Pty Ltd.)

Region	*N (tonnes)*	*P (tonnes)*	*Ratio N:P*	*N Av rate, kg/ha*	*P Av rate, kg/ha*
Mossman-Tableland	4062	700	5.8	215	37
Cairns-Tully	10791	2390	4.5	147	33
Herbert	8858	1503	5.9	148	25
Burdekin region	16230	1590	10.2	220	22
Proserpine-Sarina	21469	2550	8.4	173	21
Bundaberg-M'borough	11712	2186	5.4	189	35
Totals or average	***73122***	***10919***	***6.70***	**182**	**29**

The reported increase in the use of P fertilisers on sugarcane in reef catchments in recent years is a surprise. This is because average levels of acid-extractable P (0-250 mm depth) from a 1996 nutrient survey of Qld canelands (Rayment *et al* 1998) were mostly (75-80% of sites) well above the P critical value of 20 mg/kg mentioned in Table 1 of Schedule 1 of the *Code of Practice for Sustainable Cane Growing in Queensland* (Anon, undated) (above this value, a measurable cane-yield response to P fertiliser is unlikely). Moreover, the present Code recommends 20 kg fertiliser P/ha if the soil tests is >40 mg/kg for plant cane and nil fertiliser P for ratoons.

While less fertiliser P is needed in cane-growing areas than previously (Rayment and Neil, 1996; Rayment *et al*, 1998a), there exists considerable scope for increases in application of P onto broad-acre crops [by a factor of 6 (Burdekin) and of 7 (Fitzroy)], which would be within the bounds of recommended agronomic practice. Such increases could worsen water quality in these catchments in the future, as P loadings would increase (Rayment and Neil, 1996).

Few pesticide-use audits have been conducted in catchments draining to the GBRWHA. Of those completed, the most comprehensive covers use for sugarcane in the mid-1990s (Hamilton and Haydon, 1996). For this crop, quantities of all pesticides used in each mill area and river catchment of the Queensland industry were obtained by integrating label information with knowledge of numbers of applications annually and the areas treated. Local experience was vital to this process. Sixteen pesticides were identified as being in contemporary use out of 40 allowable for use in sugar cane. The most used herbicides across Queensland canelands were atrazine (331 000 kg), diuron (197 300 kg), 2,4-D (141 000 kg), glyphosate (86 000 kg), ametryn (76 000 kg), and paraquat (43 000 kg), all expressed as active ingredient annually. For the insecticide chlorpyrifos, annual usage was 75 000 kg of active ingredient, while the quantity of the fungicide Shirtan (methoxyethylmercury chloride, an organo-mercurial containing approximately 68% mercury) was 1890 kg active ingredient. Less is known of the market penetration and environmental consequences of emerging products such as Flame (imazapic), Confidor (imidacloprid) and Balance (isoxaflotol).

5.1.2.4 Nutrient Loss

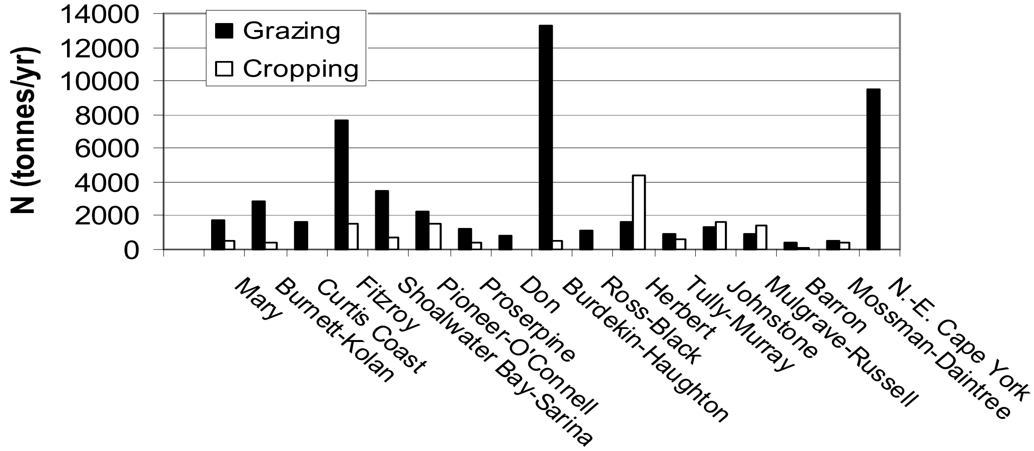
There are many reports (Anon,1995c; Garman and Sutherland, 1983; Addiscott *et al*, 1991), of positive correlations between the use of fertilisers and nutrient enrichment of waterways, stream sediments and groundwaters adjacent to and downstream of agricultural lands. Sugar cane production and horticulture are targets for attention as both are major users of N and P fertiliser on a unit area basis. For example, there is good evidence that at least 50-75 kg N/ha is being lost annually from the root zone of sugarcane.

Evidence from several years of intensive water quality monitoring in the Johnstone Catchment, supported by modelling, is that all major land uses in the catchment are responsible for losses of soil/sediment and nutrients (Table 6) (Hunter *et al*, 1996; Hunter and Walton, 1997). In the first half of the 1990s, an average of about 4 tonnes/ha/yr (a total of 75 164 tonnes/yr) of soil moved to the waterway. Total N at 40 kg N/ha/yr (total 752 tonnes N/yr) was divided between sediment (about 50%), nitrate-N (27%) and ammonium-N (3%). Corresponding P losses averaged 7 kg P/ha/yr (total 132 tonnes P/yr), of which 81% was bound to or in the sediment. A disproportionately high amount of these land-to-water movements came from canelands, including almost 50% of the nitrate. However, the quantities and proportions of N and P in the river differed each year as did the atom ratios of N:P. During Cyclone Sadie the N:P ratio was 3.3:1, contrasting with a ratio of 10.4:1 during drought conditions. Five-year (1990-1994) annual average N and P fertiliser applications to canelands in the catchment were 4730 and 765 tonnes, respectively, which corresponds to an atom ratio of 6.2:1. (See Section 5.1.3.1 of this report for further details on sediment and nutrients.)

Table 6. Estimates (%) from 6 years of monitoring and subsequent modelling of suspended sediments and nutrients – Johnstone River Catchment (data of Hunter and Walton, 1997).

Johnstone Catchment	Sq km	Catchment area %	Sediment load %	Total P load %	Total N load %	Nitrate-N load %
Rainforest	849.7	52	41	43	36	11
Cane	187.9	11.5	36	32	35	48
Bananas	31.0	1.9	8	7	8	14
Unsewered residential	8.2	0.5	0.5	0.5	4	15
Dairy pasture	129.1	7.9	3	4	6	12
Beef pasture	328.4	20.1	12	14	11	0.001

Findings from a study of nutrient balances and transport in the Johnstone Catchment (Prove *et al*, 1997; Reghenzani et al, 1996) with sugarcane have shown: i) plant crop losses of N beyond the root zone are greater than losses from ratoon cane losses; ii) N losses via runoff and leaching averaged over 50 kg N/ha/yr in the plant crop and mostly <50 kg N/ha/yr in ratoon crops; iii) N loss was positively related to N application rate, with loss pathways dependent on the form and placement of the N fertiliser, and mounding of the cane row was responsible for reduced water flux through fertiliser band; iv) there was no loss of yield when N was applied in non-volatile form (Nitram), at a 33% lower application rate; and v) there was a substantial contribution of soil N to the crop, indicating significant soil reserves. Typically, N losses from bananas were higher. For more details, refer to the review of water and N balance in natural and agricultural systems in the Wet Tropics (Bristow *et al*, 1998). Modelling by Moss *et al* (1993) suggests that around 73% (51400 tonnes) of the N discharged annually from “reef” catchments is sourced from grazing lands and around 21% (14500 tonnes) from cropping lands (Figure 6).



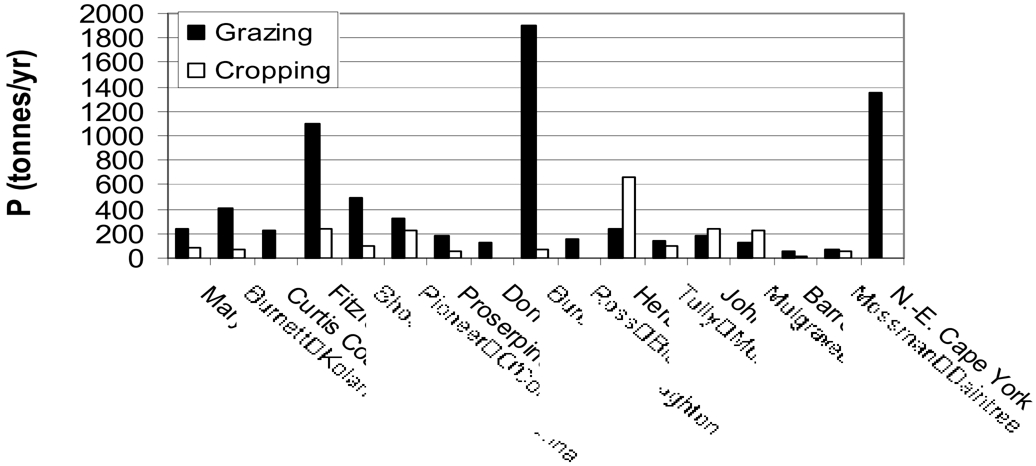


Figure 6. Modelled estimates of annual discharges of total N and total P discharged from "reef" catchments to the sea (from Moss *et al* 1993)

With respect to P, it has been estimated from a mass-balance approach (Bloesch *et al*, 1997) that 1450 tonnes of P are lost annually to stream sediments and as dissolved P from Queensland sugar lands. Highest losses were projected to occur from Northern canelands (759 tonnes), equivalent to 4.6 kg P/ha. Corresponding loss estimates from the Burdekin, Central and Southern regions averaged 1.8, 2.3 and 2.8 kg P/ha. Despite these losses, there were net gains in P to Northern, Central and Southern cane-growing regions and a slight depletion (-0.2 kg P/ha) in the Burdekin, mainly due to fertiliser inputs. Model 2 of Moss *et al* (1993) suggests that around 10100 tonnes of P are discharged annually from"reef" catchments, including 7300 and 2200 tonnes from grazing and cropping lands, respectively. Priority catchments for attention are apparent in Figure 6 above.

The evidence is that historical fertiliser P additions (Bloesch *et al*, 1997) account for approximately 30% of the total P in the top 300 mm of canelands in the Northern, Central and Southern regions, and 10% in the Burdekin region. The authors estimated that present-day additions of P fertiliser increase total P concentrations in the top 300 mm of canelands soils by up to 1% annually, an observation that also suggests that reducing fertiliser P inputs will only slowly change soil P reserves. Thus, reducing fertiliser P inputs in efforts to minimise P losses via soil erosion to waterways can only be considered as a long-term option for canegrowers and natural resource managers. That is, the environmental benefits in terms of lower in-stream concentrations of P will only slowly emerge over the next two to three decades. Given the build-up in soil P fertility of canelands that has already occurred, it should be possible to lower P fertiliser rates slightly in regions other than the Burdekin without any overall adverse regional impact on yields of millable cane. However, in canegrowing areas of the Burdekin region, P fertiliser usage should be increased slightly to prevent the further depletion of soil P reserves.

Given that the present GBRMPA "targets" seek a 47% reduction in the quantity of P being exported by coastal rivers, the question arises; "How can this be achieved?", given that over 80% of the P in rivers is typically attached to particulates. Appropriate management options are to:

(a) minimise soil losses, noting that contemporary soil loss from canelands is low in recent years, due to benefits from trash blanketing and because cane has been moved in some areas from erosion-prone to less erosion-prone land; and

(b) run down the total P status of soil in paddocks where fertiliser and/or by-product applications have increased soil P fertility to levels well above the immediate needs of the production system (many cane and horticultural soils)..

It follows that at erosion rates of say 2 to 10 tonnes/ha/yr, it will take many years to remove the added P that took over 50 years to supply. Time scales of 30 years or more need to be envisaged, and success would only then be reasonably assured if P inputs were seriously curtailed

It may become necessary, if it is not already, to declare all intensively farmed coastal catchments draining to the GBRWHA as **Nutrient Sensitive Zones** (NSZs). This would not be a unique action; there are examples in the USA and Europe**.**

Conditions that might apply to farm-sized areas are as follows:

(i) purchase of commercial quantities of fertiliser (or permission to apply biosolids, mill mud, feed-lot litter, etc) to be permitted only if there is a *Nutrient Management Plan* (NMP) for the block or property, perhaps as a component of a more comprehensive Property Management Plan;

(ii) NMPs can only be made by *Certified Nutrient Advisers* that have several years (eg. six or more) of proven nutrient management experience and/or training;

(iii) NMPs must be supported by contemporary soil and/or plant testing of the area/farm in question, using approved sampling and analytical methods and undertaken by

providers with independent accreditation and/or certification of their measurement performance (eg. NATA and ASPAC); and

(iv) records of all fertiliser inputs, including other materials used as an alternative to commercial fertiliser (eg. biosolids, mill mud), must be maintained for a minimum of five years, and be made available for annual collation by an authorised department or agency.

At the process level, P desorption studies indicate that with the exception of heavier clay soils, the majority of river sediments derived from lower Herbert soils have moderate to large desorption risk classes between 5-10 mg and >50 mg P/kg, at a river-water P concentration of 0.05 mg P/L. Laboratory simulations using the same soils suggest that the P is much more strongly held when in marine water than in fresh river water – ie, any environmental threat posed by the transport of P via eroded soil is likely to be greatest in upstream areas and least when eroded into sea water (Bramley et al, 1998).

5.1.2.5 Pesticide Loss

Recent reports indicate that the herbicide diuron is present and persisting in estuarine and marine sediments at concentrations that could interfere with photosynthesis in those seagrass species preferred by dugongs (Haynes *et al*, 2000b,c), and perhaps also damage mangroves such as *Avicennia marina* (Duke *et al*, 2001). Data for a range of locations along the north Queensland coast provides convincing evidence of wide distribution, but the full range of source/s of the diuron have not been resolved. The off-shore diuron concentrations were 0.5 – 1.7 ppb in 3 of 16 intertidal sediment sites sampled in 1997. In 1998, the range in 14 of 25 sub-tidal sediments from the same region was 0.2 – 10 ppb, and the range in corresponding seagrasses was 0.8 – 1.7 ppb (dry wt) (Haynes *et al*, 2000a). There are also unpublished reports of low but measurable concentrations of diuron in Harvey Bay and in downstream locations of the Mary and Pimpama Rivers in south Queensland.

Much more could be added on this general issue, including mention of international research and monitoring on booster biocide and their broad spectrum activity. This broad spectrum capability is necessary because there are >4,000 fouling species to contend with (http://www.environment97.org/text/reception/r/techpapers/papers/g61.htm)(8pp.). In addition, tributyltin (TBT) as an antifoulant has been banned in the EU, Canada, USA, Australia and South Africa since 1989 (or soon after) for vessels <25m length, while there is pressure on the International Maritime Organisation (IMO) to phase out TBT on all ships by 2003. The minutes of the UK's 278th Meeting of the Advisory Committee on Pesticides (APC) on 7th September 2000 http://www.pesticides.gov.uk/committees/ACP/ACP-278.min.htm) indicate agreement that the use of products containing Irgarol 1051 and diuron on vessels <25m length should be revoked according to standard procedures and timescales due to adverse environmental data.

Irgarol 1051, one of the s-triazine group, is not registered in Australia as an antifouling agent (it is about 4 times more toxic than diuron, metribuzin and bromacil and about 70 times more toxic than atrazine to periphyton) but has been detected in 9 of 10 samples from the Great Barrier Marine Park and the outer reef. Levels up to 118 ng/g wet weight were in samples from the Gold Coast. Moreover, Irgarol 1051 was detected in an antifouling paint purchased in Australia, despite its non-registration [Scarlett, A., Donkin, P., Fileman, T.W., and Morris, R.J. (1999). Occurrence of the antifouling herbicide Irgarol 1051 within the coastal water-seagrasses from Queensland, Australia. Marine Pollution Bulletin 38, 687-691.]

It follows that with improving understanding of the risks and benefits of boat antifoulants and the relatively little attention paid to the consequences of their escape to the environment of the GBRWHA, antifouling formulations and use-practices should be reviewed to ensure all possible measures are taken in Australia to protect reef organisms, particularly in enclosed waters and in areas subject to significant movement of boats > 25 metres in length.

When pesticide residues are found in sea waters and off-shore sediments, the source may not always be land-based. For example, diuron is now an active ingredient of about 30 registered boat antifouling paints and slime control formulations used in Australia. Diuron in these typically ranges from 5 to 80 g/L. Moreover, diuron in seawater associated with antifouling paint has been reported to range from 0.01 to 0.18µg/L (Ferrer *et al*, 1997; Voulvoulis *et al*, 2000) while residues detected in sediment from an enclosed marina in the United Kingdom were at a concentration of 1.4 mg/kg. Indeed, the Advisory Committee on pesticides in the UK has recommended (1998) that approvals for the use of diuron in antifouling products should be revoked, in view of adverse environmental monitoring data collected in 1998.

No studies have been undertaken in reef waters to determine with certainty the source of diuron found in inter-tidal sediments along the north Queensland coast, although there have been suggestions that the diuron had its source from some areas where sugarcane is grown. Support for these suggestions comes from the detection of 470 kg of diuron (2% of the annual application), 75 kg of atrazine (0.3% of the annual application) and lesser quantities of three other herbicides (ametryn, hexazinone, 2,4-D) entering Dumbleton Weir on the Pioneer River in a single 1-in-2 year flow event in February 2002 (Simpson, 2002).

This report takes the suggestions of the source of the diuron as an unproven assumption at this time.

There are several other examples of pesticide movement to waterways and biota in eastern Queensland (Haynes *et al*, 1999; Mortimer and Cox, 1999; Müller *et al,* 2000). For example, sampling from 1995 to 1997 showed that 27%, 24% and 11% of samples of groundwaters and surface waters from small creeks and major streams from the Johnstone Catchment contained median concentrations of atrazine, 2,4-D and diuron of 0.3, 3.5 and 1.2 µg/L respectively in a population of 90 samples (Hunter *et al*, 2001). While canelands are a likely source, this was not confirmed. Moreover, it is often overlooked that pesticides (insecticides, herbicides, etc) are used by local authorities, foresters, graziers, and by urban dwellers, but there have been no audits of these users in “reef” catchments. A study on the impact of diuron on photosynthesis by three sea grasses suggests a degree of sensitivity much greater than for land-based plants. A “glasshouse” study of the sensitivity of mangrove species to diuron is current

Detection of active ingredients of pesticides in sediments and water does not confirm internal biochemical activity but techniques for this are now being developed. For example, Cytochrome P-450 1A activity as measured by ethoxy-resorufin *O*-deethylase activity can be used as an indicator of the exposure of fish to selected organic contaminants (Cavanagh *et al*, 2000). Techniques of this type offer an interesting alternative to traditional approaches to pesticide residue monitoring.

There is concern at the use of pesticides in land-use practices in general. For that reason we believe that there should be further efforts for scientists to work with pastoralists and farmers to understand methods whereby agrochemical and veterinary (AgVet) chemicals are retained where they are needed, and not lost from the area or site of application.

It is recommended that **efforts be intensified to**

- **(ii) continue to accredit, reaccredit and further train primary producers on responsible and environmentally sound use of AgVet chemicals;**
- **(iii) develop and train relevant people to use a practical ‘decision-making tool’ to help in assessing the local risk of off-site pesticide movement in “reef” catchments, and to provide guidance on ways to reduce risks of pesticide loss at the individual farmer level; and**
- **(iv) conduct research into alternatives to pesticides or on pesticides less prone to contaminate aquatic environments.**

5.1.2.6 Loss of Heavy Metals

CRC Sugar data (Rayment *et al*, 1997; Rayment *et al*, 1998b) exist for total heavy metal concentrations in canelands of Queensland on a regional and soil depth basis. Cadmium (Cd) and mercury (Hg) were the only heavy metals with higher concentrations in canelands following 10 or more years of cropping, relative to ‘paired’ uncropped sites. Mean cadmium concentrations in Queensland canelands at 0-250 mm depth were four times greater relative to the mean background concentration of 0.01 ± 0.02 mg/kg. At a depth of 250-500 mm the cadmium was twice a similar background concentration. The increase for mercury was almost threefold at 0-250 mm (background concentration of 0.024 mg/kg) and twofold at 250-500 mm.

Using only the canefield-soil data for 0-100 mm depth, averages of 4.9, 0.06, 17, 107, 23, 0.08, 1.1, 32, 24, 0.45, 0.20 and 61 g of arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), mercury (Hg), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), thallium (Tl) and zinc (Zn), respectively, will be lost for each tonne of surface soil from canelands moved to the waterway, assuming no heavy metal enrichment occurs (Rayment, 1999; Rayment, 2002a).

Total heavy metal (Cd, Cr, Cu, Hg, Ni, Pb, Zn) concentrations in sediments of some "reference" Queensland rivers, including several from cane-growing catchments, were last reported in 1998 (Semple and Williams, 1998). The median Cd concentration in sediments from fresh-water zones was 25 times higher than the mean concentration in surface soils from Queensland canelands, suggesting the source or sources lie elsewhere. Copper concentrations were similar but reported sediment concentrations (in fresh water zones) for total Cr, Ni, Pb and Zn were around 1.6, 1.6, 4.8, and 1.4 times lower, respectively, than corresponding mean concentrations in Queensland canelands.

It has also been has established (Barry *et al*, 1998) that mean concentrations of Cd and Zn in mill mud are, respectively, about 5 times and 3 times greater than the reported mean total concentrations of these heavy metals in canelands. Levels of other metals are mostly similar or lower than total soil concentrations. Heavy metal loadings in mill mud at 150 wet tonnes/ha equate to loadings of 0.01 and 5.1 kg/ha of Cd and Zn, respectively. The fungicide MEMC adds about 1.56 tonnes of Hg annually to Queensland canelands. About 49% of the fungicide is applied to the plant crop in the Wet Tropics.
The movement of heavy metals is not only from the land to the sea. There is recycling back to the land through impurities present in sea products such as captured fish and crustaceans. In addition, there is considerable heavy metal enrichment of Raine Island, an uninhabited 30 ha coral cay and significant bird rookery located in the far northern section of the GBRWHA. Metal concentrations, particularly of Cd, Cu, Se and Zn, increase progressively in the vegetated beach, vegetated sand ridge and central depression regions, as do the concentrations of total P. Moreover, concentrations in the surface (0-100 mm) of the central depression are considerably higher than those of unpolluted soils worldwide. In contrast, concentrations of Co, Cr, Hg, Ni and Pb are very low by world standards and relatively constant in the four land-forms of Raine Island. Relocations via bird and animal waste and possible enrichment via geothermal upwelling from the adjacent deep ocean are likely causes. It is therefore acknowledged that some heavy metal enrichment may occur for reasons other than mainland use of synthetic chemicals.

5.1.2.7 Sugars and dissolved oxygen (DO)

The occurrence of fish kills, particularly since 1998, in coastal waterways stretching from north Queensland (Veitch, 1999) south to the northern rivers of NSW has focussed attention on the importance of dissolved oxygen (DO) in water, as decreases in the levels of DO are a possible cause of mass fish kills.

It has been suggested that dunder (a by-product of ethanol production from sugar cane), green cane trash blanketing (GCTB), and leachates from mill mud could have an effect on the levels of DO in water. In the case of GCTB, anecdotal reports refer to pungent, black-brown water draining from canelands after rain, particularly where water has been ponded for some time.

As part of a review of water quality pressures and status in cane-growing areas (Rayment, 1999; Rayment, 2002a; Rayment and Bohl, 2002), it was postulated that cane juice lost during cane-harvesting operations could contribute to low DO in nearby waterways. Estimates were made of likely losses of sucrose from cane (CCS) and sucrose-carbon, based on the assumption that the post-harvest CCS of trash and leaf increased by an average of 1.8 units over the pre-harvest samplings. The resulting sucrose-carbon equivalents (t C/ha/year) were 0.095, 0.137, 0.106 and 0.096 for the Northern, Burdekin, Central and Southern regions, respectively. The Queensland arithmetic average based on these conservative estimates was 0.105 t C/ha/year, which corresponds to around 46 200 tonnes of highly labile carbon annually. In practice, cane harvest losses of up to 25t/ha have been recorded under adverse field conditions whilst harvesting large unburnt crops, although losses to the ground of 3-8 t/ha are more common. Ecosystem health is affected only when the labile carbon moves to the waterway.

We recommend that:
greater priority be given to minimising cane juice and cane billet losses during harvesting and during subsequent transport to the sugar mills.

Preferred levels of DO, expressed as a percentage of the total amount of oxygen that can dissolve in water (% saturation), vary in “reef” catchments with latitude and the type of water-body. Table 7 shows the ANZECC 2000 guidelines for ecosystem protection in cane-growing regions.

Table 7. ANZECC water quality trigger values for DO in ‘slightly disturbed’ ecosystems (Anon. 2000).

Ecosystem type	DO (% saturation – daytime)[A]			
	Lower limit		Upper limit	
	Sth-east Aust	Trop. Aust	Sth-east Aust	Trop. Aust
Upland river	90	90	110	120
Lowland river	85	85	110	120
Freshwater lakes/ reservoirs	90	90	110	120
Wetlands	No data	90 in Qld	No data	120 in Qld
Estuaries	80	80	110	120
Marine	90	90 (in- & off-shore)	110	no data

[A] The median DO concentration for the period should be calculated using the lowest diurnal DO concentrations. As a performance indicator, measurements should be made under low flow conditions for rivers and streams and during low flow and high temperature periods for other ecosystems.

There are guidelines for DO, biological oxygen demand (BOD_5) and chemical oxygen demand (COD) for the protection of aquaculture species in freshwater and for DO in saltwater. DO levels > 5 mg/L apply to the two systems. Recommended guidelines for BOD_5 and COD in freshwater are < 15 mg/L and < 40 mg/L, respectively. For recreational purposes, a guideline value of > 80% saturation of DO applies (this comes to about 6-7 mg oxygen/litre of water, although this varies with water temperature). Mean BOD_5 and COD concentrations in secondary-treated municipal effluent are typically in the range 17 and 50 mg/L, respectively, while the Queensland EPA limit for BOD of municipal effluent is 20 mg/L. It should be pointed out that recent research (e.g. Pearson et al 2002) indicates that current ANZECC guidelines are frequently not met in natural waterways in the tropics as a result of natural processes and that the guidelines require local adjustment (as they themselves recognise). Nevertheless, natural processes that might reduce water quality have also been shown to be exacerbated by agricultural runoff.

The presence of sucrose and related water-soluble carbohydrates on surface soil after cane harvest has subsequently been confirmed (Bohl *et al*, 2001a,b; Rayment and Bohl, 2002). In recent research (Bohl *et al*, 2002a), high BOD_5 concentrations (up to 400 mg/L) were found in runoff from the first irrigation after harvest of both green and burnt cane in the Burdekin. Sugar concentrations were also high in both cases (up to 500 mg/L) and were identified as the major contributor to the high BOD_5. Runoff-water with BOD_5 values of around 300 mg/L, if allowed to reach a local waterway, could cause a potentially serious hazard for aquatic fauna. Every litre of runoff would contain sufficient labile carbon to consume all of the oxygen in 50 litres of that waterway, if the ambient DO concentration were 6 mg/L or less.

Follow-up field and laboratory experiments are investigating the processes that might be occurring. Fresh cane trash and all the materials left behind after harvesting burnt cane have been soaked in water under controlled conditions. After just 1 h, BOD_5 exceeded 1000 mg/L in both cases. After 20 h, BOD_5 values had increased to > 4000 mg/L (burnt) and 2400 mg/L (trash). It is likely – but still to be confirmed – that BOD_5 levels as high as these can develop under field conditions. Implications for local fish stocks are obvious, but it is less clear what the effects could be on fish that move between coastal waterways and "reef" waters. High BOD values have been recorded in waterways on the Herbert floodplain, and are linked to low values of dissolved oxygen, fish kills and/or absence of sensitive fish species (Pearson *et al.* 2003).

5.1.2.8 Pharmaceuticals and Other Organic Substances

Provided they are partly soluble in water, many widely used chemicals or their derivatives – including drugs, food additives and components of domestic soaps – may reach waterbodies in forms that remain biologically active (Heberer and Stan, 1994). In some cases, these compounds in the water, despite their extremely low concentrations, may be able to affect the endocrine function of various organisms .

An example is clofibric acid, the active metabolite of the once widely used drug clofibrate, a blood lipid regulator. Clofibric acid, which can inhibit lipid metabolism in grasses, was found in a German groundwater aquifer at depths greater than 70 m, demonstrating its persistence and mobility through the soil profile. It has also survived water treatment processes to appear in Berlin drinking water (albeit at low levels).

In the early 1990s both bromocyclene (a persistent halogenated pesticide used in Denmark to treat dogs against fleas and lice) and moscusxylene (a nitro-compound used in soaps and perfumes for its fragrance) caused export trade problems in Europe due to their presence as residues in food. In addition, there have been reports that pollution of drinking water by oestrogen and compounds that mimic female sex hormones had depressed sperm counts and average testes weight, and also decreased male fertility in humans. Octophenol (1,1,3,3-tetramathylbutylphenol), found in fish from polluted rivers, is of particular concern because of its confirmed oestrogen-like properties in rats and mice.

In another example, the synthetic hormone ethinylestradiol has been detected in effluent and water in a pharmacologically active form, even though is excreted from the body as inactive conjugates, suggesting that chemical changes during the sewage treatment process could lead back to the pharmacologically active compound.(Th. Heberer &H-J. Stan (1994). Other hormones, such as progesterone, are degraded during secondary sewage treatment.

In addition, B. Martin & M. Day, New Scientist, January (1997) noted that pollution of drinking water by oestrogen and compounds that mimic female sex hormones were depressing sperm counts, average testes weight, and male fertility in humans. Octophenol, already found in fish from polluted rivers, was mentioned, with a recent study by Nair-Menon *et al*, (1996) confirming the compound's oestrogen-like properties in rats and mice.

The herbicide atrazine was recently added to the chemicals known to be associated with endocrine disruption (Lazaroff, 2002), suggesting that the list of confirmed hormone-disrupting compounds is incomplete. What makes this area even harder to study is the fact that measurements of these compounds in water and sediment is very difficult. However, some indication of the "pressure" on aquatic ecosystems can be inferred from the quantities in use. Examples collated by JCU/CRC Sugar of the quantities of most commonly prescribed drugs in Australia in 1997 that warrant environmental assessment are listed in Table 8. Similar statistics on possible endocrine function disruptors associated with food additives (e.g. butylated hydroxyanisole) and cleaning products (e.g. carboxylic acids of nonylphenol) are lacking.

Table 8. Use statistics for major pharmaceuticals prescribed in Australia in 1997.

Prescription Drugs	kg/year	Prescription Drugs	kg/year
Paracetamol	190637	Frusemide	4248
Metformin hydrochloride	45095	Amoxycillin with clav. Acid	4052
Ranitidine hydrochloride	22521	Ketoprofen	3013
Gemfibrozil	20011	Atenolol	2890
Codeine with paracetamol	19163	Cefaclor	2711
Aspirin	18223	Diclofenac	2384
Amoxycillin	11291	Isosorbide mononitrate	1974
Cephalexin	9795	Roxithromycin	1084
Allopurinol	9416	Famotidine	1075
Verapamil hydrochloride	5212	Oxazepam	1003

Concentration of dioxins/furans (mainly octachloro-p-dioxin; OCDD) were reported to occur in two topsoil samples (25 mm depth) from a sugar cane farm in the Herbert Valley, North Queensland (Müller et al, 1996). Both trash blanket and raked and burnt cane gave relatively high readings of OCDD. They were also higher than a subsequently sampled "control" soil from the Herbert that had not knowingly been used for cane. The guideline in Germany for soil with unrestricted agricultural use is a maximum of 5 nanogram of 2,3,7,8 tetrachloro-p-dioxin (2,3,7,8-TCDD) per kilogram of soil. The toxic equivalents of the two cane soils were 6.1 and 11. A similar chemical "signature" between the types of dioxins in cane soils and those in dugongs was subsequently reported (Haynes *et al*, 1999). Research on how dugongs absorb dioxins, including the source/s of the dioxins, is underway in Queensland. There is now clear evidence that cane farming practice is not the cause, although a land-based source is likely and probably of ancient origin (Prange, J.A., Gaus, C., Päpke, O. and Müller, J.F., 2001). Investigations into the PCDD contamination of topsoil, river sediments, and kaolinite clay in Queensland, Australia. Chemosphere. See www.elsevier.com.locate.chemosphere, 24 November 2001).

5.1.3 The Catchments of Concern

The mainland river drainage basins (catchments) draining into the GBRWHA can be divided into four typological groups on the basis of geography, rainfall, hydrology, vegetation communities and land use.

These four broad groupings are the:

Cape York Peninsula catchments (Jacky Jacky Creek, Olive-Pascoe, Lockhart, Stewart, Normanby, Jeannie, Endeavour)

Wet tropics catchments (Daintree, Mossman, Barron, Russell-Mulgrave, Johnstone, Tully, Murray, Herbert, Pioneer)

Dry tropics catchments (Black, Ross, Haughton, Burdekin, Don, Proserpine, O'Connell, Plane Creek, Styx, Water Park, Shoalwater, Fitzroy)

Sub-tropics catchments (Boyne, Calliope, Baffle Creek, Burnett, Burrum, Mary)

Basic statistics of the mainland drainage basins discharging into the GBRWHA are given in Table 1. Data sources: BOM, QNR&M

The first comprehensive collation of water quality data for north Qld coastal rivers and streams (including Wet and Dry Catchments) occurred in 1990(Rayment 1999, 2002). Monitoring data (from 5 to 142 samples per stream) were from Birthday Creek to the O'Connell River. The main features were wide fluctuations in nutrient concentration, with suggestions of higher concentrations in wet seasons. Mitchell *et al* (1991) noted that nitrate-N concentrations appeared to increase downstream in some rivers adjacent to sugarcane cultivation. In addition, there were suggestions that increases in nutrient concentrations occur in the first flushes after dry periods. There are water quality data (including suspended sediments) across several years for the Johnstone (Hunter et al) and for the Lower Herbert (Bramley and Roth 2002)

5.1.3.1 Wet Tropics Catchments

Sediments

Suspended sediment concentrations have been measured in various rivers in the wet tropics (Barron, Johnstone, Tully, Burdekin/Barrattas Murray, Herbert). Limited data are also available for the Russell-Mulgrave Rivers. Data from three of these rivers (Johnstone, Tully, Herbert) are appropriate to estimate annual or seasonal export loads from catchments over one or more years. With the exception of the Tully River (Furnas, 2002, Mitchell *et al*, 2001a), none of the data are appropriate to demonstrate multi-year trends in suspended sediment load or delivery from wet tropics river catchments.

Barron River – A number of water quality monitoring programs have been carried out in the Barron River catchment over the last two decades. The most recent (Cogle *et al*, 2000) deals with relationships between water quality and land. The data set is not long enough to detect trends in water quality. Overall, nutrient levels in the Barron River water tend to be higher in the sub-catchment affected by land clearing or agricultural land use. There is a general downstream increase in total N and P transport within the catchment, though the distribution of nutrient species changes.

Johnstone River – Personnel from QNR&M (formerly DNR) carried out a 6-year investigation of water quality, sediment exports and nutrient exports from the Johnstone River catchment and their relation to land use (Hunter, 2001; Hunter *et al*, 1996; Hunter and Walton, 1997). Overall, most of the sediment exported from the Johnstone catchment is derived from forested land (41%) and land planted with sugarcane (36%), with pastures contributing 15% of the exported load (Table 9). In terms of land cover, rainforest, sugarcane and pastures comprised 52%, 12% and 28% respectively of the catchment. Along the river systems within the Johnstone River basin, the lowest suspended sediment concentrations were measured at mid-catchment sites, with the highest at the lower catchment sites.

Table 9. Relationships between proportion of land use in the Johnstone River catchment and estimated sediment and nutrient export as estimated by HPSF modelling and five years of water quality monitoring

Land Use	% Area	% Sed Export	% N Export	% NO_3 Export	% P Export
Natural Forest	52	41	36	11	43
Pasture	28	15	17	12	18
Sugarcane	12	36	35	48	32
Bananas	2	8	8	14	7
Urban	0.5	.5	4	15	0.5
Other	6	~	~	~	~

A smaller number of suspended sediment measurements were made by AIMS at South Johnstone over several years (1989-1992). The sampling was insufficient to estimate sediment export, but showed that concentrations of particulate nitrogen (PN) and particulate phosphorus (PP) in river waters were strongly correlated with suspended sediment concentration. The highest concentrations of particulate N and P (and suspended sediment) occurred during flood events.

Suspended sediment and nutrient concentrations were measured in the Johnstone River during the cyclone Sadie flood event (February 1994). Over the four-day event, Hunter and Walton (1997) estimated that 200 000 tonnes of suspended sediment, 860 tonnes of N and 314 tonnes of P were discharged from the river. On a volume basis (tonnes km^{-3}), exports of sediment, N and P from the Johnstone River during this event were 3,3 and 7.5 times higher than recorded contemporaneously in the Herbert River (Mitchell *et al*, 1997). This is most likely because the flood in the Johnstone River was larger in magnitude than in the Herbert River.

Pailles *et al* (1993) reported on an extensive survey of P in sediments of the Johnstone River system. The amount of P in the sediment varied between the wet and dry seasons and longitudinally along the axes of the Johnstone and South Johnstone Rivers. Sediment P was overwhelmingly concentrated in the finest size fraction (<10 µm). P concentrations in sediments collected from agricultural areas (tributary streams and agricultural drains) were higher than in sediment collected from rainforest streams, indicating additional P inputs from fertilised agricultural soils. River sediments had a higher P concentration during the winter dry season when fine sediment would remain trapped in the drainage and stream system. Experimental studies to measure P absorption/desorption from Johnstone River sediments (Pailles and Moody, 1992) suggested that over short time frames, most of the sediment P would remain particle-bound in both marine and freshwater settings and have little effect on water quality.

<u>Moresby</u> <u>River</u> – Eyre *et al* (1993) examined the distribution of sediment-bound phosphorus in the Moresby River system, a small (126 km^2) catchment in the Johnstone River drainage basin. Elevated concentrations of nitrogen and phosphorus were measured in fine sediments (<2 µm) associated with agricultural lands in the catchment (about 30% of catchment area). In contrast to the Johnstone River catchment (see above) concentrations of P in fine sediment also varied with season, but with higher P levels during the summer wet season, reflecting enhanced erosion from sugarcane paddocks. Lower concentrations of sediment phosphorus in the estuary and adjacent nearshore waters were attributed to the preferential removal of P-enriched very fine sediments from the estuary, dilution with low-P offshore sediments, and dissociation of phosphorus from sediments in the estuary and offshore. Lower concentrations of extractable P in estuarine and nearshore sediments compared to agricultural soils indicate that over longer time frames, P is desorbed from terrestrial sediment particles.

<u>Tully</u> <u>River</u> – Suspended sediment loads and exports from the Tully River catchment have been estimated in a number of studies. Neil (1994) and Neil and Yu (1996) estimated sediment export from the Tully River catchment using discharge-export models derived from discrete sampling about the Tully River catchment. Neil (1994) suggested that sediment yield from the Tully River catchment has increased several-fold since the introduction of cropping. A more focused examination of one sub-catchment (Banyan Creek) showed a clear positive correlation between median suspended sediment loads and the extent of land clearing above the sampling site (Neil, 1994). Relationships between sediment load and extent of clearing were also related to the amount of annual rainfall in the catchment (Neil, 1994).

The Australian Institute of Marine Science (AIMS), in collaboration with the BSES, measured suspended sediment and particulate nutrient concentrations and export loads in the Tully River over a 13-year period (1987-2000). Sampling was carried out at a number of sites within the catchment over a 5-year period (1989-1994). Instrumental monitoring of suspended sediment loads and exports (as turbidity) has continued since 2000.

Analysis of particulate matter collected in the lower Tully River (Euramo) shows that concentrations of particulate nitrogen and phosphorus are closely correlated with suspended sediment concentration (Furnas, 2002). Based on instrumental monitoring of turbidity, annual exports of suspended sediment were found to be directly correlated with annual discharge (Furnas, 2002, Mitchell and Furnas, 2001).

Over 13 years of nutrient and suspended sediment sampling in the lower Tully River, a distinct change in the variability of particulate nitrogen and phosphorus concentrations (a proxy measure of suspended sediment) was observed from the early 1990s. From about 1990 onwards, the number of 'spikes' of elevated PN and PP concentrations increased. There was no change in the sampling procedures. This was interpreted as being due to more frequent erosion events within the catchment, which add, suspended sediment (with attached N and P) to the river (Furnas, 2002, Mitchell *et al*, 2001a). A change in land use in the upper floodplain region of the Tully River catchment began in the late 1980s as perennial pasture was converted to more intensive (and more fertilised) cultivation of bananas and sugarcane. This change also coincided with a steady increase in baseflow nitrate and phosphate concentrations (Mitchell *et al*, 2001a).

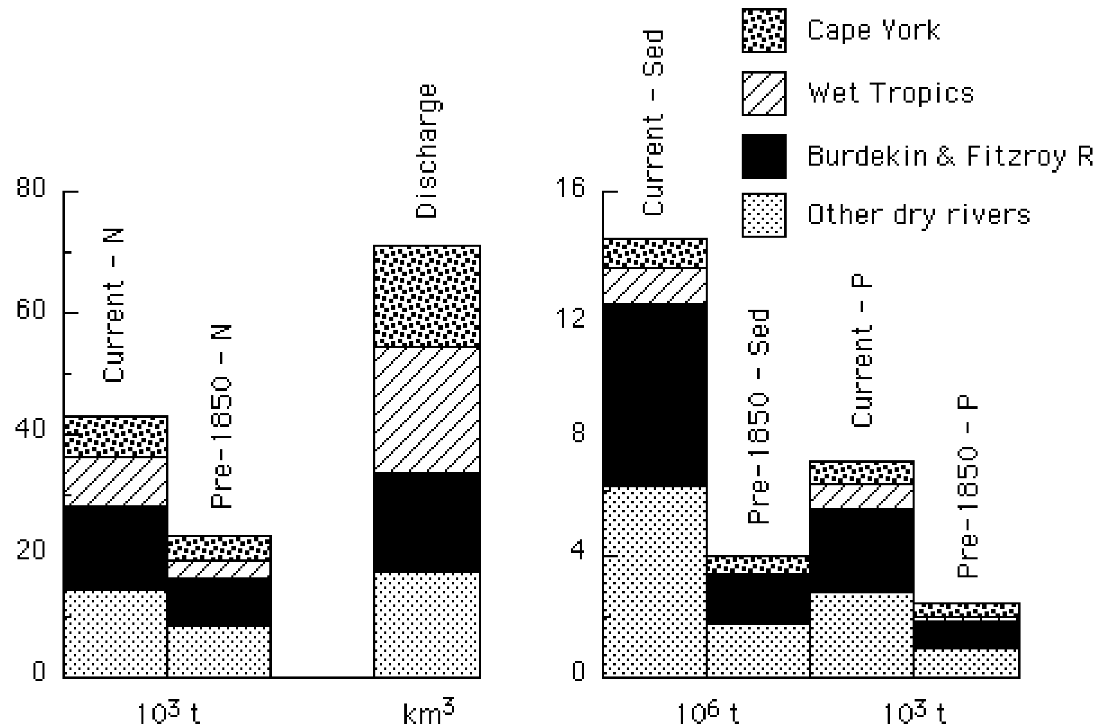
Herbert River – A number of studies have been carried out in the Herbert River catchment to estimate suspended sediment exports from the catchment and relationships between sediment load and land use (Bramley and Roth, in press; Furnas, 2002). Based on average annual water discharges and volume-averaged suspended sediment loads, Furnas (2002) estimated that 420 000 tonnes of suspended sediment is exported annually from the Herbert River catchment. On a year-to-year basis, annual fine sediment exports are directly correlated with annual discharge (Furnas, 2002). This estimate of sediment export does not include bedload transport or over-bank sediment losses during major flood events. Based on discharge records and measurements of river channel cross sections, Ladson and Tilleard (1999) found no evidence for sediment accumulation in the riverbed of the lower Herbert River. Sampling in other river systems suggests that the coarse (bedload) sediment makes up a relatively small proportion of total sediment exported from GBR catchment rivers (e.g. Burdekin River; Belperio, 1978). Considerable amounts of sediment can accumulate on the floodplain, particularly following overbank flow during major flood events (Roth *et al*, Draft), and results from stratigraphy of floodplain deposits indicate that there has been an approximately threefold increase in the rate of sediment accumulation on the Lower Herbert floodplain since European settlement (Olley and Wasson, in Roth et al, Draft).

Bramley and Roth (2002) carried out an extensive survey of suspended sediment concentrations in waterways of the lower Herbert River catchment. They found that median suspended sediment concentrations at individual sampling locations were greater the more that land upstream of the sites was used for sugarcane cultivation, and less in areas where more land was used for grazing purposes.

Nutrients

Dissolved and particulate nutrient (N, P) concentrations have been measured in several wet tropics rivers (Barron, Russell-Mulgrave, Johnstone, Tully, Murray, Herbert). Since 1991, there have been several reviews of nutrient concentrations in river systems of the GBR catchment, and exports from them. Two reviews by Mitchell *et al* (1991, 1996) summarised much of the then current knowledge regarding nutrient concentrations in waterways of the GBR catchment and provided preliminary estimates of nutrient exports from a number of river systems based upon volume-weighted discharge-export relationships. Subsequent considerations of nutrient dynamics in rivers have been presented by Mitchell and Furnas (1997), Furnas and Mitchell (2001a) and Furnas (2002).

Sufficient and appropriate data are available from three of these rivers (Johnstone, Tully, Herbert) to estimate annual or seasonal loads from catchments over one or more years. In the case of the Tully River (Furnas, 2002, Mitchell *et al*, 2001a), there is appropriate time series data to demonstrate multi-year trends in baseflow nutrient concentrations. A significant body of longitudinal data is available from three catchments (Johnstone, Tully, Herbert). Figures 7 and 8 (Furnas, 2002) summarise nutrient data collected over a number of years in rivers along the north and central Queensland coast.



Average annual freshwater discharge and estimated exports of nitrogen suspended sediment and phosphorus at the present time and prior to modern land use (pre-1850). From: Furnas, 2002

Figure 7. A summary of concentrations of dissolved and particulate nitrogen species measured in rivers draining to the GBRWHA by AIMS between 1987 and 2000.

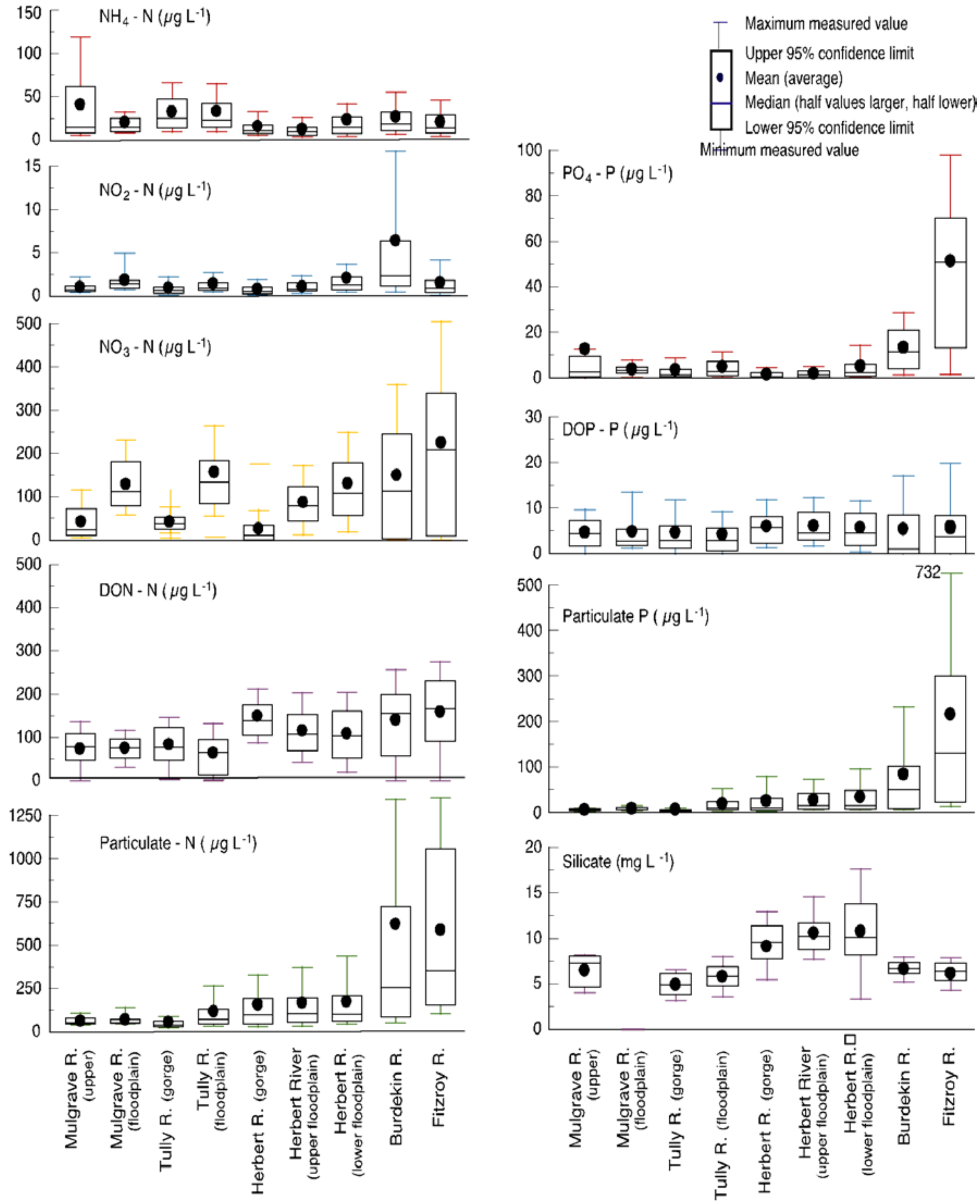


Figure 8. A summary of concentrations of dissolved and particulate phosphorus species and silicate measured in rivers draining to the GBRWHA by AIMS between 1987 and 2000.

Mulgrave River – A limited amount of nutrient sampling was carried out in the Mulgrave River between 1988 and 2000. Nitrate concentrations at the lower catchment site were higher than at an upstream site above most agriculture. No difference was seen for other nitrogen or phosphorus s species

Johnstone River – QNR&M - Dissolved and particulate nutrients were sampled over a 6-year period at a number of sites within the Johnstone River catchment. The lowest concentrations of dissolved nitrogen and phosphorus were found at mid-catchment sites at the upper end of the main agricultural area in the catchment. Slightly higher concentrations of nitrate and phosphate were consistently measured at two upper-catchment forested sites on the Atherton Tablelands. Reasons for the decline in concentration between the upper- and mid-catchment sites are unclear. There were distinct increases in concentrations of nitrate (NO_3^-) and phosphate ($PO_4^=$) between the mid-catchment sites and the estuary of the Johnstone River, reflecting N and P losses from lower-catchment agricultural lands dominated by sugarcane and, to a lesser extent, bananas.

Hunter and Walton (1997) modelled relationships between land-use and nutrient losses in the Johnstone River catchment. The results are summarised in Table 6.

These results indicate that agricultural activity within the Johnstone River catchment makes a disproportionate contribution to nitrogen and phosphorus exports from the catchment. Losses of N from unsewered residential areas had the highest area-specific nitrogen export, though the area involved is relatively small.

Tully River – Dissolved and particulate nutrients (N and P) were sampled at a number of sites in the Tully River between 1987 and 2000 (Furnas, 2002; Mitchell *et al*, 2001). Two sets of data relate to nutrient loads and changing land use within the Tully River catchment.

Between 1987 and 2000, water samples were collected on a bi-weekly to daily basis at a lower catchment site near Tully. On a sample-to-sample basis, all the time series are highly variable, reflecting the natural variability of freshwater runoff within the catchment and nutrient delivery to the stream network. Nitrate concentrations typically showed peaks coincidental with flow peaks, indicating inputs of nitrate from catchment soils during rainfall events. From about 1990 onwards, however, there was a progressive increase in baseflow concentrations of nitrate (NO_3^-), phosphate ($PO_4^=$) and particulate nitrogen (PN) (Furnas, 2002; Mitchell *et al*, 2001). From the same time, the readings for PN and particulate phosphorus (PP) show many more peaks (see above), due to more frequent inputs of sediment and sediment-associated nutrients brought about by more frequent erosion within the catchment. The increase in NO_3^- and $PO_4^=$ since 1990 reflects inputs of N- and P-enriched groundwaters from catchment soils due to fertiliser N and P infiltration from agricultural areas. Beginning in the late 1980s there has been a progressive conversion of unfertilised or relatively unfertilised perennial pasture in the Tully River valley to more intensive (and fertilised) banana sugarcane cultivation. Most of the conversion to sugarcane, however, has been in the adjacent Murray River drainage basin.

Longitudinal sampling in the Tully River (Furnas, 2002) from 1987 to 1995 shows that measured concentrations of dissolved inorganic nitrogen (chiefly NO_3^-) in the lower Tully River are consistently higher than in the upper Tully River valley and in tributary creeks draining tropical rainforest (Furnas, 2002).

Herbert River – Three data sets collected within the Herbert River catchment provide evidence for changes in water quality and nutrient exports as a result of modern agricultural land use (Bramley and Roth, 2002; Furnas, 2002).

Bramley and Roth (2002) sampled nutrient levels in streams and watercourses draining land used for agricultural and forestry purposes. Total fixed nitrogen concentrations above the "interim trigger levels for assessing possible risk of adverse effects due to nutrients" (ANZECC, 2000) were found in 31% of samples collected from streams draining land largely used for sugarcane cultivation, 9% of samples from waterways draining grazing land, and only 3% of samples from forestry drainage waters. For total P, approximately 86%, 47% and 33% of the samples from streams draining land used for sugarcane cultivation, grazing and forestry respectively were above the ANZECC trigger values.

Furnas and co-workers (Furnas, 2002; Furnas and Mitchell, 2001 Furnas *et al*, 1995) sampled a suite of nutrient species (N & P) at three sites along the Herbert River floodplain between the Herbert River gorge (Yamani Falls) and the lower floodplain (Ingham). Concentrations of ammonium (NH_4^+) and phosphorus ($PO_4^=$, DOP, PP) did not change appreciably downstream. Exports of these nutrients, however, must largely come from the lower catchment, because 60-70% of the water discharged from the Herbert River is known to be derived from the lower third of the catchment

In contrast, approximately 90% of the nitrate (NO_3^-) exported from the Herbert River catchment is derived from the lower catchment. On average, nitrate accounts for 30% of the N exported by the Herbert River. The average annual export (about 1000 tonnes of nitrate nitrogen) is a similar amount to the quantity of N lost from lower catchment soils in sugarcane-growing areas through infiltration to groundwater (Bohl *et al*, 2000). The highest nitrate concentrations at Ingham occur during baseflow periods, indicating a groundwater source for the nitrate.

Concentrations of nitrogen and, to a lesser extent, phosphorus in the lower Herbert River were found to be consistently higher than in waters draining surrounding rainforest (Furnas, 2002). Bramley and Roth (2002) found significant correlations between concentrations of N and P in waterways of the Lower Herbert floodplain and the area under cane production upstream of the sampling points (Figure 10).

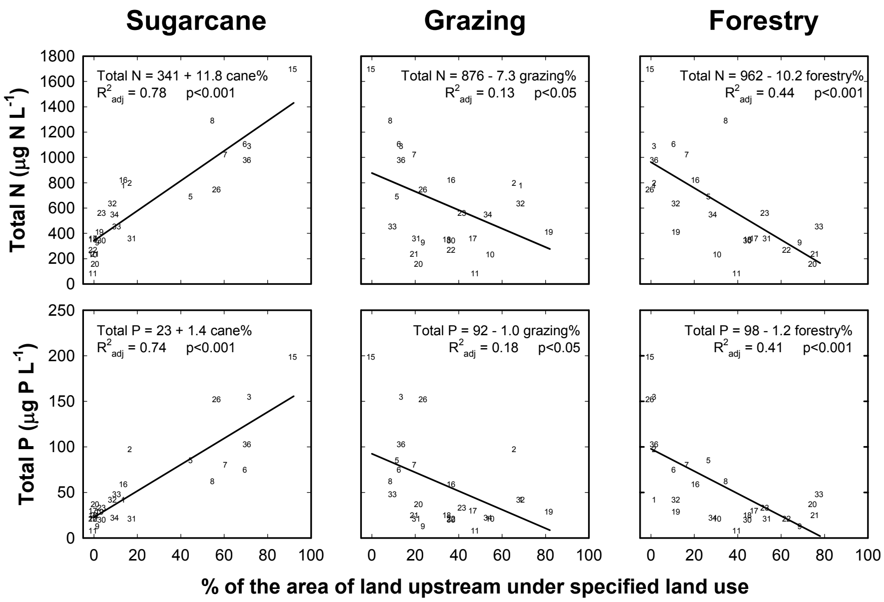


Figure 9. Impact of land use on median concentrations of total N and total P in lower Herbert streamwaters of 5th order or less. The numbers refer to the sampling sites (Bramley and Roth, 2002).

Wet tropics - Overall, rivers draining wet tropical catchments with sugar cultivation have been found to export a higher proportion (30-50%) of nitrogen in the form of soluble nitrate (NO_3^-) compared to dry tropics rivers (<10 – 25%). Nitrate concentrations are usually higher in the dry tropics rivers, but suspended sediment (and particulate N and P) are much lower in the wet catchment rivers. (Furnas, 2002)

Pesticides

Many herbicides and pesticides are used by the agricultural industries, councils and other bodies within the wet tropics catchments (Hamilton and Haydon, 1996). Most of these are used for agricultural purposes. To date, however, herbicide and pesticide use has only been extensively surveyed in the sugar industry (Hamilton and Haydon, 1996). On a mass basis, atrazine is the most used herbicide (331 tonnes a year), followed by diuron (about 200 tonnes per year). Where applications of pesticides and herbicides in a catchment have been tracked over time (Johnson and Ebert, 2000), varying patterns of use have been discerned. Applications of organochlorine compounds largely ceased between the 1970s and the mid-1980s. (See Table 10 below.) On the other hand, usage of organophosphate (chlorpyrifos) pesticides and herbicides (2,4-D, diuron, atrazine) has increased steadily.

Table 10. Information on early pesticide formulations used for sugarcane production in Queensland (and for many other purposes). Source: Rayment, G.E., Moss, A., Mortimer, M. and Haynes, D. (1997) - Monitoring of Pesticides in Queensland's Aquatic Environment. 11 pp. (Briefing Paper to DEAP 97-1. DNR, Brisbane.)

Pesticide	When Introduced	Comment
Aldrin	1961	Replaced early 1980s
BHC	1946	Withdrawn 1987
DDT	early 1950s	Not legally used since early 1970s
Dieldrin	late 1950s	Restricted use, permits after 1987
Heptachlor	1960s	Restricted use since 1987
Hg fungicides	late 1940s	Use decreasing; a registration condition requires monitoring for Hg in canelands. Since 1990, methoxyethylmercury chloride has been used on 50% or less of the area planted to cane in that year. Other uses now withdrawn.
Thallium rodenticides	1950s	Registration difficulties; alternatives preferred.

Müller *et al* (2000) surveyed pesticide and herbicides in waterways throughout agricultural areas of Queensland, including waterways within the wet tropics. One or more pesticides were measured in three-quarters of the samples collected. A number of pesticides and herbicides were detected in wet tropics waterways. The herbicides diuron and atrazine were the most frequently detected and at the highest concentration in waterways and drains within sugarcane farming areas.

Cavanagh *et al* (1999) sampled residues of long-lived organochlorine pesticides in agricultural soils and coastal sediments of the Burdekin and Herbert River districts, including the Hinchinbrook Channel. While DDT residues in agricultural soils were readily detectable, even after more than a decade of non-use, almost no residues could be found in coastal sediments, indicating either significant dilution, dissociation from sediment particles or metabolism by sediment microbial populations.

Recent (1990s) surveys of organochlorine pesticides in fauna from wet tropics rivers show a decline in the proportion of samples with detectable organochlorine residues compared to surveys carried out in the 1970s (Hunter *et al*, 1996). (Tables 11 and 12)

Table 11. Examples of fauna monitoring for pesticide residues in Queensland' reef catchments. (Adapted from Rayment *et al* 1997)

Location	When	Pesticides monitored	Indicator / Who	Findings
Coastal estuaries of SE Qld and Gladstone	95 & 96 (Summer)	Organochlorines, organophosphates, synth. pyrethroides	Mud crabs (*Scylla serrata*) */Mortimer, D of E.*	Always detect traces of DDT & metabolites, dieldrin, heptachlor epoxide & occasionally chlorpyrifos.
Central and Nth Qld Catchments	Recent	Samples held in storage; insufficient funds to analyse.	Mud crabs (*Scylla serrata*) /Mortimer, D of E.	Expect similar findings for mud crabs from all estuarine locations near to major rivers draining agricultural catchments.
Burdekin /Barrattas	11/90	Organochlorines, organophosphates. Herbicides (2,4-D,	Composite sample of molluscs. Also shrimps & fish.	Endosulfan sulfate (a metabolite of endosulfan) detected in molluscs, but not in shrimps and fish from the same areas.

Location	When	Pesticides monitored	Indicator / Who	Findings
		245-T, atrazine)	shrimps & fish. /Rayment *et al*	No other insecticide or herbicide residues were detected in molluscs, shrimps or fish (Rayment 1991)
Johnstone to Daintree Catchments	1975-78 and 1990-93	Organochlorines, organophosphates, 2,4-D, 245-T, atrazine, other triazines and trifluralin	Fish (muscle), oysters, mud crabs, mussels.	Russell *et al* (1996) and (Hunter I*et al* 1996) reported the detection of residues of superseded organochlorines as well as 2,4-D, atrazine and 2,4,5-T in biota from the Johnstone River Catchment, but only 2,4-D was detected in biota from the Daintree River. Recent samplings contained fewer residues than samples collected in the 1970's.
Qld (fresh, estuarine & inshore waters	Prior to 1988	Organochlorines, organophosphates	Marron, eels, mullet, lobsters, prawns, scallops, barramundi, mackerel, coral trout, mud crab, trochus.	Detectable levels (0.02-0.07 mg/kg) of DDE in eels; dieldrin (0.1), DDE (0.02), chlordane (0.02) (all mg/kg) found in mullet roe; 0.02 mg/kg of chlordane in mullet (Walter and Graham 1988).

Table 12. Examples of monitoring for pesticide residues in waters and sediments of Queensland' reef catchments. (Adapted from Rayment *et al* 1997)

Location	When	Pesticides monitored	Indicator / Who	Findings
Mary River	1996; (3 samples during Jan. flood.)	Organochlorines; organophosphates; herbicides (atrazine; metolachlor; diuron; ametryn; fluometuron; prometryn; trifluralin; triclopyr; 2,4-D; 2,4,5-T; 2,4-DB; dichlorprop)	Flood water (surface) /A. Moss, D of E	Positive detections at low concentrations of 2,4-D (0.2 μg/L) and triclopyr (0.1-0.4 μg/L). (Interin report to DEAP Committee, May 1996)
Lower Burnett	mid-1990s	Organochlorines; organophosphates; carbamates selected phenoxy and triazine herbicides	Bore water /Hargreaves and Osborne; reported by Keating *et al* (1996).	Traces of 2,4-D (0.39 μg/L), atrazine (0.26 μg/L) and chlorphenvinphos (1.1 μg/L) detected in 3 of 52 bores.
Theodore Weir (Dawson River) and Selma Weir (Emerald; Nogoa River)	during or before 1978	Organochlorines;	Water /(Anon 1978)	"Low" and "close to zero" levels of pesticide pollution were recorded in the Theodore and Selma Weirs, respectively, despite the prior use of large quantities of DDT, dieldrin and endrin on cotton grown in those regions.
Dawson, Nogoa & Comet Rivers; Riverslea on Upper	1994/95	Organochlorines; organophosphates; & range of herbicides	Surface water /R. Noble, DNR	Positive detections in the Dawson & Negoa Rivers - at relatively low concentrations - of endosulfan (mostly as the sulfate), profenofos (once in 1994) and prometryn (up to 5 μg/L). Atrazine residues are often detected in

Location	When	Pesticides monitored	Indicator / Who	Findings
Fitzroy				the Fitzroy Catchment, up to 1.2 µg/L in May 1995. (Report by R. Noble and Project Team).
Fitzroy Catchment	1994 -- 1996 research study	Organochlorines; organophosphates; other insecticides & range of herbicides	Surface waters - on farm, in drains and in Nogoa River / B. Simpson *et al* (1996)	Concentrations of 3 and 15 µg/L of endosulfan (early and mid-season concentrations in drainage water), one storm event with a flow of 1,200 ML mobilised 3.6-18 kg endosulfan. Residues of DDT metabolites still being detected. Pesticides, including the herbicides detected in soil (eg. Trifluralin, prometryne, fluometuron & diuron) have been measured in runoff water from furrows, tail drains & drainage channels (Simpson *et al* 1996).
Burdekin Delta/Irrigation Area	1992 & 1993	Broad spectrum - 80 chemical forms	Groundwaters /J. Bauld, LL Leach and L.W. Sandstrom	Bauld *et al* (1995) confirmed the presence (30 to 76%) of low concentrations of atrazine (including decomposition products) in groundwaters of the Burdekin River Delta and the Burdekin River Irrigation Area.
Burdekin Delta/Irrigation Area	1995-1998	Organochlorines; organophosphates; & herbicides	On-farm irrigation tail water /G. Ham, BSES/CRC	Pesticide residues, including herbicides, detected at quite variable concentrations.
Burdekin /Barrattas	11/90 & 1993	Organochlorines, organophosphates. Herbicides (2,4-D, 2,4,5-T, atrazine trifluralin, and hexazinone)	Surface waters and sediments /Rayment & Hunter, DNR	Rayment (1991); Rayment and Hunter (unpublished data) found generally low concentrations of pesticide residues in waters and sediments from the lower Burdekin / Barratta Creeks region of the superseded organochlorine insecticides and the herbicides 2,4,D, 2,4,5-T (only in sediments) and atrazine. No detections of α and β - BHC, lindane, δ - BHC, HCB, heptachlor, aldrin, heptachlor epoxide or chlordane (δ and α) in both 1990 and 1993, a situation that applied to chloropyrifos, and to the herbicides trifluralin and hexazinone when monitored in 1993 only.
Atherton Tablelands	1987	Atrazine	Bore waters (12 sites) /Simpson *et al* (1988)	Nil detections (lower detection limit of 0.01 µg/L)

5.1.3.1 Wet Tropics catchments

Habitat and Ambient Water Quality

Along with the major changes in catchment land use, the period since European settlement has seen very significant losses or degradation of aquatic habitat. Natural riparian zone vegetation has been reduced or removed altogether over extensive areas. Freshwater wetlands (Melaleuca and Palm swamps) have similarly been lost through in-filling and drainage aimed at providing additional cropping areas. This loss of habitat has significant effects on the local aquatic ecosystems. However it also has implications for downstream areas. Both riparian zones and wetlands trap some of the sediment and pollutant loads in water running off from catchments. Riparian zones act as natural filters while wetlands operate as sedimentation and retardation basins. Removal of these habitats therefore simply increases the proportion of the pollutant load from the catchment that is able to enter the rivers and subsequently enter the reef lagoon.

As well as removing pollutants, wetlands act to buffer inflows to streams. The wetlands act like giant sponges, soaking up peak flows and then releasing them slowly over the post flood period. Consequently, removal of these wetlands leads to higher peak flood flows which in turn increase the power of flood events to erode stream beds and banks and further add to the sediment and nutrient load.

Riparian vegetation helps to protect stream banks from erosion. Its removal therefore not only reduces its filtering capacity but also at the same time leaves the banks more prone to erosion.

For all these reasons, removal of riparian zones and wetlands compounds the effects of changes in catchment land use. It follows therefore that to reduce sediment and nutrient loads to the reef lagoon we need to not only improve land management practices but at the same time to restore both riparian zones and freshwater wetlands.

Just how significant are the losses of riparian zones and wetlands in Wet Tropics catchments? The following data, summarised by Finlayson *et al* (2002) indicates they are very significant indeed.

- 80% of Melaleuca systems on the Herbert River floodplain – (Johnstone *et al* 1997)
- 65% of all freshwater wetlands on the Johnstone River floodplain – (Russell and Hales 1993)
- 54% of all freshwater wetlands on the Russell-Mulgrave River floodplain – (Russell *et al* 1996a)
- 65% of all freshwater wetlands on the Moresby River floodplain – (Russell *et al* 1996b)
- 71% of melaleuca and palm swamps on the Tully-Murray Rivers floodplain – (Tait 1994)

Losses of riparian habitat are of a similar order. Data summarised from State of the Rivers surveys carried out by the Queensland Department of Natural Resources shows:

Herbert – 83% of riparian in poor or very poor condition

Tully - 50% of riparian in poor or very poor condition

It is difficult to precisely quantify the effects of these habitat losses on nutrient and sediment loads reaching the reef lagoon. However, the loss of between half and three quarters of these habitats over entire catchments is likely to have had some significant impact. It follows that any strategies to reduce catchment loads should include restoration of these habitats.

While flood events deliver the largest loads of nutrients and sediments from catchments to coastal waters, the most important water quality issues within the catchments occur during the extended periods of low flow. Moreover, delivery of water to the GBR from agricultural areas tends not to be via the main river channels, but via floodplain distributaries (and probably via groundwater flow). The effects of this steady input of materials to the GBR is unknown, as most monitoring focuses on river channels and flood events.

Ambient (i.e. non-event) within-catchment processes can have a major influence on habitat quality, and the distribution and abundance of aquatic organisms, including species that travel between coastal and inland waters to feed or breed, species of direct human value such as barramundi and mangrove jack, and many species of invertebrates and fish that provide food for these high value fishes. Recent research in GBR catchments by the Australian Centre for Tropical Freshwater Research, the Sugar CRC and CSIRO has demonstrated the important links between agriculture, ambient water quality, environmental requirements of organisms, and distribution of invertebrates and fish. An example of this research is an SRDC-funded project which reports on water quality in the Herbert floodplain, and interactions with plants, invertebrates and fish (Pearson *et al* 2002), as follows. The conditions described apply similarly in other floodplain areas, such as that of the Burdekin River.

Major factors variously affecting habitat and water quality include:

- absence of natural riparian vegetation, facilitating weed invasion, channel congestion, loss of major habitats for invertebrates, fish, reptiles, birds and mammals;
- sediment inputs from cane fields, altering habitat values and plant growth;
- fertiliser-derived nutrient inputs from cane fields, increasing plant growth, respiration and nocturnal oxygen demand;
- organic material inputs from cane fields (especially sugars leached from cane trash), stimulating microbe growth, respiration and oxygen demand;
- input of fertiliser-derived ammonia from cane fields, excluding fish from affected waterways;
- substantial increase in these effects during minor (non-flooding) rain events;
- substantial reduction in dissolved oxygen in affected waterways, frequently falling below critical levels for invertebrate and fish avoidance behaviour and survival.

These factors are interlinked. For example, a typical scenario in lagoons is of a deep lower layer of deoxygenated water, resulting from enhanced microbe and plant growth, becoming mobilised and mixing with the oxygenated surface waters, reducing the overall dissolved oxygen levels below critical values, and resulting in a fish kill. While it is possible that such events occur naturally from time to time, they are greatly exacerbated by the inputs of agriculture-derived nutrients and organic material. Furthermore, escape of fish from affected waterways may be barred by choking growths of weed (e.g. para grass) or by slugs of high concentrations of ammonia, which would not occur naturally.

The overall picture of many floodplain areas is similar – the main issues are reduced habitat area resulting from drainage and weed invasion, poor habitat quality, intermittently severe water quality, and absence of fish, or fish kills. The influence of this situation on the GBR has not been measured, but it is likely that the impact of a loss of diversity and biomass of wetland species has substantial indirect and direct effects on marine species (some of which are also wetland species). However, the very processes that cause these problems can actually reduce concentrations of contaminants delivered downstream. Therefore, the greater the area of wetland remaining, then the less contaminated is the water delivered to the GBR lagoon for most of the year (i.e. in non-flood periods). The loss of large proportions of the original wetlands from many floodplain in the GBR catchments (e.g. see Land and Water Audit data) is probably a major factor in the deterioration of water quality in coastal waters.

5.1.3.2 Dry Tropics and Sub-tropical catchments

Habitat

The general effects of loss of aquatic habitat – freshwater wetlands and riparian zones - on sediment and nutrient loads are detailed in Section **5.1.3.1 Wet Tropics catchments** and are not repeated here.

For the Dry tropics and sub-tropical catchments, there are less data on the loss of these habitats. However, what data there are suggest that losses are of the same order as those in the Wet Tropics. Finlayson et al (2002) quote the following numbers for loss of freshwater wetlands:

- 50% of large ephemeral wetlands on the Burdekin River floodplain – (Lukacs 1995)

Data on riparian zones summarised from State of the Rivers surveys carried out by the Queensland Department of Natural Resources in Fitzroy subcatchments shows:

- Dawson River - 83% of riparian zone in poor or very poor condition
- Comet/Nogoa/Mackenzie - 50% of riparian zone in poor or very poor condition

As with the Wet Tropics, it is clear that strategies for reducing pollutant loads to the GBR lagoon need to include restoration of these habitats.

For the purposes of this report the 'dry tropics and sub-tropical' catchments include all the QNR&M mainland drainage basins from the Black River (Basin 117) to the Mary River (Basin 138). The Burdekin (130 126 km^2) and Fitzroy (142 537 km^2) basins are the largest of the dry tropics catchments (Figure 2). Table 1 summarises basic hydrological features of dry tropics river basins. Rivers in the dry tropics typically have very high flow variability over seasonal, annual and decadal time scales. This means that in these systems, water quality, and the quantity and type of sediment and nutrient exports, are also highly variable. At various times during the year, and especially during drought periods, there may be no flow in individual dry tropics rivers. The upper reaches of some may be dried out, and water in others restricted to billabongs in the riverbeds.

Sediments

At present, there are no long-term sediment monitoring programs in place which can strictly demonstrate a change in the amount of sediment transported by dry tropics and sub-tropical rivers. In the dry tropics, such a monitoring program would have considerable difficulty in empirically establishing a trend because the dry tropics rivers discharge virtually all of their water during brief wet season flood events (Furnas, 2002). Because of the considerable variability in suspended sediment concentrations during any one wet season (Furnas, 2002; Furnas and Mitchell, 2001), detection of trends in concentration through monitoring is not likely within decadal time periods. Attempts to determine trends in volume- or area-specific discharge are currently limited by the short lengths of available records (<10 years ; Furnas, 2002) and stochastic interactions between regional climate (droughts), land cover and major cyclone-driven flood events. There are, however, two cases of indirect evidence which suggest that exports of fine sediment from dry tropics rivers have increased over the last 150 years.

In the first case, McCulloch examined the relationship between coral bands and sediment discharge from the Burdekin River (McCulloch and Fallon, 2001; McCulloch *et al*, 2002). Geochemical tracers (using ratios of barium to calcium), measured in dated cores taken from long-lived coral colonies (*Porites* species) on coastal reefs adjoining the central GBR, have indicated changes that suggest an increase in terrestrial erosion rates in the 1860s. This was when cattle were introduced to the Burdekin River catchment. Increased erosion within catchments would lead to increased solubilisation and runoff of barium (Ba), which partially substitutes for calcium in coral skeletons. While the initial populations of cattle were not large, the herds would have been concentrated near rivers and streams in the erosion-prone riparian zone for access to water and well-watered riparian pastures. This is corroborated by our knowledge about the impact of cattle on soil loss via removal of ground cover, trampling and gully initiation near waterways (Ciesiolka, 1987; McIvor et al, 1995; Scanlan et al, 1996; Roth, 2002). The second case providing indirect evidence is the comprehensive modelling carried out by Prosser et al as part of the National Land and Water Resources Audit (2001a), which is corroborated by the recent findings of Neil *et al* (2002). Catchment-scale erosion and sediment export modelling indicate that changes such as reducing groundcover and land-clearing) since 1850 have led to a substantial increase in sediment export from dry tropical catchments where grazing is the major land use (Prosser *et al*, 2001b). Modelled estimates of current sediment export are similar to measured sediment export fluxes (Furnas, 2002), lending credence to the accuracy of the modelling process. Importantly, the models show that a large proportion of the sediment delivered to the mouth of the major rivers is derived from only a small proportion of the catchment.

Nutrients

At present, there are no time series data which show unambiguous trends in nutrient concentrations within or exports from dry tropical catchments, and which are attributable to modern human land use. It is clear that dry tropical catchments export a significant proportion of their nutrients in particulate form (Furnas, 2002), either as particulate organic matter or as nutrients adsorbed to fine sediment particles. Both particulate N and P concentrations in river waters are closely correlated with the suspended sediment concentration (Furnas, 2002). Particulate nutrient exports can be expected to follow temporal trends or spatial patterns in sediment loss from dry catchments (see above).

The longest time series of nutrient data (1987-2000; Furnas, unpubl.) from a dry tropics river was collected from the Burdekin River. There is little or no flow in the Burdekin during the dry season. Wet season nutrient concentrations vary considerably within any one year due to flow conditions, the timing of rainfall within the wet season and catchment conditions over the previous dry season (Furnas, 2002). Over the 13-year period of sampling, no clear trend in concentrations of either N or P was observed. Year-to-year variations in nutrient concentrations and the relative abundance of dissolved organic and inorganic N and P appeared related to the climatic wet and dry cycling of the region.

Longitudinal changes in nutrient concentrations, with downstream increases, have been observed in the O'Connell River (Mitchell *et al*, 1991) and Fitzroy Rivers (Noble *et al*, 2000).

Pesticides

Several pesticide (including herbicide) sampling projects have been carried out in dry tropics rivers.

Müller *et al* (2000) sampled agricultural drains and waterways in a number of regions within dry tropics agricultural areas. Pesticides and/or herbicides were detected in most samples. In cotton-growing regions, insecticides, especially endosulphan derivitives, were most commonly found along with DDT breakdown products. Herbicides were also commonly measured.

At least 39% of the groundwater samples taken in the Burdekin River Delta and irrigation were atrazine-positive (Bauld *et al*, 1996). In the 1990s, atrazine was occasionally detected in surface waters and sediments from the Burdekin, Haughton/Barratta Creeks (Rayment and Neil, 1996). Noble *et al*, (1997) also detected traces of atrazine and endosulphan in the Fitzroy River.

Most recently, Noble and Collins (2000) summarised the results of pesticide/herbicide sampling in the Dawson River sub-catchment of the Fitzroy River basin, carried out as part of a larger water quality monitoring program. Dryland grain and irrigated cotton cropping were the major land use activities involving pesticide use in this catchment. As previously observed (Noble *et al*, 1997), the herbicide atrazine was the most commonly detected pesticide. In all, atrazine was detected in 55 water samples, most of which were collected during the summer, when atrazine is used on grain and cotton crops. Overall, atrazine (in 55 samples), diuron (in 16 samples), endosulfan (in 11 samples), profenofos (in 6 samples) and trifluralin (in 1 sample) were detected. In all cases, concentrations of these pesticides were below the trigger level of 0.5 $\mu g\ L^{-1}$ that is in the ANZECC guidelines.

Other Contaminants

Downstream of Mt. Morgan, the Dee River is heavily contaminated by leaching from old Mt. Morgan mine workings and spoil heaps. Concentrations of Cd, Cu and Zn were found, respectively, to be 158, 240 and 12 times greater than ANZECC trigger guidelines. (Jones, 2000).

5.1.3.3 Cape York Peninsula catchments

The Cape York Peninsula catchments are the QNR&M drainage basins (101-107) located between Cape York and the Endeavour River. With the exception of the Normanby River basin, most are relatively small. Two (Jacky Jacky Creek and Lockhart River) are not gauged. Rainfall and runoff characteristics of these basins are inferred from those of adjoining basins. Compared to the other drainage basins of the GBR catchment, the Cape York Peninsula basins are relatively unused, and the area is pristine or nearly so. Cattle grazing is the principal human land use.

Sediments

We know little about suspended sediment loads in Cape York Peninsula Rivers and exports from them, and nothing about trends. Some studies of suspended sediment dynamics have been undertaken in the lower Normanby River (Ref??) While this section of the river is highly turbid, the turbidity is due to natural tidal mixing of the estuarine section of the river.

The first estimate of sediment exports from Cape York rivers was presented by Belperio (1983a). This estimate is almost certainly far too high as it was based on sediment export characteristics of the Burdekin River. More recently, Woolfe and Larcombe (1998), assessing terrigenous sediment accumulation, estimated that modern sediment export from Cape York catchments to the adjoining shelf was approximately one million tonnes per year.

Furnas (2002) measured suspended sediment loads (based on turbidity) over two wet seasons in the Normanby River (Lakefield). Peak concentrations occurred at the peak of wet season floods. Furnas found that the quantity exported in the wet season (volume-averaged) lay between the values measured for wet and dry tropical rivers.

Nutrients

Only a limited amount of nutrient sampling has been carried out and reported from rivers draining eastward from Cape York Peninsula into the GBR. There are no published time series sampling from any river system to detect trends or estimate annual exports of nutrients from catchments.

Eyre and Balls (1999) sampled nutrients during the wet and dry season from the estuaries of 2 river systems on Cape York Peninsula. Additional samples have been collected from estuaries during along the Cape York coast during the wet and dry seasons by AIMS researchers (Furnas, unpubl.). These samples are generally characterised by low nutrient concentration. They are not related to flow from the catchment, so they are insufficient to estimate status and trends in water quality, or export from these catchments.

A small number of nutrient samples have been collected in the Normanby River (Lakefield) over one wet season. Median concentrations of all nitrogen and phosphorus species are relatively low compared to river systems to the south (where there is extensive land clearing or use of fertiliser). Indeed, the Normanby samples are comparable to concentrations in streams draining pristine or largely pristine wet tropical sub-catchments (Furnas, 2002).

Pesticides and other Contaminants

At the present time, there is no published information on levels of pesticides and other contaminants in river systems of Cape York Peninsula. Westernhagen and Klumpp (1995) examined fish eggs from estuaries along the wet tropical and Cape York Peninsula for evidence of pollutant-derived developmental deformities in fish embryos. Deformities were few and the region was regarded as indicative of pristine or near-pristine conditions.

5.1.4 Overall Assessment of Catchment Water Quality and Delivery of Pollutants to the GBRWHA

Over the last two decades, many studies have dealt with sediments, nutrients, water quality in, and sediment, nutrient and contaminant exports from waterways and rivers of the GBR catchment. These studies have been undertaken for a variety of purposes and have used a range of sampling and analytical approaches, depending upon the goals and resources of the individuals and organisations involved. Most of these studies were relatively short (< 1 year), with most involving just one or a few sampling visits to the systems studied. The brevity and small spatial domain of most of these studies make it difficult to generalise about the effects of land runoff to the reef, or to extend the results obtained with a high degree of certainty.

Several features of the regional climate and hydrology strongly affect measurements of water quality in streams and estimates of exports from catchments to the Great Barrier Reef. The first is the strong seasonal nature of the climate, with approximately two-thirds to three-quarters of the annual runoff occurring during the summer wet season (November – April). Within any one wet season, rainfall, stream/river flow and discharge/exports predominantly occur during short-lived flood events, many of which are associated with post-cyclone or monsoonal rainfall. These events may last for periods of days to weeks. Peak flows (with associated peak concentrations or exports) may only last hours to days. Over inter-annual and decadal time periods, there are also significant variations in discharge from individual river systems. Rivers in the wet tropics tend to have minimal inter-annual variations in rainfall and discharge, while rivers of the dry tropics are characterised by infrequent flood events and large variations in discharge from year to year. Wet tropical rivers (e.g., Tully, Russell-Mulgrave) typically flood at least once and often several times a year while dry tropical rivers (e.g., Don, Styx) may go years to decades between major flood events. The Burdekin experiences a significant flood every 2-3 years, while the Fitzroy River has floods of similar magnitude every 10-20 years. Monsoonal rivers on Cape York Peninsula typically experience one major flood event each year.

On a relative basis, biological processes in stream and river systems are greatest during low-flow conditions of the winter dry season when water residence times are longest and biological processes have greater opportunity to influence smaller volumes of water.

There have been several attempts to estimate terrestrial sediment inputs from the GBR catchment. Due to the size of the GBR catchment, these estimates are based upon extrapolations from sampling in one or a few rivers or modelled estimates of soil loss from different types of land use. The first estimate of sediment input (Belperio, 1983b) extrapolated a measured sediment export from the Burdekin River to the GBR catchment as whole. This is almost certainly an over-estimate as suspended sediment loads in the Burdekin River are at the high end of measured sediment loads in the GBR catchment.

Using soil loss rates measured in areas with different types of land cover and land use, Moss *et al* (1993) prepared the first comprehensive estimate, in relation to land use, of sediment (and associated nutrient) exports from catchments bordering the GBR. Neil *et al* (2002) estimated sediment export based upon discharge data and discharge export models. More recently, Furnas (2002) estimated sediment export to the GBR based on discharge-weighted export coefficients measured in a number of wet and dry catchment rivers. Prosser *et al* (2001b) estimated sediment export from catchments bordering the GBR using a sediment transport model with spatially distributed input of soil erosion (SEDNET) as part of the National Land & Water Resources Audit. Although working from different approaches, Furnas (2002) and Prosser *et al* (2001b) arrived at roughly similar estimates for average annual sediment inputs to the GBR (13-15 x 10^6 tonnes year^{-1}). Estimates of pre-1850 sediment inputs are also of similar order (1-5 x 10^6 tonnes year^{-1}).

As with sediment, there have been several attempts to estimate nutrient (chiefly N and P) inputs to the GBR from adjacent catchments. These efforts have followed two general approaches: extrapolating nutrient inputs to the GBR from sediment inputs using an assumption on sediment/nutrient relationships (e.g. Moss *et al*, 1993); and extrapolation from discharge export relationships measured empirically in a subset of river systems (e.g. Furnas *et al*, 1995; Furnas and Mitchell, 2001; Furnas, 2002). The use of sediment fluxes provides a useful first-order estimator for nutrient inputs, as about 80% of the P and 40-50% of the N is associated with fine sediments carried by rivers.

Table 13. Contribution of regional drainage basins to runoff, sediment export and nutrient export to the GBR. From: Furnas, 2002.

Region	% Runoff	% Sediment Export	% N Export	% P Export
Cape York Peninsula	23.6	6.7	15.4	9.9
Wet Tropics	29.0	8.2	18.9	12.1
Dry Tropics and Sub-tropics	47.4	85.1	65.6	77.9

Table 14. Estimates of average annual sediment and nutrient inputs to the GBR from literature sources.

Source	Time	Sediment	N	P
		10^6 t yr^{-1}	10^3 t yr^{-1}	10^3 t yr^{-1}
Belperio, 1983	Current	27.4		
Moss *et al* 1993 (model 1)	Current	13.0	82	11.0
Moss *et al* 1993 (model 2)	Current	14.0	67	9.6
Neil and Yu, 1996	Current	26.6		
	Pre-1850	6.9		
Mitchell and Furnas, 1997	Current		33	2.4
Furnas and Mitchell, 2001	Current		47	2.4
Furnas, 2002*	Current	14.0	43	7.0
	Pre-1850	4.4	22	2.2
NLWRA, 2001	Current	13.6	54	10.9
	Pre-1850	1.5	22	2.8

* also given in Brodie and Furnas, 2002

A variety of evidence clearly shows that the bulk of sediment delivered to the GBR by rivers remains in the nearshore zone as a wedge of sediment. Initially, at least, the bulk of the sediment-associated nutrients is likely to be deposited with this sediment as well. The surface layer of this coastal sediment deposit is continually re-suspended and moved by wind, waves and wind-driven coastal currents. Coral communities, coral reefs and seagrass beds in the coastal zone are recurrently affected by this re-suspended sediment and associated materials. Very high concentrations of suspended sediment can occur in this coastal boundary layer under strong wind conditions.

5. 2 Evidence for Adverse Effects of Changing Water Quality on Ecosystems of the GBR (TOR 2) .

5.2.1 Effects of land-based sediment and nutrient runoff on corals and coral reefs.

The fundamental question to be answered here is “ Can any effects of land-based sediment and nutrient run-off on the GBR, be unambiguously identified and separated from other effects?”

We have specifically identified the GBR as being the World Heritage Area, a complex system of waters, reefs and islands, and that certainly includes the inshore waters and the fringing inshore coral reefs and corals.

These inshore corals and coral reefs are regarded as areas of high risk, with respect to impacts of land-based activities, especially from materials dissolved in or carried by river run-off.

There are many coral reefs in these areas of high risk from run-off events that appear to be degraded, and/or slow to recover from other disturbances.

However, it is not practicable to link this situation unequivocally to the effects of river run-off alone, on the basis of scientific evidence. Experiences elsewhere (for example, with nearshore corals and coral reefs in Hawaii and in Florida) show that by the time the amount and nature of dissolved and suspended pollutants reaching corals and coral reefs, can be easily detected and unambiguously linked to coral deaths, the system is severely degraded and unlikely to recover to its former state and function, within several to many years, and without significant changes to land-use practices.

The evidence that we now have for the GBR is as follows:

a. Land-sourced pollutants such as chemicals used by humans in current urban and rural activities are reaching the GBR. These include chemicals used in agricultural and veterinary applications (AgVet Chemicals)
b. Excess nutrients that are transported by rivers in peak floods, reach the GBR
c. Some areas of the GBR, most affected by river run-off appear to be degraded and/or slow to recover from natural events, such as cyclones. In this regard, we note the experiences documented overseas that the first major signs (that is, hard proof of adverse impact) comes when the coral reef system fails to recover from other disturbance (including natural events such as cyclonic level events).

There has been recent media debate claiming that turbidity in the waters of the GBR has not increased, and therefore, that adverse impact on the reef can not have increased. Such claims overlook the facets of river run-off, other than turbidity alone; sediments, which cause turbidity, may today include very different adsorbed and absorbed chemicals from those present in previous decades, and the dissolved substances in the sediment-carrying waters may also modify the characteristics of the sediments. The evidence is clear, that the levels of some chemicals in some rivers discharging to the GBR, notably of nutrients containing nitrogen and phosphorous, is increasing, and has increased over several years.

The Panel is of the view that the current declines in river water quality in several catchments that drain to the GBR, should not be allowed to worsen, and that, as soon as is practicable, the trends in worsening water quality should be reversed, to allow the GBR the best possible opportunities to recover from disturbances. This view includes the consideration that other disturbances, such as the predicted 'global warming', are likely to adversely affect corals and coral reefs.

The evidence that we possess is admittedly incomplete, and some will say that the situation is 'circumstantial', from the most rigid scientific approach. We agree that the scientific evidence is incomplete, but we also believe that the measures we are suggesting to be put in place, to improve the quality of water entering the GBR, are fully justified on the scientific evidence to hand.

The Panel is also of the view that the changes necessary to achieve improvement in water quality can be best achieved by close collaboration among all sectors of the community, and that corrections should be sought at the source of the problem, not 'at the end of the river' entering GBR waters.

There is abundant evidence from field studies overseas that increased nutrient availability and enhanced sedimentation caused by human activities can degrade coral reefs at local or regional scales, as follows:

Excess nutrients

* Kaneohe Bay, Hawaii – (Holthus *et al*, 1989; Hunter and Evans, 1995; Smith *et al*, 1981; Stimson and Larned, 2000; Stimson *et al*, 2001, among many others)
* Other locations in Hawaii – (Coles, 1999; Grigg, 1995)
* Indonesia – (Edinger *et al*, 1998, 2000; Tomascik *et al*, 1993, 1997)
* Barbados – (Hunte and Wittenberg, 1992; Tomascik, 1990, 1991; Tomascik and Sander, 1985, 1987a,b; Wittenberg and Hunte, 1992)
* Hong Kong – (Hodgson and Yau, 1997; Morton, 1994)
* Red Sea – (Hawkins and Roberts, 1994; Walker and Ormond, 1982)

Enhanced sedimentation

* Indonesia – (Edinger *et al*, 1998, 2000; Tomascik *et al*, 1993, 1997)
* Bermuda - (Dodge *et al*, 1974)
* Philippines – (Hodgson, 1990)
* Hong Kong – (Hodgson and Yau, 1997; Morton, 1994)

*	Kenya – (van Katwijk *et al*, 1993; McClanahan and Obura, 1997)
*	Costa Rica – (Cortes and Risk, 1985; but see Hands *et al*,1993)
*	U.S. Virgin Islands – (Hubbard, 1986)

These studies (among others) show that enhanced turbidity, sedimentation or nutrient availability lead to: (a) local losses of biodiversity, (b) reduced (or failed) coral recruitment; and (c) displacement of framework-building hard corals as the dominant visible, space-occupying group in coral reef systems. Secondary influences (potential and observed) – such as diseases, enhanced survival of crown-of-thorns starfish larvae and increased growth of carbonate-destroying bio-eroders – also have profound effects on the wider reef ecosystem.

There are often uncertainties in the interpretation of field studies on runoff or eutrophication effects because there are both natural and human impacts occurring at the same time. In such situations, the causes of reef degradation are generally not clearly identified, and are frequently disputed.

Effects of enhanced sedimentation and eutrophication on corals and coral reef assemblages have been tested in laboratory and field experiments. The results confirm many of the suggested links inferred from field observations.

Enhanced turbidity and sedimentation reduce the photosynthesis that is carried out by algal symbionts within the corals. This then increases the metabolic costs associated with tolerance or cleaning, leading to reduced growth of corals and coral communities (Dodge *et al*, 1974; Rogers, 1979; 1983; 1990; Stafford-Smith, 1999; Telesnicki and Goldberg, 1995). Increased turbidity will also reduce the depth range within which corals can survive or maintain active accretion (Loya, 1976; Stafford-Smith, 1999).

Diuron is the only herbicide or pesticide in current use to be detected in GBR sediment samples collected away from river mouths (Haynes *et al*, 2000). Preliminary investigations indicate that short-term exposure of the sea grass *Halophila ovalis* to diuron causes leaf loss and reduced photosynthesis (Ralph 2000). The effects of diuron on corals are presently unresolved. Contact due to intake of sediment-bound diuron by suspension-feeding nearshore corals (Anthony, 2000) is likely. A recent pilot study with corals suggests diuron exerts lethal effects at high concentrations, and depressed photosynthesis in *Acropora cervicornis* exposed to environmentally relevant levels of dissolved diuron (Negri, in prep).

There is a considerable amount of field and laboratory data linking freshwater runoff, eutrophication and sediment loading to reduced reproduction and recruitment success of corals:

- decreased fecundity in adult colonies (Tomascik and Sander 1987b),
- decreased fertilisation success (Richmond 1993, 1997)
- increased larval mortality (Gilmour 1999)
- decreased larval settlement rates (Babcock and Davies 1991, Babcock and Smith, in press)

- decreased juvenile densities on suitable substrate (Tomascik 1991, Hunte and Wittenberg 1992)
- increased post-settlement juvenile mortality (Birkeland 1977, Bak and Engel 1979, Sato 1985, Sammarco 1991, Wittenberg and Hunte 1992).

Collectively, field and laboratory studies indicate that enhanced sedimentation or eutrophication reduce the capability of hard coral communities to re-establish local cover dominance after disturbance events. Open space on disturbed reefs is initially occupied by turf-algae and macro-algae. If grazing pressure is naturally low, or reduced by disturbance or fishing, algae continue to monopolise reef space, inhibiting recovery of coral assemblages. The growth of algae on inshore reefs of the GBR is generally assisted by enhanced nutrient availability (Russ and McCook, 1999; Schaffelke, 1999; Schafelke and Klumpp, 1997, 1999a,b), though there is contradictory evidence for higher algal growth rates at inshore reefs in the GBR (McCook, 1996). Recruitment of some perennial macro-algae is inhibited by excessive sedimentation (Umar *et al*, 1998).

Field studies carried out in Hawaii (Kaneohe Bay,) and in Barbados demonstrated the harmful effects of chronic eutrophication on coastal reef systems and the mechanisms which led to the deleterious changes. At Kaneohe Bay, eutrophication was not the immediate cause of coral mortality. However, after the disturbance, there was a comprehensive failure of hard corals to re-establish on the eutrophied, disturbed sites. Significantly, removal of the eutrophication source caused a direct, though short-term, improvement in water quality and allowed coral community recovery to begin. Subsequent recovery has been set back by recurrent disturbances and a decline in water quality due to non-point sources of nutrient. At Barbados, a significant reduction in coral recruitment near eutrophied sites was demonstrated.

Considerable effort has been made to investigate effects of elevated nutrient concentrations (e.g. NH_4^+, NO_3^-, PO_4^{3-}) on coral physiology and health. Experiments using environmentally relevant nutrient levels have yielded varied responses (reviewed by Szmant, 2002). Overall, only abnormally high nutrient concentrations, which would be very unlikely to occur, appear to have a direct harmful effect on corals. The effects observed in many experiments are consistent with stimulation of the algal symbionts at the expense of the normal metabolic relationship between them and their coral host.

5.2.2 Evidence for disturbance of reefs in the GBR from land runoff

Currently, detrimental changes to coral reef s in the GBR cannot be unambiguously attributed either to excess nutrients or to sediment carried in runoff from well-defined point or regional sources. This is not surprising, as the GBR is a large and hydrodynamically active ecosystem. Kills or disturbances of nearshore reef systems caused by freshwater incursions or storms and their aftermath are a recurrent feature of the GBR ecosystem (Banfield, 1908; Rainford, 1925; Hedley, 1925; van Woesik, 1991; van Woesik *et al*, 1991; 1995; Ayling and Ayling, 1995). More recently, nearshore reef systems have been subject to substantial disturbance from bleaching due to warmer water temperatures and from crown-of-thorns starfish outbreaks. Significant nutrient inputs which affect water quality in the coastal zone are seasonal and episodic (Devlin *et al*, 2001, 2002). Dissolved nutrients introduced into coastal waters are widely dispersed along the coast by river plumes and currents (King *et al*, 2002). Terrestrial sediments, with associated nutrients, however, are retained within the nearshore zone (Gagan *et al*, 1987; Lembeck and Woolfe, 2000; Maxwell, 1968).

Because of a historical focus upon mid-shelf and offshore reef systems, nearshore reefs in the GBR have not been widely or systematically surveyed until recently. Only one nearshore reef (Pandora Reef) has been systematically observed for as long as 20 years.

The extant evidence for runoff effects on reefs in the GBR is circumstantial. In the absence of recent disturbance by natural processes (cyclones, bleaching) on coastal and nearshore reef systems, non-extreme locations (e.g. Broad Sound; Kleypas, 1996; van Woesik and Done, 1997) are or once were characterised by active reef accretion (van Woesik *et al*, 1999), high levels of coral cover and high coral species diversity (Veron, 1995; Fabricius, unpubl. data).

Recently, Fabricius (in prep.) has compared communities on nearshore island reefs adjoining the wet tropics (16-18°S, such as Russell Island, Dunk Island, High Islands, Frankland Islands), which are now exposed to near-annual river plumes from catchments with significant agricultural development (sugarcane, horticulture, grazing), with reefs on nearshore islands at a similar distance from the coast off Cape York Peninsula (14°S). These northerly reefs are exposed to runoff from catchments where there is some cattle grazing but negligible vegetation-clearing or agricultural development. The two sets of reefs are characterised by significant differences in the extent of coral and macro-algal cover, coral community structure, biodiversity and coral recruitment. Overall, the northern reefs have higher levels of coral cover, higher coral diversity, higher levels of larval recruitment and higher levels of recruit survival.

5.2.3 Recent evidence for runoff related changes in GBR coral reefs

5.2.3.1 Properties of Inshore Reefs of the Wet Tropical Coast and Princess Charlotte Bay (unpublished data by K. Fabricius)

The graphs below show a comparison of the coral communities on reefs exposed to terrestrial runoff from agriculture in the Wet Tropics (WT) with reefs in Princess Charlotte Bay (PCB) (exposed to runoff from land that has little agriculture and limited cattle grazing).

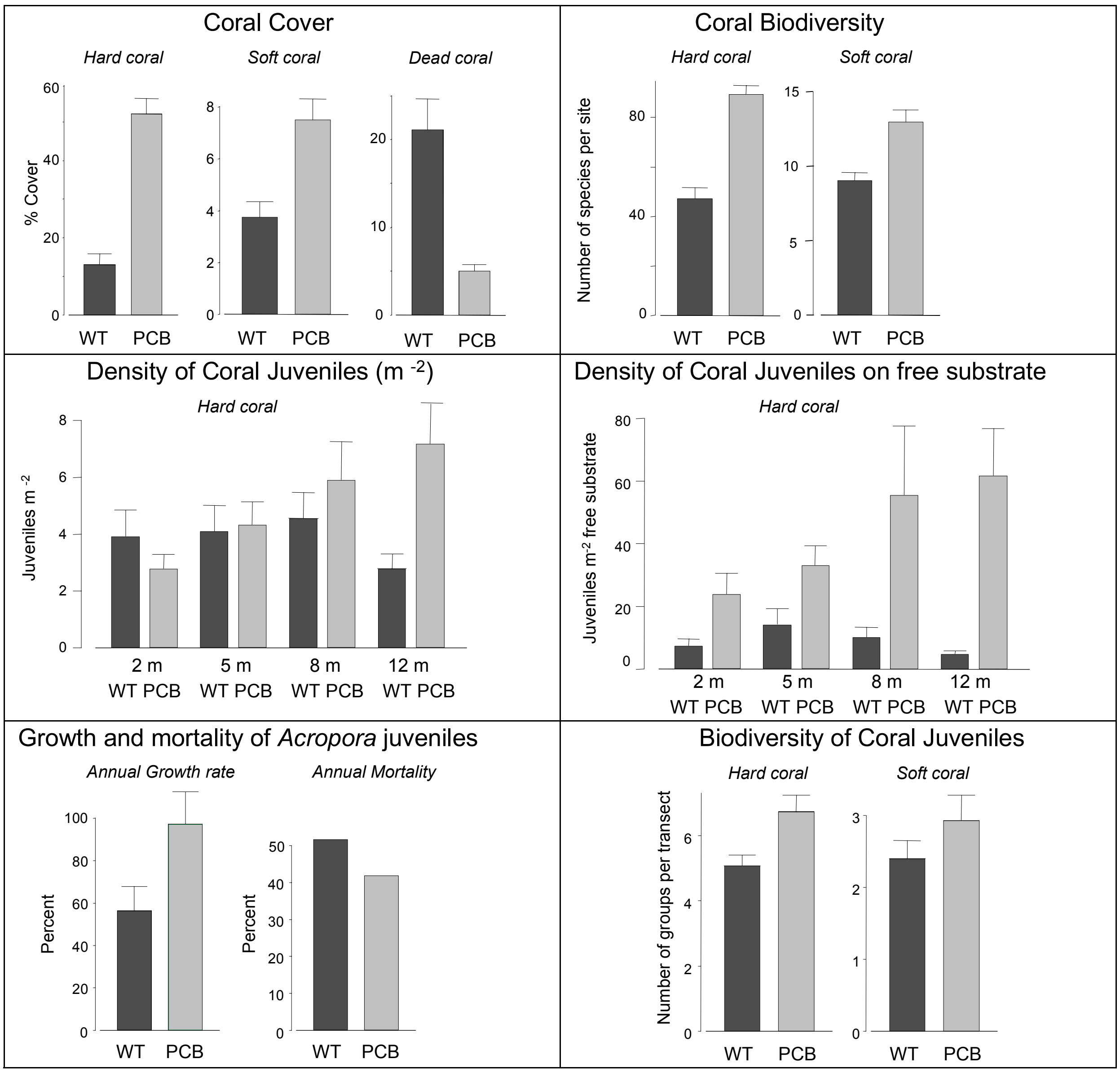


Figure 10. Ecological properties on inshore reefs in the Wet Tropical Area between Tully and Port Douglas (Dark Bars, WT) and Princess Charlotte Bay (Light Bars, PCB).

- Soft and hard coral cover: Estimates based on line transects at 8 m, 5 m and 2 m depth on 70 sites. Dead coral cover: estimates based on 48 swim surveys at 2 depths.
- Coral Biodiversity: Number of hard coral species, and number of soft coral genera encountered during expert swim surveys per reef (HC: 48 surveys at 2 depths, SC: 201 surveys at 5 depths from 0.5 m to 18 m).
- Densities of coral juveniles (m^{-2}): Estimates of density per square metre transect area, based on 122 belt transects at 2 m, 5 m, 8 m, and 12 m depth.
- Densities of coral juveniles on free substrate: Estimates of density per square metre of substrate suitable for coral settlement (i.e., excluding sand and live coral on which recruits can not settle). Data based on 122 belt transects at 2 m, 5 m, 8 m, and 12 m depth.
- Growth and mortality of *Acropora* juveniles: preliminary estimates based on the repeat survey of 196 tagged juveniles after a period of 5 months (Dec. 2001 – May 2002).
- Biodiversity of coral juveniles: Estimates based on 122 belt transects at 2 m, 5 m, 8 m, and 12 m depth.

5.2.3.2 Effects of "Marine Snow" and Sediment on Reef Organisms

Amorphous organic aggregates (known as "marine snow" or transparent exopolymer particles -TEP) are commonly observed in GBR waters. These aggregates span a considerable range in size, from < 0.1 mm to several cm. The organic matter which forms marine snow is derived from a variety of sources, including plankton (appendicularian houses), coral mucus, resuspended benthic organic matter and coalesced algal exudates. The sources, concentrations, distribution and composition of marine snow in the GBR are poorly characterised. However, marine snow is more common in productive coastal and offshore waters of the GBR. Suspended fine sediment may be incorporated into marine snow aggregates, forming "muddy marine snow".

Fabricius and co-workers compared the survival rates of four-week old hard coral recruits (*Acropora willisae*) after exposure to muddy coastal sediments, either with and or without enrichment from naturally formed TEP (Fabricius, Wild, Wolanski and Abele). About 33% of recruits died after 43 hours of exposure to TEP-enriched muddy coastal sediments (Figure 2), which had been applied in concentrations found on inshore reefs off the wet tropical coast. In contrast, little mortality was observed when recruits were exposed to muddy coastal sediments without TEP enrichment, or to TEP without mud, or to unfiltered sea water. Larval mortality increased to >80% when the quantity of TEP was tripled and sediment increased by 50%. Thus, coral recruits can survive short-term exposure either to low levels of TEP or to low levels of muddy sediments, but the combination of sediments mixed with TEP proved to be detrimental.

Concentrations of TEP were highest around coral reefs within 10 km of the wet tropical Queensland coast (latitude 16 - 18° S) in summer, the season of coral recruitment. TEP concentrations declined with increasing distance from shore. The study suggests that the characteristics of suspended particles and their short-term sedimentation both affect the survival of coral juveniles. These findings have implications for the capacity of inshore reefs to be recolonised by corals after disturbance.

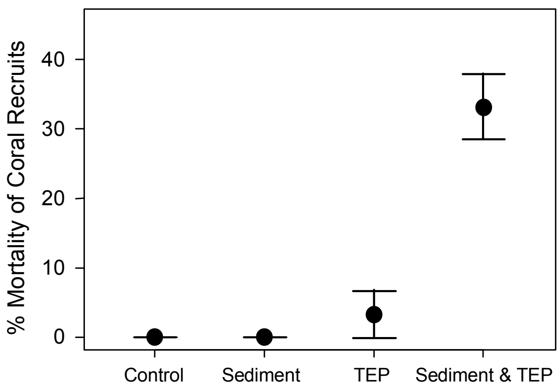


Figure 11. Percent mortality of young recruits of the coral Acropora willisae after 43 hours of exposure to muddy coastal sediment, (Transparent Exopolymer Particles) TEP-aggregates, or TEP adhering to muddy sediment ("Sediment & TEP"). Unfiltered seawater without added particles was used as a control. Data are mean mortality per run and treatment, ± one standard error. Each of the four runs included eight tiles carring live recruits (two per treatment). Concentrations of Sediment and TEP applied in the experiments are similar to those recorded on inshore reefs between Tully and Cairns in summer.

Enhanced nutrient availability is known to contribute to biologically mediated flocculation (Fabricius and Wolanski (2000). Estuarine mud, when resuspended in nutrient-rich near-shore water, can become bound to marine snow, and within hours can exert detrimental effects on small coral reef organisms. In a pilot study, estuarine mud was suspended in near-shore and off-shore waters of the Great Barrier Reef. As part of the study, the scientists video-recorded the short-term responses of coral (*Acropora* sp.), coral-inhabiting barnacles (family Pyrgomatidae) and copepods. In the off-shore water treatment, flocculation was minor, and aggregate sizes were ~ 50 µm. The test organisms were able to remove these small aggregates at low siltation rates (< 0.5 mg cm^{-2}). Corals struggled and produced mucus only at high siltation (4 - 5 mg cm^{-2}). In experiments using near-shore water, the suspended mud became aggregated into large sticky flocs of marine snow (200 - 2000 µm diameter). The organisms responded to a thin coat of deposited flocs with vigorous cleaning activity. After a short period, the barnacles stopped moving, calanoid copepods were entangled in the aggregates, and the coral polyps exuded a thick layer of mucus. Both barnacle and copepods died after < 1 h exposure; a short time compared with natural occurrences of marine snow deposition on coral reefs. This pilot study suggested that suspended mud and flocculated organic matter together can synergistically affect small reef organisms after short exposures.

5.2.3.3 Effects of Sedimentation on Coral Physiology

Philipp and Fabricius (in review): In this study, the effects of short-term sedimentation on common inshore corals of the Great Barrier Reef were experimentally assessed. In the laboratory, changes in photosynthetic performance (measured as dark-adapted quantum yields of photosystem II) in *Montipora peltiformis* were observed in response to various levels of sedimentation (0 – 234 mg cm^{-2}) and durations of exposure (0 – 36 h). The ratio of variable to maximal quantum yields of photosystem II (F_v/F_m – a measure of photosynthetic health) of sediment-covered fragments declined monotonically, reaching levels below 0.1 after 36-h coverage, while F_v/F_m in control colonies ranged from 0.67 to 0.71 and did not exhibit any temporal trend. Yields in *M. peltiformis* declined linearly in relation to the amount of sediment deposited (mg cm^{-2}) and the duration of exposure. Thus, prolonged low-level sedimentation caused photosynthetic stress similar to a short exposure to high levels of sedimentation (Figure 12). Colonies recovered from short-term, or low-level, sedimentation within 36 h, whereas longer exposure, or high levels of sedimentation, killed exposed colony parts. Burial stress was confined to coral tissue directly underneath the sediment. Field experiments comparing responses to sedimentation in 12 common coastal coral species showed clear differences in tolerances between species.

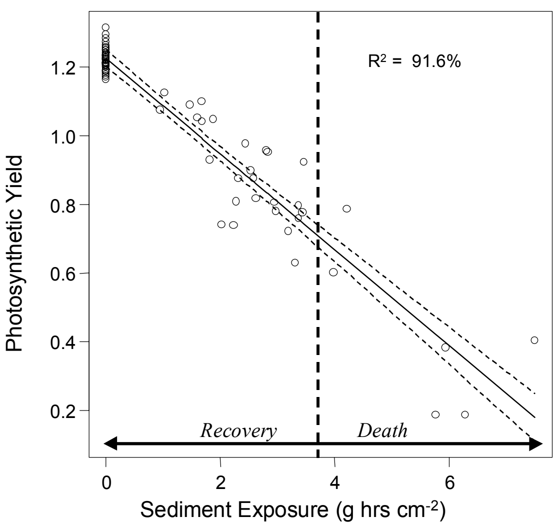


Figure 12. Photosynthetic yields (transformed F_v/F_m) in *Montipora peltiformis* as a function of sediment exposure (duration x dose). Each data point represents the photosynthetic yield of a colony after having been exposed to a given amount (0 – 234 mg cm^{-2}) of sediment for a give duration (0 – 36 h). The solid line represents the mean response, the dashed lines represent upper and lower 90% confidence intervals. The vertical dashed line indicates the sediment exposure threshold for this species, above which the coral dies.

5.2.3.4 Association between Sedimentation and Abundance of Coralline Algae

Fabricius and De'ath (2001b): Crustose coralline algae (CCA) fulfil two key functional roles in coral reef ecosystems. They contribute significantly to reef calcification, and they may induce larval settlement of benthic organisms. Percentage cover of CCA and environmental conditions were visually estimated on 144 reefs in the Great Barrier Reef between 10°S to 24°S latitude. Relative distance across the shelf and sedimentation jointly explained 84% of variation in CCA cover. Three regions running parallel to the shore were identified, with a mean CCA cover of < 1% on the inner third of the shelf, and > 20% cover on the outer half of the shelf, with a narrow transition region between the two (Figure 13). Within each region, the cover of CCA was unrelated to distance across the shelf, but was related to the sedimentation environment. CCA cover was relatively higher on reefs with low sedimentation. On the inner third of the shelf, the most sediment-exposed reefs were unsuitable habitats for CCA. The inverse relationship between CCA and sediment has implications for the recruitment of CCA-specialised organisms, and for the balance between reef accretion and erosion.

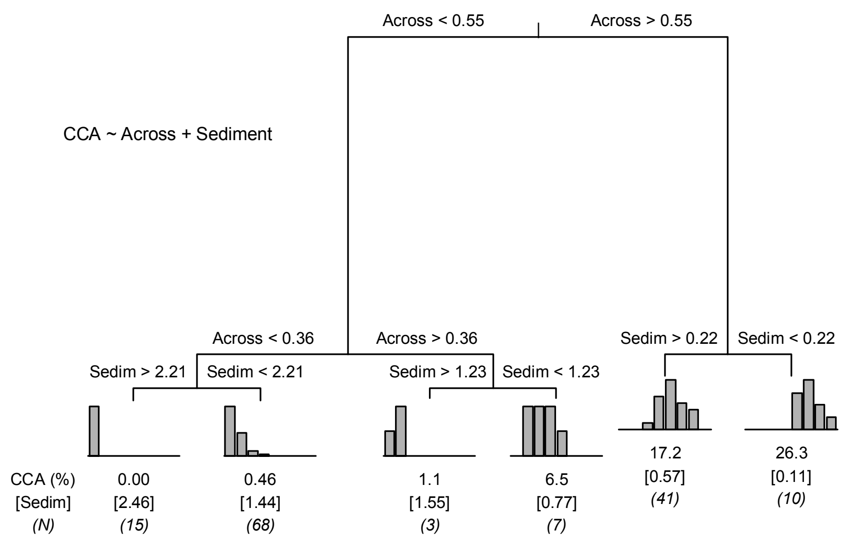


Figure 13. Regression tree explaining the percent cover with crustose coralline algae (CCA) on 144 reefs of the Great Barrier Reefs in terms of relative distance across the shelf (Across) and sediment deposits (Sedim, rated on a 4-points scale of 0 to 3). For each of the six leaves of the tree, the distribution of CCA cover is illustrated by a histogram, and the mean values of CCA cover (%), sediment rating, and the number of reefs are given. The lengths of the vertical drops at each split are proportional to the variation it explains. The tree defines three regions across the shelf (< 0.36, 0.36 - 0.55, and > 0.55 across), within each of which higher sediment deposits are related to lower levels of CCA. The tree explains 85% of the total CCA variation.

5.2.3.5 Association between Octacoral Biodiversity and Turbidity

Fabricius and De'ath (2001a): Spatial patterns and abiotic controls of soft coral biodiversity were inferred from extensive reef surveys on the Great Barrier Reef. Taxonomic inventories of soft corals, cover estimates for the major benthos forms, and measures of the physical environment were obtained from 161 reefs, spread relatively evenly along and across the GBR. Mid-shelf reefs between latitudes 13° and 16°S were characterised by the highest taxonomic richness of soft corals. Taxonomic richness decreased with increasing latitude, and was relatively even across the shelf north of 17°S and south of 20°S. Soft coral taxonomic richness was low in areas of high turbidity, and low in inshore areas between 17° and 20°S. Total cover of both hard and soft corals was poorly correlated with physical and spatial variables.

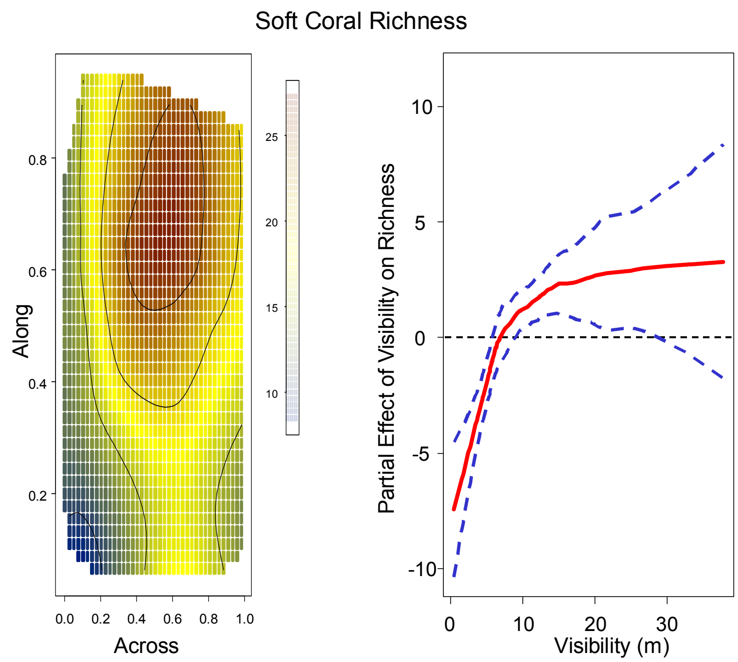


Figure 14. Left: Spatial contour plot of soft coral taxonomic richness (number of genera encountered during ~10 surveys per reef between 0.5 m and 18 m depth), indicating the high mid-shelf zone of biodiversity north of Port Douglas. Local regression spatial smoothers were used for the spatial plot. Right: Partial effects of visibility (turbidity) on soft coral taxonomic richness. The red line is the partial effect (i.e. the effect of visibility holding the spatial variables constant), estimated by a local regression smoother (loess, span of 0.5) (left panel). The blue dashed lines represent 95% confidence intervals, and the horizontal dashed line indicates the no-effects level. The plot indicates a relationship between low visibility (<10 m) and locally reduced number of soft coral genera. Further analyses (not shown) demonstrated that this effect was more pronounced for soft coral genera that contain zooxanthellae, whereas genera without zooxanthellae (thus no dependence on light for photosynthesis) were not affected by reduced visibility. For visibilities >10 m there was no effect on soft coral richness.

These findings have two major management implications:

(1) Turbidity and sedimentation affect the community diversity of soft corals at the generic level. The reefs with the highest soft coral richness are typically < 20 km from the coast, well within the range of terrestrial run-off. Increases in the width of the coastal band of turbidity (or the frequency of enhanced turbidity conditions) would potentially reduce biodiversity.
(2) Taxonomic composition of soft coral assemblages is more strongly related to environmental conditions than simple measures of total hard and soft coral cover. Taxonomic inventories appear to be better indicators of environmental conditions (and human impacts) than are assessments of total coral cover.

Collectively, turbidity and/or enhanced sedimentation directly influence the accessible depth range of corals, coral photosynthetic parameters, larval recruitment success and the survival of small or juvenile benthic organisms. A range of coral species can settle and grow in turbid coastal habitats; however, as turbidity or sedimentation increase, the diversity of coral assemblages decreases (Fabricius and De'ath, 2001; van Woesik and Done, 1997) and community reef-building capacity decreases (Kleypas, 1996; van Woesik and Done, 1997).

Despite modern increases in sediment delivery to the coast, turbidity and sedimentation in the coastal zone are still predominantly controlled by physical processes in shallow waters (wind waves, re-suspension) operating upon a large pool of coastal sediments deposited over thousands of years (Larcombe *et al*, 1995; Larcombe and Woolfe, 1999). The extent to which modern increases in sediment inputs have changed this sedimentation regime has not been resolved. The matter remains controversial.

5.3 Methodology of End-of-River Target-setting

5.3.1 Introduction

Target-setting is part of a larger adaptive management framework (Section 6.2) designed to improve resource management and thereby attain a desired outcome. Targets as objectives can be considered measurable forms of vision and environmental goals, and thus a measurable achievement of outcomes.

A draft document entitled "National Framework for Natural Resource Management Standards and Targets" (2001) has been prepared as part of the Intergovernment Agreement for the National Action Plan (NAP). The framework sets *aspirational targets* – a vision by the community for a region; achievable *resource condition targets* – the desired outcomes in the medium term of 10-20 years; and *management action targets* for the short term of 1-5 years.

For NAP, the targets should be:

- Based on best available scientific information;
- Benchmarked against current natural resource conditions and trends;
- Capable of being linked to management actions;
- Defined at appropriate specified scales and set in specific locations;
- Able to take account of cumulative impacts of actions and the dynamic nature of natural systems;
- Meaningful and achievable, reflecting the agreed natural resource outcomes sought;
- Measurable so that outcomes can be quantified;
- Time-bound, moving progressively towards agreed outcomes, within agreed time-frames, and providing readily identified benchmark reference points for future comparison.

For the GBR, targets were set in September 2001 based on current estimates of the sediment and nutrient loads from land-based sources at the mouth of catchments draining to the reef compared to estimated pre-European values.

The logic of the argument is that:

1. The GBR is an international icon of WHA status and legally has to be protected.
2. The reefs in the near-shore zone bordering the central GBR show significant signs of stress and even death.
3. Sediment, nutrients and pollutants resulting from human activity in rivers draining into the GBR are significantly higher than the estimated pre-1850 conditions.
4. The increased sediment and nutrient loads are regarded as the cause of the stress on the GBR.

5. The long-term effects may be catastrophic to a WHA.
6. A reduction in land-based loads is warranted based on the precautionary principle, and therefore
7. Targets have been set as a basis to implement measures to reduce the loadings.

Because the attainment of these targets will affect certain individuals, industries and practices, the scientific basis needs to be solidly justified and has therefore been detailed in section 5.2 of this report. Secondly, the basis of the quantum of the targets needs justification.

5.3.2 Targets as a Concept

Target-setting and performance-monitoring are widely used to set benchmarks for performance monitoring and are expected features of frameworks within ISO14001 standards. For the GBR, runoff targets need to consider the ecological values for the health of the Reef, as well as wider concerns.

This can be expressed by the term 'ecoefficiency' (Unilever ref). This approach considers the reduced inputs of materials, improved efficiency of practices and modification to outputs that can result in significant improvement to water quality and provide financial cost-savings in the practices. These targets can be amalgamated to provide an "end of catchment" integrated measure. Within the National Water Quality Management Strategy (2001), targets are based on protecting ecological values.

5.3.3 Difficulties with Targets

Targets can introduce unforseen distortions to current practices by concentrating on short term and directly measurable parameters that are not necessarily ecosystem-based or appropriate to the time response of ecosystem change. Ecosystems are inherently complex, and depend on compensating feedbacks of which we have very limited knowledge. Targets need to be appropriate to the expected end result and taken into account other impacts that could change as management practices are altered. Good target-setting therefore requires a conceptual understanding of the complex processes operating to ensure the overall plan can actually be achieved.

Targets are usually required to be SMART: **S**pecific, **M**easurable, **A**chievable, **R**elevant, and **T**imed (Anon 2001) but will they actually measure the appropriate response? Targets are achievable if the incentives are high or can be legislated. In the latter case, particularly where mutual gains are not available, distortions are more common and thus require independent auditing and risk-based adaptive management reporting processes (section 6.3) to achieve change.

Targets that are too specific or prescriptive can stifle creativity and local management; on the other hand, if they are too general they will not be appreciated at the smaller scale (e.g. paddock or river reach), which is where change is required.

5.4 Assessment of Appropriateness of GBR Targets

The current GBR targets specify an "end of catchment" sediment and nutrient loading for the major catchments draining into the GBR lagoon (GBRMPA 2001).

These targets have been developed based on estimates of current (2001) and pre-1850 exports of sediment and nutrients derived from multi-year monitoring of sediment and nutrient loads in GBR catchment rivers (Furnas and Mitchell, 2001; Furnas, 2002 - current outputs) and the SedNet model (Prosser, 2001) for pre-1850 sediment and nutrient outputs. The magnitude of the difference in loadings between pre-European settlement, taken as 1850, and those current at 2001 was achieved by changing the parameters in the model for gully and stream bank erosion by assuming neither events occurred before 1850. The model redistributes sediment and nutrients on floodplains and, for the purposes of the target-setting, was run in steady state using 100 year data to produce annual average figures. The degree of change between 1850 and 2001 was used as a basis to set the target reductions in loadings from the current loads for each catchment. This is an entirely appropriate approach for the number of catchments being considered and the short time frame available for the setting of the initial targets.

There are a number of aspects with this process that warranted detailed consideration by the panel. The aspects considered and the panel's conclusions are detailed below:

- major episodic events deposit most of the loads to the GBR Lagoon and average annual loadings tend to weight water quality targets to underestimate the impacts of major events. The estimates in the target document were normalised to volume of flow which has minimised this effect. Survival of corals under sediment inundation indicates a maximum of 3 days before death of coral polyps (Fabricius, Wild, Wolanski and Abele, in review) from which recovery may be very slow. Coral death results are likely to be a species-specific response and therefore will be difficult as a direct ecosystem measure.
- what constitutes an "end of catchment" value from the model is very difficult to measure spatially because:
    - ❖ estuaries process large quantities ofnutrients and sediments in all but extreme flow events, so that the loads and concentrations that enter the GBR are inherently highly variable and often lower than the loads calculated at the upper tidal limit. The SedNet model is based on delivery at the upper tidal limit, which is the upper point of estuaries. For the large episodic events, estuary processes are of limited impact since the river flows straight through the estuary and out to the shelf. Under these conditions, estuaries will process relatively little of the total flux.
    - ❖ overbank and floodplain flow can significantly improve water quality of the overbank component of total flow through trapping of sediment and nutrients on floodplains. Tropical rivers actually experience fewer overbank floods than temperate rivers (Alexander, Fielding and Pocock, 1999). This aspect is

catchment-specific and can be accommodated within individual catchment targets.

- the spatial deposition of sediments outside the river mouth in the GBR lagoon and the shape and movement of the sediment plume are variable but predictable. In addition, the sediment plume may represent less than 10% of the sediment that enters the coastal lagoon, with the remainder being deposited within 10km of the river mouth. More than 90% of the sediment load carried by rivers in north Queensland is transported as suspended load with virtually all going out of the mouth, and being deposited nearby. A significant fraction of this material will become active over longer periods through resuspension and thus can be considered a loading on the GBR lagoon.
- an "end of catchment" target (which is a computed value of an input to the GBR) is open to debate and will be less achievable where people's livelihoods are affected. The targets for the major rivers were based upon measured exports – calibrated discharge-export relationships – using measured data for 2-13 years). SedNet was calibrated at a national scale. Despite this, in most cases, predicted results were less than 2 times different from average input derived from measured values using a flow-weighted approach. Where additional data are available, there can be improvements to the predictions from the model as has been demonstrated in the Mary catchment. This is totally expected. The study of Heather Hunter using the HSPF model for the Johnstone catchment gave quite different results for N and P export from those predicted from the SedNet model. This is a small catchment with a significant area of rainforest and has used local calibration data to improve the predictions. Further investigation is required for this catchment.
- an end-of-catchment target must be translated to areas of high risk in a catchment with an ability to identify contributing areas so that local managers can act to minimise the loadings. Thus progressive targets and indicators need to be specified as discussed in section 5.6 of this report. Much more work is required for this to be finalised so as to minimise unnecessary actions in areas of limited impacts.
- So-called end-of-catchment locations need to be very carefully chosen to accommodate discharges from floodplain distributaries, wetlands and groundwater.

5.5 Characteristics of good targets (SMART – Specific, Measurable, Achievable, Relevant, Timed)

In view of the SMART attributes of good targets and indicators, an assessment of the utility of the current GBR targets is undertaken below

Specific

Specific values for identified spatial and temporal situations are required. As discussed, a computed value for an "end of catchment" target is useful for setting the broad indication of direction but requires specific points for measurement and validation over time. In view of the dynamics of estuaries, for load-based estimates, a value at the upper tidal limit of major rivers and other important discharges is the effective measure in representing the loads of material leaving terrestrial regimes and entering the GBR during major flood events. From the GBRWHA perspective, an end of catchment is the appropriate number to consider inputs into the reef lagoon. End of catchment targets give catchment resource users a specific focus on what can be related to upsteam management.

Measurable

As discussed above, there is no single location that is most appropriate for measurement. Measured values need to be repeatable and have longer-term meaning. In view of the variable flood dynamics and estuary and floodplain processing, and the importance of major episodic events, an integrated time–based, accumulated value is required at several points in the range-to-reef continuum. This will also be targeted towards identified 'hot spot' areas that contribute sediment and nutrients to waterways in quantities that are greater than expected.

Achievable

The reductions identified in the GBRMPA (2001) document are expected to result in significant social and economic issues that will need to be addressed. Also, by using an estimated pre-European settlement value, which could be quite harsh in some catchments, the degree of change required to meet targets may be unachievable in the medium-term. A staged time-base for achievement of targets will address these concerns. The precautionary principle needs to be applied across social, economic and environmental aspects to be able to assess the achievability of the targets. A way forward is illustrated in Figure 15?

Relevant

For individual landholders, an end-of-catchment target needs to be readily related to any 'hot spot' areas in the catchment, as these areas could skew the aggregated value and, thus, the target. It will be necessary to integrate the impact of best management practices for specific landscape units and stream reaches, based on predictions and estimates within a social, economic and environmental context, in order to understand the expected benefit to cost ratio of applied management actions. (Thus significant resources will be required to identify areas of concern and to estimate the relative impacts of broad-scale low intensity modified practices versus limited scale high intensity remediation in the critical areas of the catchment.)

Timed

The largely episodic effect of the processes in the GBR catchments together with the long lag times in the response of these systems to any resource management change means that multi-temporal targets will be required to maintain sufficient involvement by stakeholders to achieve goals and to allow an effective adaptive management approach where changes can be assessed in relation to the achievability of the overall targets. Thus, a cascading hierarchy of timed spatial targets and associated management practices needs to be integrated into an end of catchment target.

5.6 Proposed approach to target-setting in GBR catchments

Targets for the GBR catchments and GBR lagoon will be affected by a combination of anthropogenic and natural causes, particularly extreme events. Most complex systems exist in a state of dynamic equilibrium, maintained by many feedback processes, in which small changes can greatly influence the state of the system. System theory indicates that it is often not possible to separate out the causes of change during the critical period of incipient instability, in which any small change could result in a large shift in the equilibrium. Thus, changes may be identified as multi-factorial because of the limitations in our ability to identify and include all of the contributing processes. The concept of trigger values and critical thresholds is not universally applicable near the critical state unless the series of feedback loops are well understood. Critical thresholds are useful guides and should be used as conservative indicators of likely changes of state which will be modified by other factors. The current ANZECC [Ref] trigger values for tropical waters are set too high for non-disturbed conditions. For example, most plankton would be saturated with nutrients at the trigger values and so would not grow any faster if more nutrient were added (assuming that light intensity remains optimal). ANZECC values are also irrelevant during flood events, when the system is not easy to control.

On this basis, evaluation of the trends towards achieving end-of-catchment targets will be quite difficult and will require a combined, convergent approach. Such an approach is proposed for the GBR with:

- improving trends in end-of-catchment parameters, including volume-specific export coefficients such as tonnes km^{-3}.
- ongoing monitoring of water quality objectives for the GBR lagoon and the GBR itself being used in a parallel approach as the basis for measurable indicators. While these are too insensitive some research needs to be targeted at linking end-of-catchment values with impacts.
- integration of catchment studies and modelling providing an identification of the high risk areas contributing major sources of sediment and nutrients within the catchments for identified actions. Studies on the effectiveness of various best management actions will provide suitable quantitative data.
- catchment modelling providing an overall proportioning of the inputs and outputs of the catchment. At this stage more than one model will be required to adequately handle the processes form range to reef.
- receiving water quality models developed to assist with the translation of catchment loads to receiving water quality, and to allow comparison with water quality objectives and targets

The water quality objectives which are set for the GBR need to specify temporal and spatial situations; there should be no reduction in light transmission (for photosynthesis) due to turbidity and minimal increase in nutrients, such that there is a minimal possibility of reduction in species biodiversity, which may include 'nuisance' or 'pest' algae. There are some issues to be resolved in this process, including the complications with wind-driven and storm-driven resuspension as opposed to plume turbidity and nutrients, macroalgae or other flora or fauna. Where the best indicator is likely to be a bio-indicator of some type, water quality data provide a context – and therefore should stay relatively constant. Impacts of changes on the essential food webs of supporting reef systems may be determining factors. Recovery indicators are seen to be better indicators than food webs since many species adjust. Further work is required here. A series of water quality objectives for the landform units within the range to reef continuum is required which collectively can comprise the GBR objective.

The outcome for the main GBR of a healthy functioning ecosystem can be used as the basis for target-setting requiring water with low nutrients and turbidity. The water quality parameters required for this are known/estimated to be turbidity <1 NTU, NO_x <1µg/l etc. – probably amplified with some exceedence criteria to deal with resuspension events

The evidence of Section 5.2 indicates a strong link between catchment discharge and death or destruction of inshore reefs indicating that a water quality currently measured as __ is too high and __ is necessary for these reefs.

Because of the uncertainty of translating these environmental values for "end-of-catchment" water quality to the paddock and river scale, we need to consider a mass balance approach looking at the stages from range to reef and targeting the inefficiencies and impacts of land disturbance in each of these regions. These series of approaches are given in Figure 15 below.

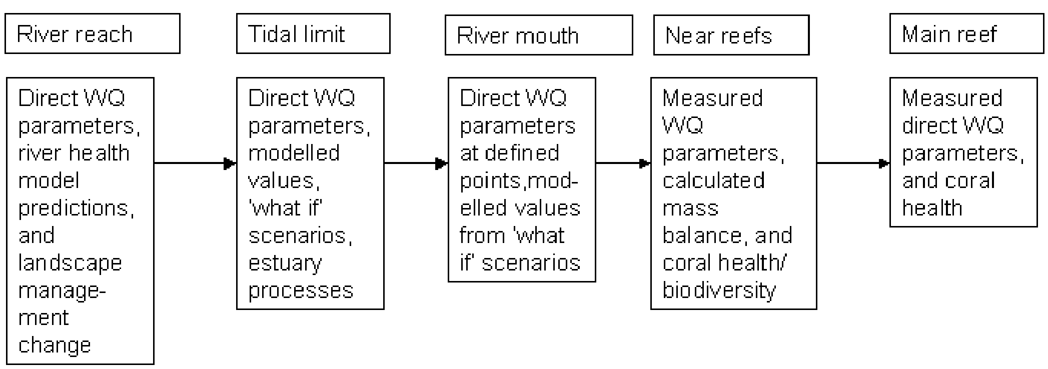


Figure 15. A series of targets, model-based predictive targets and measured parameters at various parts of the range to reef continuum. Land and water management targets for each region and protection or reclamation goals can be included.

The end of catchment indicator as discussed in the earlier Section 5.4 is a good overall indicator for catchment activities. The additional factors contributing to the river mouth indicators would suggest that indicators for this region not be included at this initial stage and further work be undertaken to evaluate their potential utility in the future.

For example, evidence of excessive nutrient application for sugar above that required for plant growth (Rayment, 2002) suggests improvements and cost savings are possible in the inputs.

Estuaries and associated wetlands are capable of processing considerable sediment and nutrient exports if not 'improved' or dredged and are an effective buffer against specific flood events and against increased runoff from land disturbance.

Target-setting for the GBR thus needs to consider the range of spatial and temporal factors that collectively impact on the GBR lagoon and then set values and targets for each of these landforms. Any targets should follow the SMART approach, and should be integrated so as to help in identifying improvements in efficiency and allow management to improve "end of catchment" targets. The target-setting process must be part of a formal adaptive management cycle with independent monitoring and auditing and formal processes for making the adaptive change over time. This is discussed further in Section 6.2. The adaptive target-setting approach is outlined in that section as well as Section 5.7 below.

5.7 Adaptive Target-setting Process

Once the process for adaptive management has been established and the target-setting commenced, appropriate targets will be identified to align with the values and objectives (see Section F…). Associated with this a commitment is required to evaluate the outcomes fo the performance and target monitoring in relation to the achievements of the implementation practices and the potential modifications to the targets. In modifying the targets, an appropriate approach is outlined below.

Taking the concept of Sherden (1998), as shown in Figure 16, and applying target-setting, we can define components as follows:

- The upper dotted line represents a target close to steady state pristine conditions as might be estimated from the SedNet or other model of an end of catchment mass load.
- The lower dotted line is the expected boundary if the current rate of development and current resource management practices continue into the future.
- The dotted lines are end of catchment targets (or other catchment-specific targets) based on the convergence of current knowledge, modelling and predictive "what if " scenarios which are then modified over time through monitoring and the adaptive management process. These targets will be set as both short- and long-term targets but will be reviewed and adjusted at, say, five-yearly intervals based on independent auditing of outcomes.

- The bold jagged line is the expected progress towards the set target, given appropriate incentives and requirements.
- Diversions from the bold line are possible events (within the overall area of probable events) that, through monitoring of targets and associated indicators and research, the likely causes and the risk of their occurrence can be quantified.

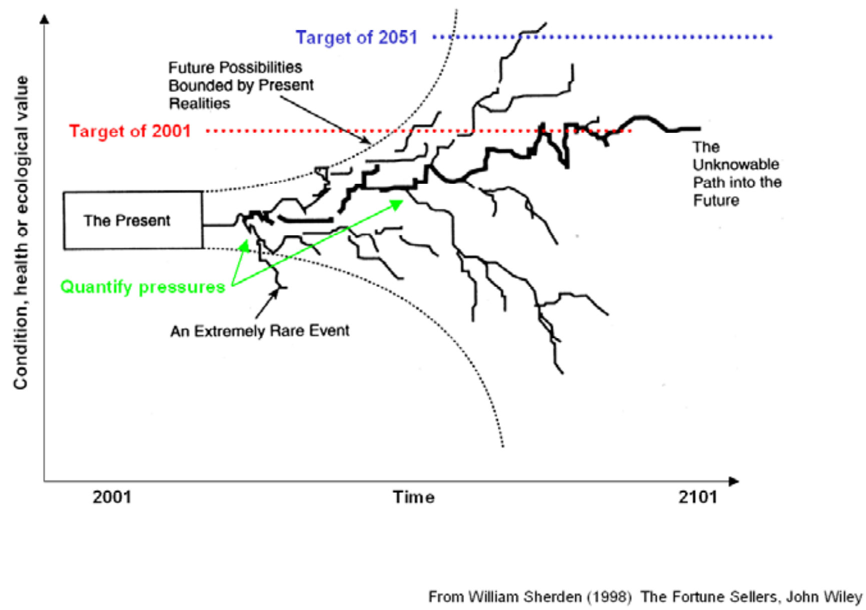


Figure 16. Conceptual understanding of target-setting in relation to possible boundaries and timeframe.

6. RESEARCH CAPABILITIES, GAPS AND PRIORITY RESEARCH NEEDS

The Panel has indicated its recommendation that a specific Workshop be held to identify the Monitoring needs to better understand all processes from land modification, through different types of land and water use, to the impacts of waters from the land on the Great Barrier Reef.

Establishment of a comprehensive Monitoring system, or modification of an existing Monitoring system, is seen as the priority need to provide systematic and continuing data, on which management plans and strategies can be developed, to ensure that land-use practices do not result in deterioration of reef water quality, which, in turn, adversely impacts on the GBR

The full analysis of current research activities requires additional consideration, as does the question of the scope of research capabilities, gaps in current research, and priority research needs.

We will provide a supplementary communication on the several components of this consideration, and will have further discussions with the Chief Executive Officers, Directors, Vice-Chancellors, etc of the relevant industry, research and government institutions, and community organisations. Some matters have already been considered. For example, the Panel believes that:-

1. A water quality and sediment pore-water survey should be commissioned in Reef catchments, targeting the discharge zone in coastal estuaries of municipal sewage treatment plants, with an emphasis on nutrients, including the levels of ammonia/ammonium, nitrate and total N, primarily to independently ascertain the "quality" of the discharge and its potential to promote or damage nearby aquatic fauna and flora.

2. Appropriate bio-physical, social and economic research should be undertaken to identify opportunities for improvement and barriers to the adoption and implementation of land and water management practices beneficial to catchment water quality. For example, measures to minimize the mobilization of sediments can be expected to include the avoidance of overgrazing, maintenance of around 75% ground cover across grazing lands, and attention to roadways, headlands and stream-banks in cropping areas where improved soil conservation measures have already been implemented. Collection/removal of cane trash as a possible green power fuel source, particularly in erosion prone areas, will need to be monitored carefully for impact.

3. All current fertiliser recommendations applicable in "reef" catchments (particularly those for sugarcane, vegetables, bananas and dairy pastures) should be reviewed, modified as necessary, and implemented as a matter of priority, with the goal of

optimising for the lowest possible application rate to just achieve the maximum yield or production plateau. This may require a new series of experiments containing sufficient fertiliser rates to fit multiple parameter linear-plateau yield models. Alternatively and expeditiously, the data for sugarcane might be generated from modeled simulations. Moreover, soil test recommendations should be discontinued that encourage additional fertiliser input when specified soil test levels exceed values known to be sufficient for maximum yield. This will, for example, require a change to Table 1 of Schedule 1 of the *Code of Practice for Sustainable Cane Growing in Queensland,* which presently specifies the use of 20 kg P/ha for plant cane at all soil P fertility levels above 40 mg/kg of air dry soil.

4. Research and development should be undertaken to produce and implement cost-effective monitoring technologies to ensure autonomous, wide-spread, long-term and consistent monitoring of key or proxy water quality parameters in the Reef and waterways of the Reef catchment. (This monitoring and the application of the results from the research would also be expected to provide methods to detect the origin of specific contaminants and pollutants transferred to streams and rivers, and/or to the Reef). In addition, the State and Commonwealth governments should establish a joint working group of experts to review and audit the outcomes and effectiveness of water quality monitoring programs on a regular and ongoing basis.

5. Technical (whole-of-system), institutional and social mechanisms for improving water quality in the Reef catchment and reducing contaminated runoff to the Reef should be trialed and demonstrated with a suitable level of support in a number of key or representative catchments (e.g. Fitzroy, Pioneer, Burdekin, Johnstone, Daintree) as a mechanism for encouraging wider adoption of effective approaches to improving water quality and reducing runoff to the Reef.

6. A concerted R&D effort should be undertaken to develop robust and effective modelling tools to support target setting processes and trade-off analysis of land management options in support of planning, policy formulation and implementation of improved land use. This would need to include:

   - Targeted data acquisition to validate and make the current sediment and nutrient delivery models more robust and scaled to information available in the various Reef catchments;
   - Additional process studies to improve our understanding of water quality effects and habitat modification on health of freshwater ecosystems in Reef catchments, and the resulting flow-on effects for marine environments;
   - Application of the refined modelling tools to determine the benefit of targeted intervention within key sediment and nutrient source areas in Reef catchments;
   - Application of the refined modelling tools to assist in options analysis at sub-catchment to local scales to identify priority actions for communities and industry.

While accepting that the sugar industry should move as quickly as possible to minimize or prevent the movement to waterways of sugars and other forms of highly labile carbon during and soon after mechanical cane harvesting operations, the Panel believes research is needed to assess the effects of acute and sustained levels of low DO in fresh waters on fish and crustaceans that interact between coastal waterways and reef waters, particularly to assess the consequences for biodiversity and population dynamics.

There is much more to consider in this part of the investigation.

7. POLICY, PLANNING AND MANAGEMENT OPTIONS FOR IMPROVING WATER QUALITY IN GBR CATCHMENTS

7.1 Introduction

Significant management changes are required in GBR catchments to minimize the risk of adverse impacts on the GBRWHA from terrestrial activities. Establishing values and target-setting is an important part of achieving this goal. Targets should be seen as a necessary condition for minimizing risk to the GBRWHA from land-based activities. At the same time, there is a range of well-known and understood management actions that also need to be implemented in GBR catchments to deliver improved water quality outcomes, as summarised below:

- Reduce soil erosion from grazing lands through improved grazing management.
- Within a farming systems approach: improve fertilisation techniques and match fertiliser application to plant demand; further reduce soil erosion.
- Upgrade urban and industrial waste-water treatment facilities and improve storm water retention in catchments to enhance contaminant-stripping processes in wetlands.
- Avoid further clearing or conversion of coastal wetlands; facilitate restoration of wetlands.
- Avoid further alterations to flow regimes and avoid further drainage in proximity to wetlands.
- Maintain fringing vegetation along stream and river channels and around other wetlands, and control aquatic weeds to safeguard wetland function.
- Avoid further clearing of riparian vegetation and revegetate cleared stream banks to restore natural functions of the vegetation (e.g., contaminant filter, bank stabilisation, habitat).
- Strategically re-allocate marginal land to enable creation of landscape components suitable for filter function.
- Develop and apply appropriate design principles for artificial wetlands, and for the re-establishment of wetland forests.

A broad range of publications providing details on specific techniques and options has been produced by government and industry groups. In some cases information on practical options to minimise downstream effects on water quality can be accessed directly via the Internet, e.g.:

- Design principles for riparian buffer strips: http://www.lwa.gov.au/downloads/PR010328.pdf
- Enhancing environmental performance of drainage in cane lands: http://www.clw.csiro.au/publications/consultancy/2000/herbert-report.pdf

- Environmental Codes of Practice in cane lands: http://www.canegrowers.com.au/environment/codeofpractice.pdf
- Improved land management on grazing lands: http://www.mla.com.au/content.cfm?sid=109

Many of these activities are already underway and are supported by industry codes of practice, best management practices and individual as well as community initiatives (eg Integrated Catchment Management and Landcare). However, it is clear that there remain many impediments to change and if targets and management actions are to have positive outcomes for water quality in GBR catchments, at least three sufficient conditions need to be fulfilled concurrently:

1. Supportive policy and planning frameworks based on a 'whole-of-government' service delivery model.
2. Effective regional partnerships that provide a basis for adaptive management in GBR catchments.
3. Practical incentives to foster on-ground actions that improve water quality.

Figure 17 provides a conceptual framework for these and their points of interaction.

Recommendation 1: At a 'whole-of-GBR' level, a supportive policy and planning framework needs to be developed to enable a 'whole-of-government' approach to water quality improvement. A core element should be the development of a 'whole-of government' service delivery model based on strong regional arrangements underpinned by real partnerships with industry and the wider community.

Recommendation 2: At the scale of individual catchments draining into the GBRWHA, adaptive management processes need to be established that enable government, industry and community participation and partnerships in planning, decision making, implementation and review.

Recommendation 3: Incentive instruments be established to enable on-ground action to improve water quality in GBR catchments.

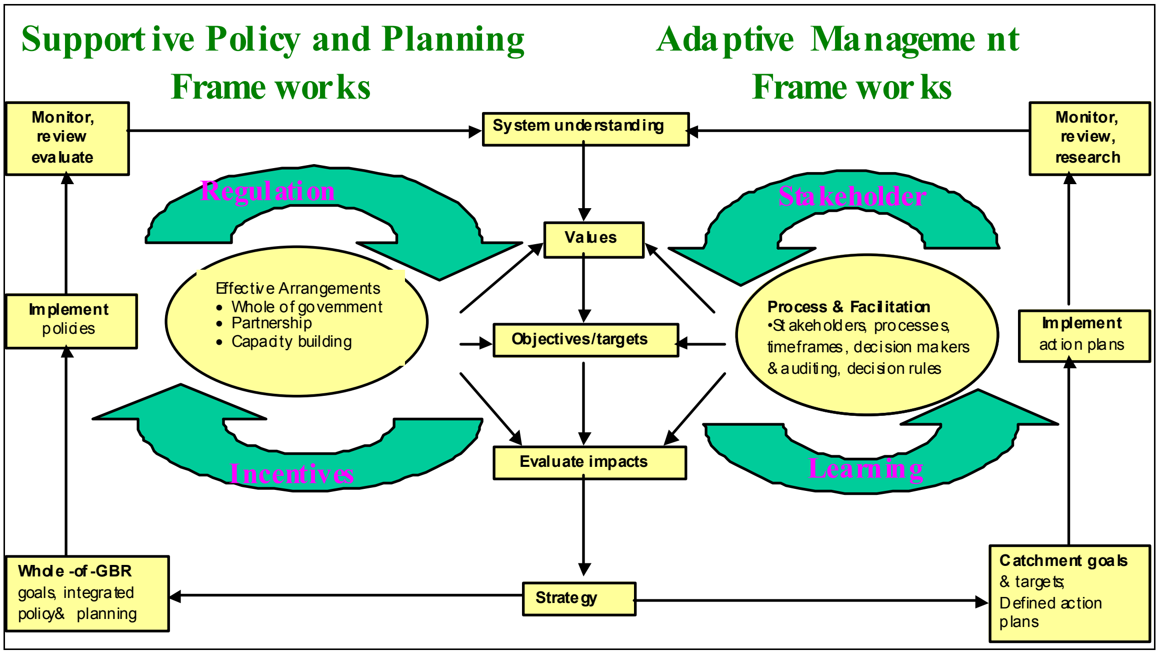


Figure 17. Integrated framework for 'whole-of-GBR' and catchment-scale processes for water quality improvement (Source: adapted and expanded from Bennett et al, 2002).

7.2. Supportive Policy and Planning Frameworks

In attempting to implement the goals of Ecologically Sustainable Development (ESD), various collaborative approaches to natural resource management (NRM) have been developed and fostered. Many of these have operated at regional level. Federal initiatives such as the National Landcare Program, Natural Heritage Trust (NHT) and the National Action Plan for Salinity and Water Quality (NAP) support ESD principles. At the state level Integrated Catchment Management (ICM) and Property Management Planning (PMP) processes have been implemented, while numerous initiatives by local government (e.g. Douglas Shire Sustainability Strategy) and industry have been prominent, although most approaches remain uncoordinated. Attempts at addressing water quality issues at the catchment and regional scale are posing enormous challenges for rural and regional communities, government and industry.

7.2.1 Adopting an Integrated Resource Management Paradigm

Any attempt to improve water quality in GBR catchments will require not only significant operational innovations, but also a conceptual shift toward adoption of an Integrated Resource Management (IRM) paradigm. The IRM paradigm recognises the interdependencies of natural systems, political systems, social and economic systems, and technology in addressing complex problems such as water quality management. IRM has a number of fundamental properties including:

- An integrated systems approach with a long-term perspective and broad spatial scale focus;
- The concept of 'the whole being more than the sum of the parts';
- Recognition of complexity and uncertainty in system interactions;
- Recognition of non-linear processes and connectivity between problems;
- Relevance of human and cultural context and diversity in values;
- People as part of the problem and not external to it;
- Management focus on the scale of landscapes, regions or catchments;
- Coordination of decision-making amongst stakeholders in government, industry and the community;
- Strategies for resolving conflict through negotiation; and
- Active involvement of the whole community to encourage community ownership of the problem and its solution.

IRM has evolved from recognition of the failures of current disciplinary or sectorally based approaches. IRM also supports the integration process moving beyond a purely coordination function to one that involves roles and responsibilities for both the implementation and the monitoring of integrated planning strategies and decisions on resource management at the catchment or regional level.

Adopting an IRM approach will contribute to improving water quality in GBR catchments by:

- *Fostering communication* across industry, government and community interests facilitated through the establishment of effective community-based forums that reveal the diversity of perspectives and the importance attributed to specific water quality issues;
- *Providing structures that foster cooperation, consensus and priority setting* amongst community and industry groups and government organizations, leading to more equitable decision making and more sustainable outcomes on the ground;
- *Facilitating coordination* of effort across government, industry and community organisations to achieve outcomes that have benefits for catchment stakeholders as well as for the environment, and which could not be achieved by any one group alone;
- *Integrating* IRM principles into government and industry planning (via plans accredited under the *Integrated Planning Act 1997*) to provide a basis for implementing a strategic direction for the catchment; and
- *Supporting an emergent strategic approach* of adaptive learning, involving key and influential community actors.

Recommendation 4: Government, industry and regional community representatives formally endorse the IRM paradigm as the conceptual underpinning for water quality management in GBR catchments.

7.2.2 Effective Regional Partnerships

Unlike other States with existing statutory catchment committees, Queensland is working towards a robust community-based NRM planning system, with NRM Regional Bodies playing a central role. The transition towards robust regional planning systems will require a substantive effort on behalf of Queensland government agencies at both the State and regional level as well as support from federal and local jurisdictions. This move to regional NRM planning represents a fundamental shift in the way the government hopes to resource and support progress towards ESD.

While final decision-making authority rests with government, effective regional partnerships between government, industry and the community offer significant opportunities to positively address water quality management in GBR catchments. However to make the transition from rhetoric to practice, two needs will have to be addressed concurrently:

1. Developing mechanisms and processes to support the participation of industry and regional communities in water quality management initiatives.
2. Enhancing the capacity of government agencies to effectively deliver services to regions.

These are discussed in more detail below.

7.2.2.1 Supporting industry and community participation

There are a number of fundamental requirements for ensuring that effective regional partnerships are in place to support improved water quality in GBR catchments in the future. In particular, successful initiatives will need to ensure that they address the following requirements:

- *To be a process of influence.* Regional arrangements should not be seen as a vehicle for radical shifts in power relations within communities, but rather a vehicle for influencing policy agendas and the system of planning processes on NRM within government, industry and the broader community. This also means they need an accountability structure.
- *To support community learning.* Regional processes need to be seen as a way of community learning that will need time before results can be expected.
- *To be a partnership between government, industry and the community.* Regional initiatives rely on existing authorities and various programs and planning processes of State and Local Governments and private and non-Government sectoral activities to implement their plans and achieve their objectives. They require a partnership approach between different levels of Government, industry and the broader community. To make this work in practice, there needs to be agreement on the exact roles of community, industry and government. For example, Government needs to ensure that clear and consistent policy signals are given and that clear roles are established before starting any activity.
- *To ensure legitimate representation.* For regional approaches to work and gain credibility within the community, representation must be legitimate, inclusive and

accountable. Representatives must keep their constituents informed of the process, interact with their constituents to understand their perspectives, and represent their constituency's interests to the partnership.

- *To provide a community forum for coordination of effort, networking and social learning.* Regional arrangements can provide an effective and legitimate community forum for networking, both within the community and between Government, industry and the community. They can also act as a vehicle for the exchange of information and more informed and inclusive discussion on NRM issues and planning processes that link State Government, Local Government and various key industry groups. Decision-making in this forum therefore needs to be based on negotiated accommodation of explicitly stated interests and social learning of new shared perspectives, rather than entrenched positions.
- *To build trust and effective interactions amongst stakeholders.* The success of regional processes in precipitating action on environmental issues depends on the willingness of the participating individuals to build trust, deal sensitively with conflicts in the catchment community and work on maintaining productive interactions within the context of workable institutional arrangements. Local leaders play a highly influential role here.
- *To ensure fairness of process.* A key determinant of broader community acceptance of decision-making is the perceived fairness of processes and procedures as well as the fairness of outcomes that people receive. Regional processes can foster fairness through: (a) establishing a legitimate system of representation; (b) working towards the development of acceptable cost-sharing arrangements; and (c) establishing decision-making approaches that are based on processes that seek consensus amongst stakeholders, while respecting and accommodating on-going differences.
- *To provide an influential voice on NRM at the regional level.* Regional initiatives can play a key role of linking water quality principles and objectives into regional processes such as regional economic development, regional planning, cultural heritage and conservation management programs and processes.
- *To demand long-term government agency commitment to the process.* The success of regional initiatives is in part dependent on (a) government agencies resolving bureaucratic gridlock among the array of fragmented but inter-dependent agency-based policies, plans and programs; and (b) ensuring long term agency commitment to the participatory process. This will require capture of long-term political support, securing appropriate financial and administrative resources, and establishing workable institutional arrangements.
- *To provide a vehicle for integrating information relevant to NRM.* The two primary sources of information for regional processes are local knowledge and existing technical information held by State and other relevant bodies. Participation provides a central pooling of local knowledge through the wide diversity of stakeholder representatives involved in decision-making processes and related activities. Agencies are also repositories of technical information on the catchment but this information is fragmented and needs to be "shared" with other agencies, industry and local interest groups. A key challenge is to foster the

capture of relevant data on water quality issues and develop locally accessible mechanisms for integrating data and delivering information.

Recommendation 5: That a Taskforce be established to guide the implementation of effective regional arrangements to improve water quality in GBR catchments. The Taskforce will comprise representatives from federal, state and local government agencies, industry and the community. The Taskforce is to report directly to the Queensland Premier and Commonwealth Minister for the Environment and be chaired by the Director General of the Queensland Department of Premier and Cabinet.

Recommendation 6: That the Taskforce ensure that the requirements for effective regional partnerships identified in this Chapter are substantively addressed in regional water quality management initiatives in GBR catchments.

Recommendation 7: That the Taskforce ensures the provision of financial, policy and project management assistance to develop and implement supportive regional arrangements that lead to the development of regional plans in GBR catchments.

Recommendation 8: That the Taskforce seeks agreement from relevant State and Federal agencies that regional natural resource management plans will be the primary vehicle for implementing actions to improve water quality in GBR catchments.

Recommendation 9: That the Taskforce ensures the implementation of an independent auditing process that can report on the accountability of water quality management initiatives.

7.2.2.2 Building Government Capacity

While State and Commonwealth Governments have traditionally supported initiatives in many rural and regional areas of Australia, it is questionable whether they are supporting the community's capacity to participate. A key issue is how can government support regional communities to address water quality management issues and in so doing move from its traditional role as a regulator, educator or provider of technical expertise, to one of facilitator, partner, supporter or catalyst?

To address these challenges, government needs to develop a multi-level response to the dynamic nature of rural and regional communities. This response needs not only to improve the formulation and delivery of policy, but also to enhance governments' role in assisting communities build their capacity to manage change.

Government also needs to recognise the dangers associated with these new modes of operation. Potential pitfalls include:

- over-involvement in communities, selectivity in dealing with community members and the risk of co-opting community organisations.
- agencies not being sensitive about when it is appropriate to help communities build capacity.
- public servants, while encouraging community input, can become local "personalities" adding their personal power to issues.
- the commitment of time and resources to community involvement, once begun, can easily burgeon and not be simply reversed, and not all community members are able or willing to be involved with public agencies.

Acceptance of a new dual service delivery/community capacity building model also means that Government agencies themselves will need to engage in many of the same capacity-building processes as the communities they serve.

Recommendation 10: That State and Commonwealth agencies develop a joint service delivery model for water quality management in GBR catchments, where service delivery is achieved in a way that facilitates community and industry networks, partnership and capacity.

7.3 Developing and Implementing Adaptive Management Frameworks

In addition to developing policy and planning frameworks to support robust regional arrangements, the Panel considers that there is a parallel requirement for the application of adaptive management frameworks to support improved water quality in GBR catchments. We argue that adaptive management approaches will need to be developed as a partnership between government, industry and the community in each GBR catchment. Adaptive management can be defined as a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs.

The advantages of the adaptive management cycle are the processes to proceed, evaluate and change, when there are considerable gaps in knowledge and uncertainty, by specifying monitoring and adjustment of targets and associated management practices. It is more applicable than the precautionary principle because it explicitly incorporates a wide range of stakeholder involvement and negotiation, a system-level understanding and associated changes in management.

Adaptive management is a formal, systematic, and rigorous approach to learning from the outcomes of management actions, accommodating change and improving management. It involves synthesising existing knowledge, exploring alternative actions and making explicit forecasts about their outcomes. Management actions and monitoring programs are carefully designed to generate reliable feedback and clarify the reasons underlying outcomes. Actions and objectives are then adjusted based on this feedback and improved understanding. Additionally, decisions, actions and outcomes are carefully documented and communicated to others, so that knowledge gained is passed on, rather than being lost when individuals move or leave the area or organisation. Adaptive management is a process that has been designed to assist decision-makers make informed choices where scientific experiments are costly, impractical or yield inconclusive results.

A framework for adaptive management based on the processes in the National Water Quality Management Strategy that specifically incorporates the concept of targets and performance indicators and is compatible with the National Action Plan processes is shown in Figure 18. Figure 18a provides a general overview of the stages in the process while Figure 18b gives the details of the steps and the linkages. A range of tools and processes are available for each of the steps in the framework to ensure that appropriate outcomes can be achieved.

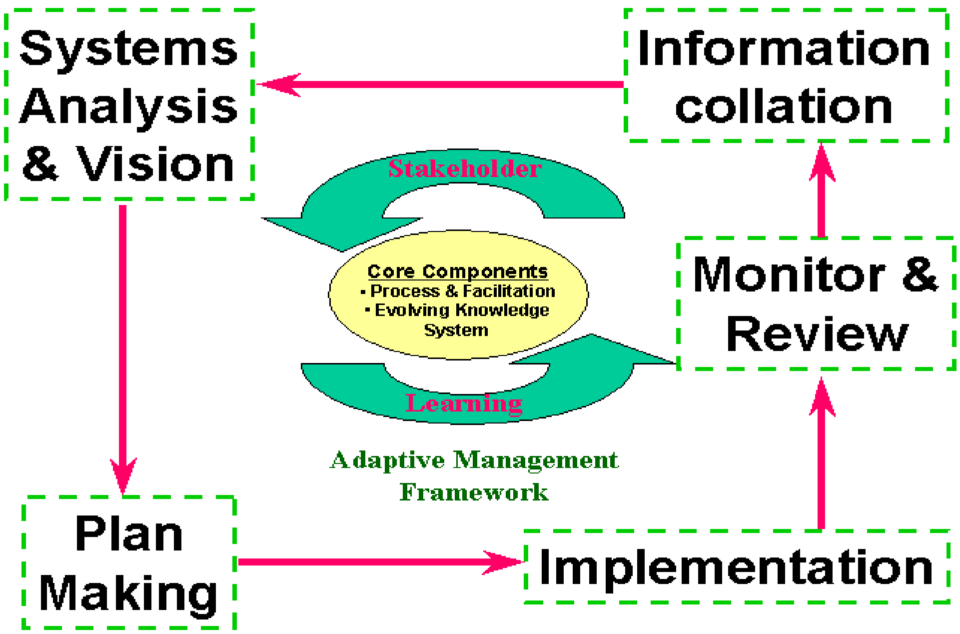


Figure 18a. Overview of the stages in an adaptive management process (Source: Bennett, 2002).

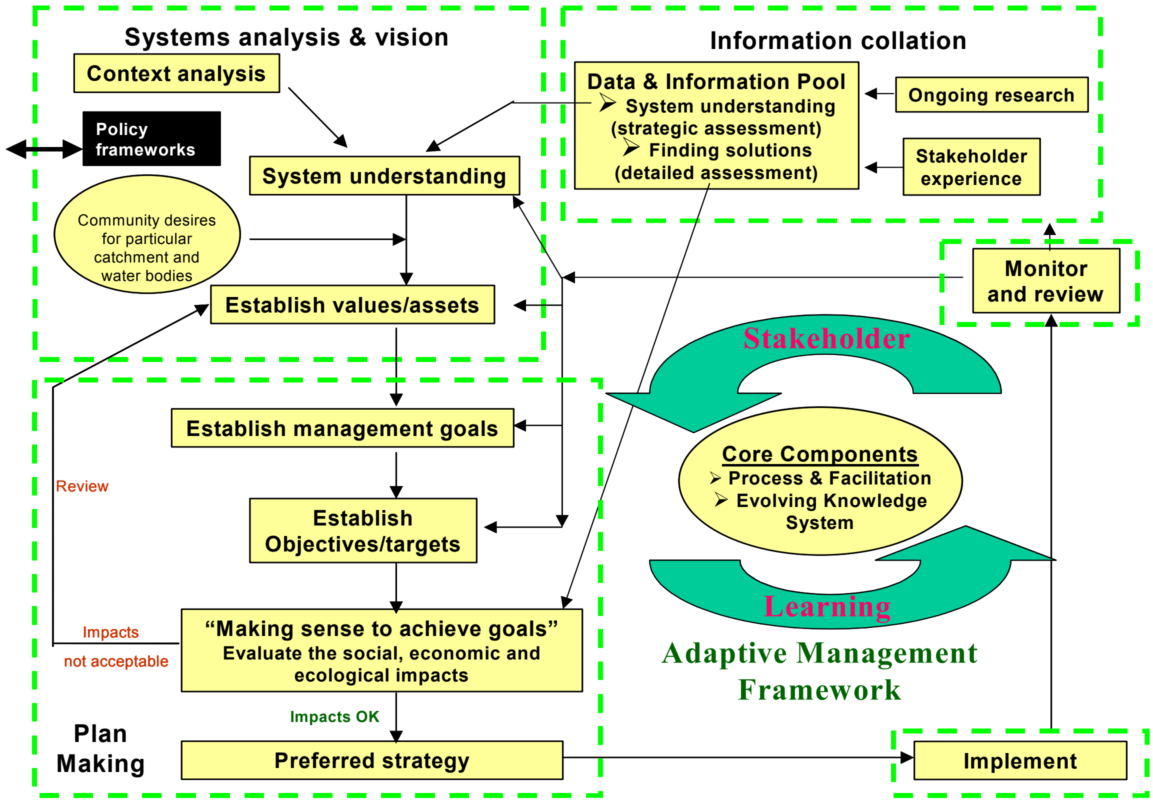


Figure 18b. Details of the steps and the linkages in the adaptive management framework and process that includes values, goals, targets, strategy, implementation and monitoring. (Source: adapted and expanded from Bennett, 2002).

There are several criticisms of the adaptive management process; however given the uncertainties in quantifying the cause and effect relationships for some aspects of the link between catchment management and impacts on the GBRWHA, the time frames for changes to become visible and the broad impact across society, some formal process of adaptive change and auditing is essential. Hence, an adaptive management approach for GBR catchments needs to:

- align closely with the processes of how environmental decisions are made in government and society;
- include non-scientific as well as scientific forms of knowledge as are often used in priority-setting and planning guidelines;
- use modelling along with other information in a convergent approach to provide the best understanding of situations. Development of more and more refined models has been a strong criticism of some previous approaches where agreement has not been possible;
- accept the concept of experimental policies rather than definitive policy positions that can cause unintended consequences by not considering the ongoing monitoring information indicating required changes;

- recognise that confounding factors occur in historical validation because when many changes occur at once this can preclude quantitative and accurate predictions of future scenarios;
- facilitate functioning partnerships to minimise institutional dysfunctionality and competing objectives, timeframes and performance of partners contributing to the outcomes to ensure longer term commitments to adapt policies and strategies in the adaptive management process;
- adaptive management focus needs to be on "creative thinking about how to make adaptive management an irresistible opportunity rather than a threat to established interests".

Recommendation 11: The Taskforce oversees the implementation and monitoring of an adaptive management framework and to appoint an independent auditing group to monitor targets and performance indicators across GBR catchments.

7.4. Providing Incentives for On-Ground Action

This section focuses on incentive instruments and examines their potential role for improving water quality in GBR catchments. Incentive instruments can be defined as administrative mechanisms adopted by government agencies to influence the behaviour of those who value the natural environment, make use of it, or cause adverse impacts as a side-effect of their activities. Incentive instruments include motivational, voluntary, financial, property rights and regulatory mechanisms.

It is clear that no single incentive will be capable of enhancing water quality in GBR catchments. Different incentives will be suitable for certain aspects of water quality management and will be capable of engaging different agents that have an impact on water quality outcomes. We argue that Australia has relied too heavily on too few incentive instruments in dealing with complex environmental issues. To seriously address the water quality challenge, improvements can be made in several areas. First, the policy instruments available need to be expanded — with a focus on introducing more market-based instruments. Second, creative use of existing instruments need to be used to attract further investment into sustainable management practices. Third, new institutions are required to facilitate investment opportunities.

7.4. 1 Options for Incentive Instruments

We have attempted to analyse a wide range of potential management instruments against evaluation criteria and guidelines, without imposing conceptual constraints on instrument choice. The term incentive instruments should be interpreted broadly and, although they play an important part, the list is not limited to market-based instruments. The spectrum of available instruments includes financial and economic instruments such as emission permit trading, user charges, developer contributions, performance bonds and management levies. They also include legal and regulatory instruments, including punitive measures designed to avoid misuse of resources, and precautionary standards. This section evaluates the instruments with particular respect to their applicability for the management of water quality. The advantages and disadvantages of each instrument are described and some examples of potential applications and policy mixes are given. We also examine alternative institutional arrangements that may facilitate the implementation of effective water quality management in GBR catchments.

7.4.1.1 Underpinning Principles

There are six underpinning principles that need to be considered in instrument design for GBR catchments. The following list is not exhaustive but includes the most essential elements:

- ***User pays*** *and* ***polluter pays***. The increasing awareness that natural resources are scarce and valuable has seen a move away from the notion that society should pay for their provision. Increasingly, the users of resources are having to pay the full cost of being able to use or consume the resource (as is the case with irrigation and domestic water in Australia). The notion that individuals and companies that want to dispose of waste products into the natural environment, should pay for this right to the extent that costs arising from negative impacts of this pollution are internalised (i.e. costed by the polluter), is gaining international acceptance.
- ***Cost sharing*** is a principle that takes a comprehensive look at all direct and indirect costs and benefits arising from the use of natural resources. In addition, it applies efficiency and equity considerations and requires that those groups in society who benefit from the provision of non-marketable public goods compensate the people who provide these goods. On this basis, contributions to be made by individuals, user groups and society are apportioned.
- ***Sense of community, ownership, and stewardship***. This principle is closely related to the concept of intrinsic motivation. It acknowledges the fact that individuals are heterogeneous and motivated in their actions by a myriad of philosophies, of which the pursuit of narrow self-interest is but one extreme abstraction. Pure altruism would be another extreme. The overall use of natural resources is the outcome of the sum of individual activities. It is important that individuals who comply with policy objectives for whatever motivational reason be reinforced in their behaviour. Intrinsic motivation goes beyond pricing and regulation, particularly in the case of open and common property resources.
- ***Adaptive systems***. Incentive instruments should be designed so that better information, as it becomes available, can be easily incorporated into the application of the mechanism. It is therefore essential to make provisions for conditions that specify when and how the framework will be reviewed.
- ***Ecosystem approach***. Rather than addressing individual problems by trying to rectify symptoms, it is crucial that systems behaviour be analysed and causes of problems be identified and addressed in a systemic manner. The underlying causes of a problem and its physical reality need to be understood in a holistic manner.

Recommendation 12: Commonwealth and State agencies jointly endorse the five key underpinning principles in designing incentives to address water quality in GBR catchments.

7.4.1.2 Analysis of Incentive Instrument Options

Governments have a range of instruments available to them to address water quality management problems. We have classified these instruments into four main categories that are summarised in Figure 19 and explained briefly below.

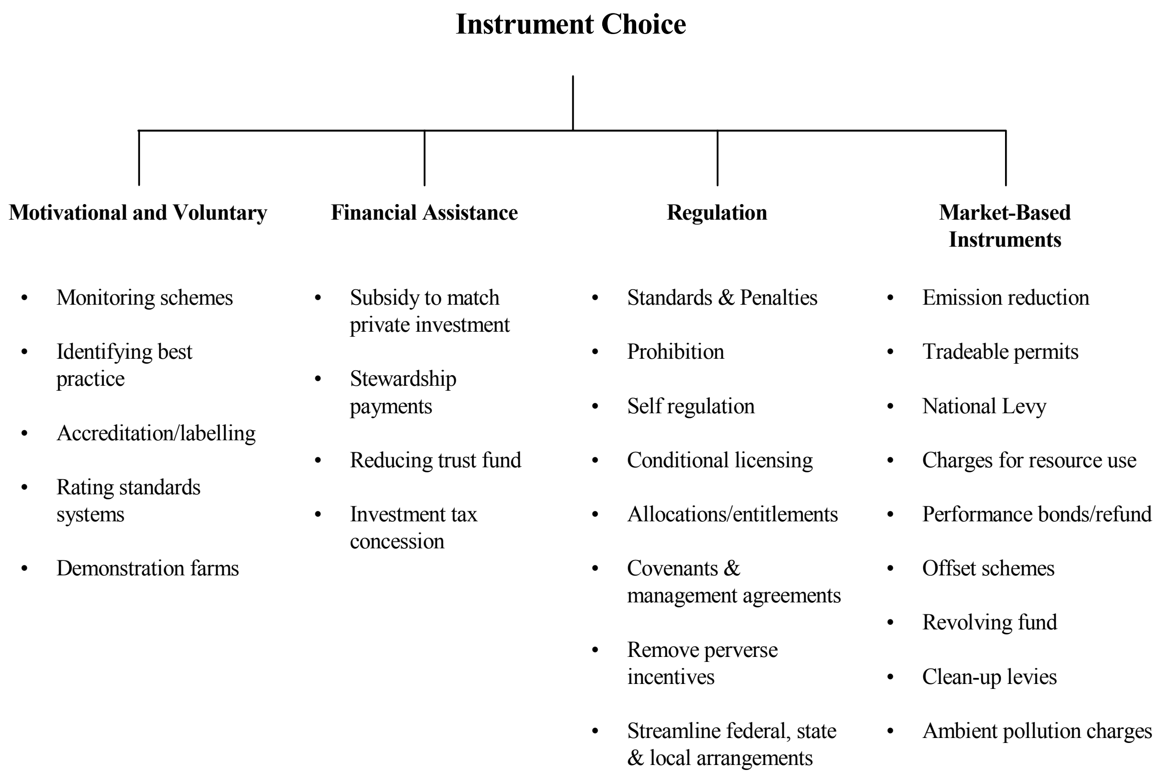


Figure 19. Categories of incentive instruments available for addressing water quality issues in GBR catchments

7.4.1.2.1 Motivational and voluntary instruments

These are aimed at increasing levels of knowledge and understanding or requiring voluntary action, are premised on the belief that environmentally responsible behaviour is far more likely to result when people have a basic knowledge of the issues at stake, and /or a commitment to achieving an outcome. Motivational and voluntary incentives encourage all stakeholders to share information and contribute to improved management. Motivational and voluntary incentives have already been used in some GBR catchments, and include activities such as integrated catchment management, the Herbert Resource Information Centre, and agricultural industry best management practices.

7.4.1.2.2 Financial assistance

These measures have been widely used to support environmental management in Australia, yet have had limited use in addressing water quality issues in GBR catchments (with the possible exception of environmental provisions in the Sugar Industry Infrastructure Package). A major issue with most forms of public assistance is the degree of difficulty in making sure that the public sector obtains value for money when it essentially becomes a purchaser of ecological outcomes on private property.

An example of an initiative in this area is the Conservation Reserve Program (CRP) established in the United States of America to protect wetlands and promote the conservation of highly erodible lands. Central to the program is the revegetation of sensitive areas to reduce soil erosion, improve water quality and enhance or establish wildlife habitat.

Under the CRP, farmers voluntarily retire environmentally sensitive cropland for 10 to 15 years. In return, the United States Department of Agriculture (USDA) makes annual rental repayments to farmers (to offset income losses, which arise from the land use change) and shares the cost of establishing approved conservation practices. The Federal government of the USA may pay up to 50% of revegetation costs (which includes grasses, cover crops, tree crops) and may make rental payments of up to $50 000 per annum per landowner during the rental period.

In Australia, the Victorian Government has recently announced a similar auction–based program for public funding of natural resource management issues. The Victorian Bushtender Trial aims to use an auction mechanism to award land management contracts through a competitive bidding process.

7.4.1.2.3 Regulation

Despite advocating motivational, social and market-based incentives, there remains an important role for regulation, because non-regulatory instruments are not always effective when they act alone. Regulations provide precautionary standards and an essential safety net to protect against the recalcitrant few who are not persuaded by other incentives. In any regional arrangements, it is crucial that industry and the community be given the opportunity to contribute to the development of standards. As regulatory incentives provide protection against those who do not respond to other measures, they are particularly important when threats to natural resources are likely to become irreversible – for example, in the case of land clearance on coastal floodplains.

Water quality management issues are indirectly addressed by *planning controls* embedded within the *Nature Conservation Act 1992*, *Environment Protection Act 1994*, *Coastal Protection and Management Act 1995*, *Fisheries Act 1994, Integrated Planning Act 1997*, *Land Act 1994*, and *Vegetation Management Act 1999*. Problems exist in areas subject to the provisions of the *Water Act 2000*, or on land with freehold tenure. An increasing regulatory role for Local government (e.g. through the invocation of planning controls if consent is required for subdivision, zone change and drainage development) provides some opportunity for improved water quality outcomes, particularly for the management of riparian and wetland areas. What is clear here is that some legislative reform is required to foster on ground action.

The State and Regional Coastal Management Plans being developed under the *Coastal Protection and Management Act 1995* have the capacity to provide the tools necessary to address management of a range of coastal and catchment activities. This Act addresses activities in the coastal zone, in its broadest definition, which would include the entire catchment of the GBRWHA. This Act was also drafted to work specifically with the main local government development, planning and assessment tools of the *Integrated Planning Act 1997.* There is an opportunity for the State Coastal Management Plan to require approvals under the *Coastal Protection and Management Act 1995* to include the submission of an accredited Property Management Plan (PMP). These PMPs are already a requirement for permissions under other legislation such as the *Vegetation Management Act 1999* and the *Water Act 2000* but at present only address very specific issues. In addition, Regional Coastal Management Plans could spatially identify constraints to development (e.g. definitively map wetlands) so that these are comparable with basic land information. This information could then be incorporated into local government plans creating the link from State level policy to local government decision-making processes.

Mechanisms are also required which place more *responsibility* on industry for determining the nature and extent of the serious environmental problems (eg acid sulfate soils) before review of an individual application for resource development. This may include developing and applying environmental impact assessment screening mechanisms that identify applicants whom must more adequately consider farm management and environmental issues with the submission of their land development applications. For example, under local government assessment processes, changes from grazing to intensive agriculture (including irrigated improved pasture) would be classed as impact-assessable development under local government planning schemes. Local government planning schemes could include an impact assessment requirement for agricultural activities such as drainage, filling or construction of levees. They could also include constraint mapping for development activities linked to regional plans. For any such development activities an applicant would also be required to submit a PMP as part of the assessment process. However, these measures would require changes to the *Integrated Planning Act 1997* to allow intensification in agricultural activities to be addressed as a ‘material change in use’ and for exemptions to be removed for activities such as drainage, filling or levee bank construction as ‘operational activities’ in agriculture. Some of these issues are presently being addressed in the development of IPA-compliant planning schemes in many GBR catchments. However, for improved management to occur, greater integration between local and state government, industry and the community must be a priority.

Since the mid-1990s, many industries have also sought to use *quality assurance* (QA) programs to improve the market quality of goods and services. Other industries have developed Codes of Practice to address environmental performance. In GBR catchments, the fruit and vegetable, sugar, dairy, pig and aquaculture industries have all developed environmental codes of practice. While these documents do not constitute a regulation, they do have legal standing via duty of care provisions under the *Environmental Protection Act 1994*. The sugar industry is pursuing the voluntary regulation pathway to an additional level through the development and implementation of the *Combining Profitability and Sustainability in Sugar* (*COMPASS*) Manual.

New internationally recognized *environmental management standards* (i.e. the ISO 14000 standards) have also recently emerged as a viable quality assurance management practice for land users. These international quality assurance standards will be a key element in Australia's global positioning in export markets. Use of ISO 14000 standards could play a key role in providing procedures to establish Australia's credibility in global markets as a supplier of products that are 'clean and green'. If so, this would represent an economic drive for building farming that does not harm. While Environmental Management Systems (EMS) solutions offer promise, it is not yet clear whether adoption of EMS will result in price premiums for landholders or whether EMS will be accepted by the wider community as best practice environmental management.

7.4.1.2.4 Market-based instruments

Two alternative types of property right incentives, namely covenants or management agreements, which cannot be separated from a specific resource, and licences to use water, which can be moved from one location to another, are relevant to water quality issues in GBR catchments. Management agreements can be used to reimburse people for the costs of resource management that cannot be recovered through normal market mechanisms. An example would be to encourage landholders to undertake specified management activity on private land adjacent to public conservation reserves or wetlands.

Conservation covenants are particularly effective in protecting remnant vegetation or wetlands, and can be used to underpin approaches such as management agreements. The use of conservation covenants can also be linked to other incentives – for example, the local government rating systems (for rate relief purposes), which recognise the value of uncleared land. Licence and permit systems are used where there is a need to link natural resource management with economic activity – pollution permits and land clearing, for example. In the design of licence systems, there is a need to place emphasis on the dependability of the licence to protect natural resources in an efficient and equitable manner. Central to this must be the establishment of effective monitoring strategies that not only assess specific activities but also general environmental performance.

The tax system provides significant opportunity for this, particularly when taxation incentives are recognised to be the most cost-effective means of encouraging altruistic investments in resource conservation by the private sector. Another method of ensuring that users pay is the imposition of levies and charges. These have the additional benefit of making users of natural resources aware of the cost of their activities. Acceptance of such levies is likely to be improved if the funds raised are clearly seen to be working towards resource management and protection, preferably by being placed in resource management funds administered by the local community and industry. Opportunities also exist for the implementation of financial incentives for retention and management of high value habitat to be dedicated as Nature Refuges or Coordinated Conservation Areas. Finally, government acquisition of riparian areas and wetlands of regional, national and international importance remains an option.

Tradeable rights systems are frequently advocated by economists, but generally have a poor track record. The benefits of transferable property rights are more apparent in areas where equivalent units (e.g. water) can be traded than where units traded may not necessarily be equivalent (e.g. wetland preservation schemes). Tradeable rights have a role in GBR catchments, but should never be seen as the sole solution. In virtually all cases, they need to be supported by an appropriate network of regulatory, financial and institutional measures.

In summary, it should be noted that the distinction between these categories is often blurred, as policy instruments generally comprise elements from across the categories and are rarely implemented in isolation. Table 15 provides a summary assessment of their advantages and disadvantages. While none of these approaches is new, not all of them have been applied to environmental issues in Australia and few if any have been applied to address water quality issues in GBR catchments.

Table 15 Incentive instrument options for improving water quality in GBR catchments.

Motivational and Voluntary			
Moral influence Best Practice Monitoring Scheme Accreditation Rating Systems	Alters behaviour by providing information.	Low cost. Enables market to make efficient resource allocations. Incentive to behave correctly and receive positive ranking (reputation).	Only limited leverage in isolation. May exclude eligible participants unfairly (particularly if accreditation or rating systems cost money).
Financial Assistance			
Subsidies	Payment by government against environment damage.	Encourages action to overcome environment problems	Externalities are not internalised by polluter. May reward poor performers. May pay those who would take

			action even without a subsidy.
Tax concessions	Alters price by the amount or rate of the tax.	Low transaction costs for firms. Low information requirement.	Monitoring requirement.
Regulation			
Standards and Penalties	Specific behaviour.	Provides outcome certainly – effective.	Monitoring requirement. May prevent innovation.
Prohibition	Prohibits activity occurring.	Provides outcome certainty – effective.	Monitoring requirement.
Conditional Licensing	Specifies the way activity is to be managed.	Provides outcome certainty – effective.	Monitoring requirement. Difficult to allocate licenses equitably.
Market Based Instruments			
Emissions and effluent charges or taxes	Changes based on the quantity of discharge.	Low transaction costs for firms of individuals.	Setting the charge at the right level. Monitoring requirement.
Covenants	Restricts use of resources.	Provides outcome certainty – effective.	Monitoring requirement.
Product charges	Levies on products that are harmful to the environment	Reduces the use of products that are harmful to the environment.	Setting the charge at the right level. Monitoring required.
Clean up or restorations levies	Levy to raise funds for clean up.	Levy funds are linked to environmental purposes.	Determining the relevant group to levy.
Water quality levy	No incentive to change behaviour.	Raise revenue and	Need to think about where to spend. Less flexible than existing tax base.
Performance bonds	Security lodged with government against environmental damage	Minimises the risk and potential costs of polluters defaulting on liability. Encourages restoration/clean up	Setting a realistic level of security.
Tradeable permits	Alters quantity, usually by constraining the supply of	Allocation of resources to the highest value use. Reduces information needs for regulators.	Establishing an efficient market. Setting overall level and initial allocation of permits.

	the regulated activity.	Offers incentives for compliance and mutual enforcement. Offers certainty but does not take account of cost. Good for issues with biophysical thresholds.	Transaction costs may be significant. May be anti-competitive.

Recommendation 13: The Taskforce commission an independent review of options for implementation of enhanced incentives for improving natural resource management and water quality in GBR catchments.

Recommendation 14: Commonwealth and Queensland governments enhance support to industries promoting development and adoption of codes of practice and guidelines for agricultural industries within GBR catchments.

Recommendation 15: The State Coastal Management Plan be amended to require approvals under the *Coastal Protection and Management Act 1995* to include the submission of an accredited Property Management Plan.

Recommendation 16: Regional Coastal Management Plans to identify constraints to development so that these are comparable with basic land information. This information to be incorporated into local government plans.

7.5. Threats to Achieving Planning/Management Options

7.5.1 Policy-Derived Market Distortions and Imperfections

Market distortions, some of which may result from a legacy of past public policy, can have a significant impact on the behaviour of individuals in GBR catchments. For example, land use planning policy for irrigated developments may fail to ensure that salinity hazards are factored into the prices paid for development rights, thereby distorting ‘markets’ in salinity mitigation. Similarly, policies of subsidising prices of timber from public forests may serve as a disincentive to invest in private plantations. Further examples of perverse policy impacts include:

- Public sector investment in water infrastructure, the specification of water allocations and water pricing strongly influence private investment in improved crops and pastures;
- Lease provisions often require land to be cleared, even where the economic benefits of clearing are transitory (or negative). Water management plans may

also encourage clearing by prohibiting flooding of native pastures, even in areas subject to natural flooding;

- Under-pricing of native forests by public agencies undermines investment in plantations and farm forestry, and discourages alternative economic uses of native forests, impeding investment in salinity mitigation and prevention; and
- Income tax provisions that undervalue livestock can contribute to overstocking, particularly because of the interaction with concessional treatment of stock sold or destroyed *after* a drought is declared.

Recommendation 17: The Taskforce seeks an urgent review of current NRM policy with a view to removing perverse incentives by 2005.

7.5.2 Adequacy of effort to meet the challenge

Increasingly, industries and regional communities are being placed under significant pressure in responding to NRM challenges. An increase in participatory initiatives is also generating substantial burnout and fatigue in regional communities. Evidence from the United States, where voluntary compliance programs and subsidies have been operating since the 1930s, clearly illustrates the ramifications of a failure to change institutional structures for implementing conservation programs. There is considerable evidence that the positive behaviour of farmers involved in programs aimed at controlling soil loss and improving water quality seldom continued once subsidies or compliance programs are removed. There is no reason to suggest that the behaviour of landholders in GBR catchments will be different unless institutional changes are made. Hence state and federal governments need to provide sufficient financial and human resources for local government, industry and the community to conduct water quality activities in an objective and effective manner.

Recommendation 18: Commonwealth and State agencies (via NAPSWQ and NHT2) should jointly provide financial, technical and project management assistance to local government, industry and the community to implement priority actions for water quality management co-operatively.

7.5.3 Legislative complexity

While it is clear that there is considerable legislation that could address water quality issues in GBR catchments, generally there is limited coverage for both policy and regulatory tools, especially with regard to agricultural activities. Hence, coordinating and streamlining arrangements between local, state and federal agencies is a key area requiring attention if water quality outcomes are to be achieved. The current planning system in a complex array of institutional arrangements at federal, state, regional and local level, to manage resource "planning" and "management". An example of the complexity that affects the sugar industry is given in Figure 20.

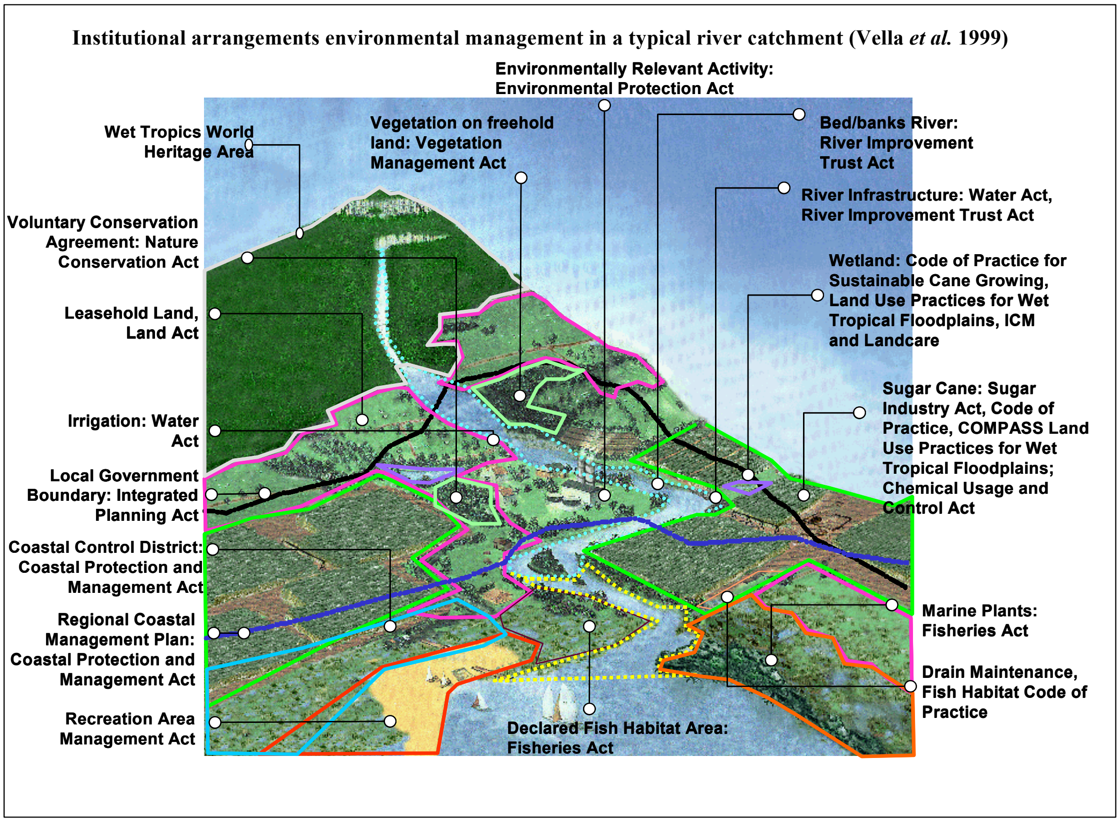


Figure 20. Example of the institutional complexity affecting the sugar industry in GBR catchments. (Source: Vella et al, 1999)

Industry stakeholders reported in submissions to this Review that their policy-making, planning and engagement activities all lack integration, and the result has been community dissatisfaction. Reform based on stronger regional arrangements (see Section 7.2) offers the best opportunity to address these issues. An alternative framework to address the integration challenge, based on the notion of “regulatory tiering”, is presented in Figure 21.

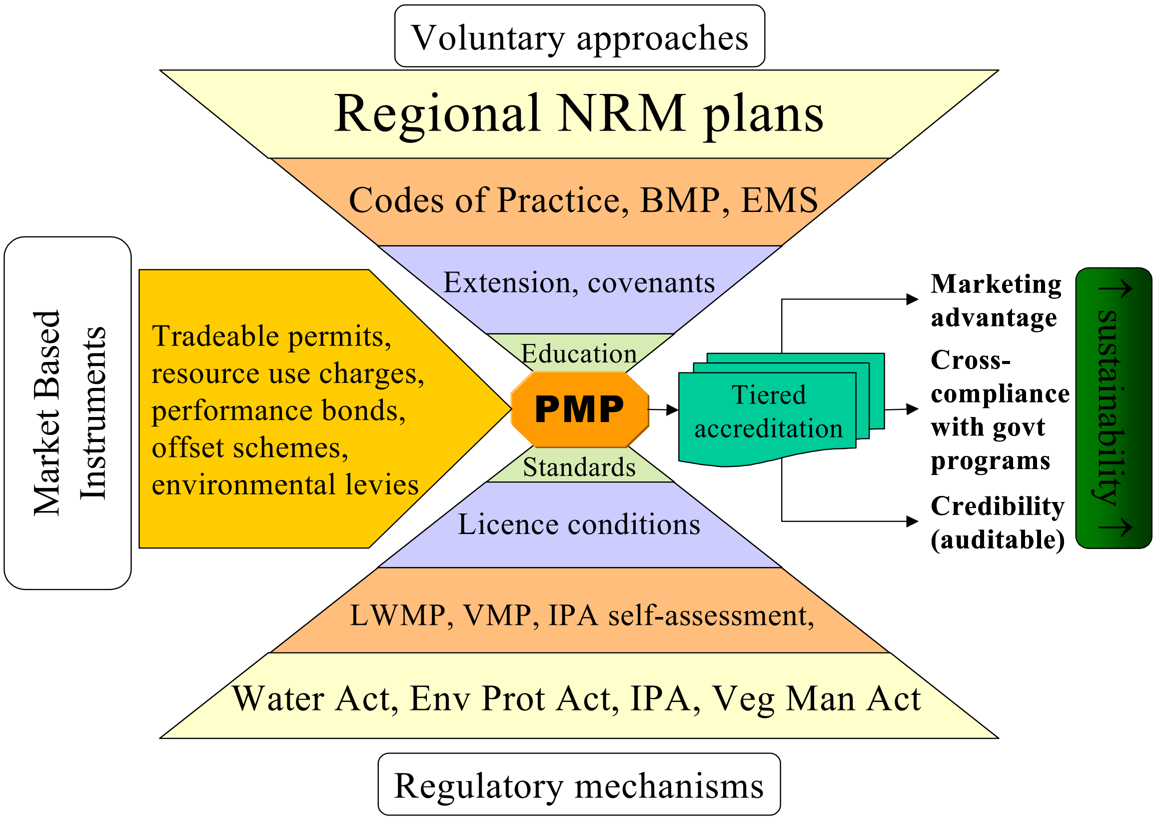


Figure 21. Suggested alternative framework of "regulatory tiering" to enhance coordination for water quality management. (Source: Ireland, 2002)

There are some areas where amendments to existing legislation are likely to deliver water quality outcomes in GBR catchments. These include:

- Leasehold land management legislation could include requirements for lessees to have accredited PMPs and regular auditing of property condition. This is likely to require amendment of the *Land Act 1994* to provide this capacity for review.
- The *Water Act 2000* could be amended to ensure that Water Boards are able to effectively engage all landowners in a catchment to ensure that water infrastructure such as drainage can be managed effectively on both a catchment and a local government basis.
- The *Vegetation Management Act 1999* could be amended to provide capacity for DNRM to manage all vegetation not just the major canopy species, especially groundcover. The issue here is that the Act does not adequately address loss of vegetation leading to potential exacerbation of erosion issues.
- Industry Codes of Practice and other initiatives such as Future Profit and COMPASS could be subject to review and auditing of both uptake and effectiveness. These codes would give direction to the necessary scope of matters to be addressed in PMP.

Recommendation 19: That the Taskforce undertakes an urgent review of current legislation and commissions an intergovernmental working party to explore options

for legislative reform aimed at integrating and streamlining legislation relevant to water quality issues in GBR catchments.

7.5.4 Complexity and Conflict - a Role for Science and Information

In order to address the range of issues concerned with water quality in GBR catchments, decision-makers require access to current scientific understanding of the biophysical impacts of alternative decisions or actions and effective means of collating, interpreting and using that information. Policy and planning cannot be expected to achieve societal goals in the absence of adequate knowledge relating to biophysical, economic and social factors that impinge on resource use.

Scientists traditionally respond to such challenges by advocating that further research is needed to fill gaps in understanding. However, a response such as this provides scientists with little opportunity to have a positive impact on water quality issues in GBR catchments. Only by being prepared to invest in understanding the context of decision-making and by helping decision-makers to use past and future research can scientists hope to have a significant and consistent impact on water quality practice.

Continued research may be needed to enable more informed and appropriate management of water quality in GBR catchments. Indeed, this review has clearly identified gaps in knowledge and understanding of physical, chemical and biological processes. Clearly, research is required for further understanding of the biophysical and socio-economic systems in which resource use occurs; however, research is also needed in the organisation of that knowledge to provide an effective basis for decision-making. A simple example of this is the development of an implementation guide for Adaptive Management being developed by the Coastal Zone CRC (see Figure 18b). The integration of information technologies such as GIS, expert systems, other knowledge-based systems and simulation modelling into decision-support systems can help in addressing these issues.

We argue that the challenge for research is to address the needs of decision-makers in three key areas: problem identification; data collection, collation and analysis; and rational use of the outputs of that analysis. Furthermore, there is a clear a role for increased collaboration in data capture, storage and distribution. Projects such as the Herbert Resource Information Centre where stakeholders from government, industry and community have invested corporately [coooperatively? RB] in acquiring key resource data and GIS provide an example for other GBR catchments.

Recommendation 20: A GBR catchments R&D Secretariat be established within the Taskforce to assist industry and regional communities in problem identification, data collection, collation, analysis and integration, information access, and use of the outputs of current and future R&D.

Recommendation 21: Commonwealth and State agencies develop strategic alliances with industry, regional communities and R&D providers to establish "demonstration sites" in the Fitzroy, Pioneer, Burdekin and Daintree (i.e. Douglas Shire) catchments to provide a focus for innovation in water quality management in GBR catchments.

7.6. Conclusions

Attempts to put into practice a comprehensive way of improving water quality in GBR catchments pose enormous challenges for communities, government and industry. This chapter has identified ways of addressing these challenges. For government, at stake is the question of how to include more voices in decision-making while recognising public and private interests. A parallel challenge is how to achieve broader societal objectives for the maintenance and preservation of the GBRWHA in a timely fashion while recognising that effective engagement with industry and regional communities is by necessity a lengthy process. There is a challenge to engage stakeholders whilst ensuring that we don't "fiddle as Rome burns".

The collaborative frameworks recommended in the Chapter will increase the chances that water quality can be improved in GBR catchments. They enhance accountability by strengthening citizenship skills, increasing compliance, making more resources available to decision-makers and, ultimately, increasing the likelihood of on-ground action. They also offer a pathway to avoid decision-making and implementation gridlock by suggesting options for improvement in a wide range of areas. Most of these suggestions come at minimal direct cost for government.

The pathways for developing supportive policy and planning frameworks, implementing adaptive management systems and providing incentives for on-ground action will not be easy. Leaders in government, industry and the community will have to deal with finding an appropriate balance between providing attention to substance (i.e. what should be done?) and providing attention to process (i.e. how should choices be made?). Procedures will have to be developed to guarantee consistent and effective public access to information, participation in environmental decision-making and access to justice. At the same time, there will be a need to minimise negative aspects such as policy paralysis, time intensity, cost effectiveness, unrealistic community expectations, inadequate representation, inaccurate information and silence of the majority.

Implementation of collaborative initiatives is acutely context-dependent. Established social networks and interactions, fundamental social values, institutional frameworks, historical problems and past actions and experiences have influenced and will continue to shape human association with natural resources in GBR catchments. Hence, participatory processes need to recognise these and work towards achieving outcomes by influencing existing networks, value systems and institutional frameworks rather than by creating a new set of structural arrangements. Core amongst these activities will be building and enhancing the capacity of rural and regional communities to participate sustainably. We contend that in order to address these issues, Government in particular needs to play a fundamental role in capacity-building in rural communities if participatory initiatives are to succeed in the future.

Industry will also have to adapt. Agricultural industries in particular will need to develop a strong culture of mutual support and information exchange with other stakeholders responsible for water quality management. They will also have to continue developing and refining locally-based industry regulations such as industry environmental codes of practice, best management practices and environmental management systems. In the longer term, there is also the challenge of applying the traditional agricultural business concept of managing an asset to water quality management activities, so as to establish strong market linkages for land and water resources management with enterprise outcomes.

If government, industry and the wider community can embrace the recommendations in this chapter, Queensland will be seen both nationally and internationally as a leader in the way in which it manages its natural resource base. In so doing, stakeholders in GBR catchments will be clearly able to demonstrate that environment-economy linkages can lead to positive economic, social and environmental benefits. This is something that cannot be demonstrated at the time of this review.

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ATTACHMENT 1

Memorandum of Understanding between the Commonwealth Government and the Government of the State of Queensland on co-operation to protect the Great Barrier Reef form land sourced pollutants

Preamble

The Great Barrier Reef World Heritage Area (the Reef) contains the largest system of coral reefs in the world. This diverse ecosystem also contains extensive seagrass beds, mangrove forests and sponge gardens. The ecosystem of the reef has a complex inter-dependent relationship with the adjacent river catchments. Many marine species rely on coastal freshwater wetlands and estuaries as breeding and nursery areas. The catchments adjacent to the reef have extensive land modification with a focus on developing land and infrastructure for urban centres, agricultural production, tourism and mining. This development has led to increases in pollutant loads in the rivers since European settlement.

General

1. The governments agree that the Great Barrier Reef is a nationally and internationally significant area with outstanding natural values that plays a significant role in the local regional and national economy.

2. The governments agree that the value of the area require protection and that a joint and co-operative approach to the reef's protection is required.

3. The governments agreed that the decline in water quality entering the reef lagoon poses a significant threat to the natural, economic and social values of the Reef.

4. The governments agree that as a first stage in the protection of the reef a major goal is stabilising and reversing the decline in water quality entering the reef lagoon as soon as practicable.

5. The governments agree that the precautionary approach needs to be used to protect the values of the reef, and that a risk management approach should be taken to address matters posed by declining water quality that might impact on the environmental, social and economic values of the reef.

6. The governments note that the major source of pollutants entering the reef lagoon emanates form land use activities in the catchments. The addressing of this source through integrated catchment management is the focus of this agreement.

7. The governments also note that there are a range of other sources of pollutants entering the reef lagoon that are, and will be, the subject of an going actions to reduce their impact on water quality I the reef lagoon. The potential impacts of these other sources and the action to constrain their compacts will need to be considered.

8. The governments further note that a significant amount of work has already been undertaken to develop water quality objectives and identify what actions are needed to protect the Reef. Governments agree that this information should be used in determining a joint way forward.

9. The governments agree that is tis important to build upon the existing participation and support of stakeholders in identifying and implementing approaches to protect the Reef.

10. The governments not the need for the public and stakeholders to be assured tat a joint approach by governments is being taken to protecting the Reef.

11. The governments note that there are other threats to the values of the Reef, for example impacts form fishing and tourism ventures, and that separate processes are underway to address these threats.

Operative

12. In order to achieve the goal of stabilising and reversing the decline in water quality entering the reef lagoon as soon as practicable, the governments will undertake the following actions:

    a. Jointly progress the development of a Reef Water Quality Protection Plan, with a target date for agreement of a draft plan by the end of the third quarter of 2002, wit a final plan before the end of 2002. The plan would include:
       - A clear statement of the objectives;
       - Clear statements of risks and priorities that arise form risk assessment, noting that connectivity is of significance in reef environments in assessing risk;
       - An analysis of the pressure on the reef lagoon associated with water quality in the catchments flowing to the reef, and what responses in these catchments are appropriate to protect the environmental, social and economic values of the reef;

- An outline of the range of activities currently undertaken in relation to water quality in the Reef catchments;
- Actions and responsibilities for implementation, including a commitment to work with regional bodies through the Regional NRM Planning process to develop more detailed actions to meet targets, including by upstream and downstream users;
- Consideration of short, medium and long-term responses;
- Costing for 'no regrets' actions and a financial plan;
- Clear auditing and reporting arrangements; and
- Noting that targets will be developed that are achievable and measurable through the regional NRM planning process where the emphasis will be on catchment by catchment approaches.

b. Co-operation in an assessment of options for short, medium and long-term actions to stabilise and reverse the decline in water quality, including the environmental, social and economic benefits and costs of those actions and implementation through the regional NRM planning process.

c. In developing the Reef Water Quality Protection Plan consider the role of measures such as pesticide and fertiliser chemical uses and practices; upstream and downstream industries for all relevant sectors; development, adoption, implementation, auditing and compliance with existing Codes of Practice, EMS systems and adoption of Property management Planning,; riparian management and re-vegetation requirements; wetlands management and rehabilitation requirements; total grazing pressure management and any other actions that may assist in stabilising and reversing the decline in water quality.

d. Determine, through the reef Water Quality protection Plan, the key sub-catchments where actions need to be undertaken, noting that the regional NRM planning processes will be defining specific actions to meet targets.

e. Jointly host a stakeholder consultative forum.

f. Jointly provide information to and engage stakeholders in consultations over particular aspects of the Reef Water Quality protection plan relevant to those stakeholders, with an emphasis on regional and industry by industry approaches.

g. Implement as a priority, agreed 'no regrets' actions that:

- provide a framework for prioritising further regional actions;
- build on industry specific initiatives aimed at improving the environmental performance of those industries, particularly reducing the discharge of pollutants to the reef lagoon;
- implement priority actions co-operatively with regional communities;

- develop the water quality audit framework build upon existing monitoring and evaluation processes being developed through the NRM Ministerial Council.

"No regrets" actions that are agreed should be of relatively low cost and have broad environmental, social and/or economic benefits beyond the benefit of protecting the reef lagoon. These actions should commence before the third quarter of 2002.

These 'no regrets' actions may include:

- Identifying the major sediment and nutrient sources in the catchments;
- Negotiating eco-efficiency agreements(s) with the fertiliser industry;
- Have the relevant regulatory agencies undertake a review of the current uses of key herbicides/pesticides used in catchments adjoining the reef;
- Promoting development and adoption of codes of practice and guidelines for agricultural industries within the catchments; and
- Negotiate and implement local water quality improvement actions where catchment communities wish to take early actions.

h. Co-operate in considering what water quality decline has occurred and what improvements are needed at the catchment and sub-catchment level, the science underpinning the analysis of the status of water quality entering the reef lagoon and the objectives and mechanisms for improving to water quality in the reef lagoon. Co-operation will include participation in and supporting consultation on water quality target-setting through the regional NRM planning process.

13. The governments agree to use best endeavours to ensure that public statements related to the implementation of the MOU will be jointly or co-ordinated between governments. Where separate statements are to be made or reports released, the government proposing to make the statement or release the report will consult the other government beforehand.

14. The Reef Water Quality Protection Plan will include the development of water quality improvement objectives and approaches to achieving these objective, to provide input into regional NRM planning processes, including target-setting.

15. it is expected that the regional natural resource management plans will be the primary vehicle for implementing the Reef Water Quality protection Plan at the catchment level.

16. In addition to these joint initiative the governments will also pursue initiative individually towards the joint goal. Governments will involve the other governments in pursuit of these initiatives.

17. The Commonwealth government will consider supporting a number of initial actions consistent with the Reef Water Quality Protection Plan. Possible actions include:

a. Undertake economic and socio-economic studies of the industries associated with the Reef and adjacent catchments, including information on the values of industries and information enabling the assessment of the benefits and costs of specific actions that are proposed;

b. Have the national Registration Authority undertake a Chemical Review of Diuron;

c. Provide through normal channels assistance and advice to stakeholders form relevant scientific, research agencies and management agencies;

d. Provide financial, policy and project management assistance to implement ‘no regret” actions agreed as priority regional actions under the NAP or NHT;

e. Provide as a priority financial, policy and project management assistance to develop and implement regional plans within the agreed NAP and NHT regions adjacent to the reef.

18. The Queensland government will consider supporting a number of actions consistent with the Reef Water Quality Protection Plan. Possible actions include:

a. Provide financial, policy and project management assistance to implement “no regret” actions agreed as priority regional actions under the NAP and NHT;

b. Provide as a priority financial, policy and project management assistance to develop and implement regional plans within the agreed NAP and NHT regions adjacent to the reef;

c. Estimating and supporting a scientific panel to investigate reef health and impact issues; and

d. Provide assistance to industry to refine and encourage industry adoption of current recommended practice.

19. To guide the development of the Reef Water Quality Protection Plan the governments will form a Commonwealth/State Steering Committee of senior officials.

20. A joint project team of officials form both jurisdictions will be formed to support the Steering Committee and the development of the Plan.

ATTACHMENT 2

GBR Reef Protection Interdepartmental Committee Science Panel

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Dr Miles Furnas	Principal Research Scientist Australian Institute of Marine Science Private Mail Bag No:3 TOWNSVILLE QLD 4810
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Prof Richard Pearson	Director Australian Centre for Tropical Freshwater Research James Cook University TOWNSVILLE QLD 4810
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Dr Christian Roth	Program Leader CSIRO Land & Water University Road DOUGLAS TOWNSVILLE QLD 4814
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Mrs Gaye Hill Secretary to the Panel	Department of Primary Industries 80 Ann St BRISBANE QLD 4000

ATTACHMENT 3

Presenters of Oral Submissions to the Panel

Name	Institution
Brisbane, 17 April	
Mr John Amprimo	Queensland Department of Natural Resources and Mines
Mr Noel Dawson	Chair of GBRMPA Reef Advisory Panel on Water Quality
Dr Norm Duke	Marine Botany, University of Queensland
Townsville, 30 May	
Dr Phillip Ford	CSIRO Land and Water
Dr Janice Lough	Australian Institute of Marine Science
Dr David Williams	CRC Reef Research Centre
Dr David Haynes	Great Barrier Reef Marine Park Authority
Dr Jon Brodie	Australian Centre for Tropical Freshwater Research, James Cook University
Townsville, 31 May	
Prof Richard Pearson	Australian Centre for Tropical Freshwater Research, James Cook University
Dr Katharina Fabricius	Australian Institute of Marine Science
Prof Bob Carter	School of Earth Sciences, James Cook University
Dr Laurence McCook	Great Barrier Reef Marine Park Authority and Australian Institute of Marine Science
Mr George Rayment	Queensland Dept Natural Resources and Mines and CRC Sugar
Brisbane, 11 June	
Dr Claudia Baldwin	Queensland Department of Natural Resources and Mines
Prof Des Connell	Environmental Toxicology and Chemistry, Griffith University
Dr Jochen Müller	University of Queensland
Ms Imogen Zethoven	World Wildlife Fund, Brisbane
Ms Felicity Wishart	Queensland Conservation Council
Dr Colin Creighton	National Land and Water Resources Audit, Canberra
Dr Brianna Casey	Queensland Farmers Federation
Mr Mark Panitz	Queensland Fruit and Vegetable Growers
Mr Ian Johnson	Queensland Farmers Federation
Ms Diana Dawson	Australian Canegrowers Council
Mr Paul Bidwell	Agforce Queensland
Dr Malcolm McCulloch	Research School of Earth Sciences, Australian National University
Dr Terry Done	Australian Institute of Marine Science
Mr Nick Heath	Queensland Seafood Industry Association
Dr Miles Furnas	Australian Institute of Marine Science
Dr Ian Prosser	CSIRO Land and Water, Canberra
Dr Heather Hunter	Queensland Department of Natural Resources and Mines
Dr Brian King	Asia-Pacific Applied Science Associates, Surfers Paradise

Townsville, 18 June	
Mr Vern Veitch	Sunfish
Dr Eric Wolanski	Australian Institute of Marine Science
Dr Mark Fenton	Environment and Behaviour Consultants, Townsville
Ms Sheriden Morris	Great Barrier Reef Marine Park Authority
Dr Laurence McCook	Great Barrier Reef Marine Park Authority and Australian Institute of Marine Science
Mr John Reghenzani	Bureau of Sugar Experiment Stations, Ingham

Presenters of Written Submissions to the Panel

Name	Institution
Ms Diana Dawson	Australian Canegrowers Council, Brisbane
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ATTACHMENT 4

A4 REPORT ON THE RISK APPROACH USED IN THE GREAT BARRIER REEF CATCHMENT WATER QUALITY ACTION PLAN

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A4.1 Scope

This report responds to a request to advise an expert Panel that has been established (under the Chairmanship of the Queensland Chief Scientist) to advise the Queensland Premier and the Federal Minister for the Environment on the scientific and management merits of the Great Barrier Reef Water Quality Action Plan (The Plan).

The government has set an initial goal to halt the decline in the water quality of the catchments draining to the Reef caused by land-based pollution and a long-term goal of reversing the trend in declining water quality. In the context of these two goals, the expert Panel has been asked to:

1. Review existing evidence for the decline in water quality of catchments draining to the Reef.
2. Review existing scientific evidence for the decline of the presence of land-based pollutants in Reef waters and of the nature and extent of the existing and potential impacts of any such land-based pollution including processing in estuaries and coastal and tidal wetlands, habitat processes and impacts, groundwater, urban stormwater, industrial contaminants and possibly human health and pathogens.

3. Advise on methodology for developing scientifically sound and effective end-of-river targets to achieve the goals.

4. Evaluate the methodology and data used to set the end-of-river targets contained in the GBRMPA Water Quality Action Plan including mass balance approaches of input sources, "in-catchment processing" and outputs

5. Assess whether these targets are valid and appropriate for the above goals
6. Assess whether the catchment risk classification contained in GBRMPA Water Quality Action Plan is valid and appropriate for the above goals.

A4.2 Information Sources

This report is based on the instructions received from Dr Andrew Johnson, a member of the expert Panel, in a letter dated 4 June 2002. The letter was accompanied by a 116 page photocopy of the Great Barrier Reef Catchment Water Quality Action Plan (A Report to Ministerial Council on targets for pollutant loads). This report is based on an analysis of the written material that was provided.

A4.3 Methods used in the Water Quality Action Plan

The WQAP notes that, *inter alia*, "the objectives of the Plan are to :
1. identify the major catchment-based threats to water quality in the Great Barrier Reef World Heritage Area;

2. identify priority catchments and sub-catchments in terms of potential risks to the world heritage values of the Great Barrier Reef;
3 recommend specific targets (including pollution loads and concentrations) for outflow water quality in individual rivers and for reef water quality consistent with the National Standards for Coastal Water Quality Protection";

The methodology used in the WQAP is as follows. For each catchment:

1. nutrient and sediment run-off were identified as the consequences of agricultural and urban land-use (WQAP, page 15).

2. a scoring system was devised for sediment load, based on the estimated increase in sediment load between 1850 and the present (WQAP, pages 16-17).

3. two scoring systems were devised for phosphorus. One was based on the estimated increase in phosphorus export between 1850 and the present. The second was based on the 1990 application rates of phosphorus-based fertilisers. The two scores were combined into a single score (WQAP, pages 17-18).

4. two scoring systems were devised for nitrogen. One was based on the estimated increase in nitrogen export between 1850 and the present. The second was based on the 1990 application rates of nitrogen-based fertilisers. The two scores were combined into a single score (WQAP, pages 18-19).

The scores in every case are referred to as "risk groups" or as "risk factors".

Table A4.1: Summary table of assignment of "risk groups" based on the estimated increase in load from 1850 to the present.

	Low risk score	Medium risk score	High risk score
Sediment	1 to 5	5 to 12	>12
Phosphorus	<4	4 to 10	>10
Nitrogen	<2	2 to 4	>4

Table A4.2: Summary table of assignment of "risk groups" based on fertiliser application in 1990.

	Low risk score	Medium risk score	High risk score
Phosphorus	0-1 kg P/ha	1-5 kg P/ha	>5 kg P/ha
Nitrogen	0-7 kg N/ha	7 - 14 kg N/ha	>14 kg N/ka

The two nitrogen and phosphorus scores (based on the categorisations depicted in Tables A4.1 and A4.2 above) were combined to form a single score using a method that corresponds to that shown in the look-up table of Table A4.3 below.

Table A4.3: Conversion of the two "risk groups" for N and P, shown as the axes, to a combined risk ranking shown in the body of the table.

	Low	**Medium**	**High**
Low	Low	Medium	Medium
Medium	Medium	Medium	High
High	Medium	High	High

The risk factors obtained for sediment, for phosphorus and for nitrogen are used to determine the export reduction factors for the catchment, to be achieved by 2011. Export targets are determined by multiplying the present export flux by the reduction factor.

Table A4.4: Export reduction factors determined on the basis of the risk factor.

	Low risk score	Medium risk score	High risk score
Sediment	1	0.67	0.5
Phosphorus	1	0.67	0.5
Nitrogen	1	0.67	0.5

Chlorophyll targets are set directly on the basis of observed samples, without any analogous attempt at categorising catchments.

The risk to the nearshore deposition zone from heavy metals, herbicides, pesticides, and other organic compounds is mentioned on page 26 WQAP, and appropriate sediment toxicity “trigger concentrations” are derived in Table 3. However, on page 27 WQAP, the Plan concedes that sediment concentration data does not fully describe potential biological risk. Thus Section 4.2 of the WQAP advocates a biota sampling program using crabs as an indicator species.

According to the text on page 6 of the WQAP, the sediment, phosphorus, and nitrogen risk factors were used to develop a risk profile for the status of the inshore regions of the Reef. This was done by placing the main river catchments into four risk categories (very high, medium high, medium and low). This prioritising of catchments is depicted in Table 1 of the WQAP, under the heading “catchment risk assessments”.

A4.4. Analysis

Despite the WQAP claiming that the mechanism for the ranking process “is explained in further detail in Part 2, Section 2 of this [WQAP] report”, this is not the case. Part 2, Section 2 of the WQAP gives the details used to determine the component parts of the risk factors but it does not explain how these are combined into the risk assessment given in Table 1 of WQAP. In an attempt to determine how this was done, Table A4.5 below reproduces the risk factors for sediment, P and N from the WQAP, and the risk assessments given in Table 1 of the WQAP.

An examination of Table A4.5 below reveals either that there is an inconsistency in the risk assessment, or that a different (and undocumented) method was used to obtain the risk assessments given in Table 1 of the WQAP. Catchments that have two medium ratings and a high rating, such as the Tully and the Murray, are given an overall Medium/High rating. There are, however, two anomalies. The Herbert catchment is given the highest risk rating, whereas the Styx is given only a Medium risk rating.

Table A4.5: Risk factors for sediment, P and N from the WQAP, and the risk assessments given in Table 1 of the WQAP.

Catchment	Sediment	P	N	Table 1
Normanby	L	L	L	L
Endeavour	L	M	M	M
Daintree	L	M	M	M
Mossman	L	M	H	M
Barron	M	M	M	H
Mulgrave-Russell	M	M	H	MH
Johnstone	H	H	H	H
Tully	M	M	H	MH
Murray	M	M	H	MH
Herbert	M	M	H	H
Black	L	M	M	M
Ross	L	M	M	M
Haughton	M	H	H	MH
Burdekin	H	H	M	MH
Don	M	H	M	MH
Proserpine	H	H	H	H
O'Connell	H	H	H	H
Pioneer	H	H	H	H
Plane	H	H	H	H
Styx	H	M	M	M
Fitzroy	H	H	M	MH
Calliope	H	M	M	MH
Boyne	M	M	M	M
Baffle	H	M	M	MH
Kolan	H	H	M	MH
Burnett	H	H	M	MH

A4.5 Discussion

5.1 Risk Framework

Risk, according to the definition of Beer & Ziolokowski (1995), is the union of a set of likelihoods and a set of consequences of the scenarios under consideration over a given time. This concept of risk as being a combination of likelihoods and consequences also underpins the Australian Standard on Risk Management (AS4360).

When this, the conventional interpretation, of risk assessment is used then a quantified risk is the product of the likelihood (expressed as a probability) of an event occurring times the consequences that will ensue if the event takes place. The consequence can be expressed in terms of a value for loss of money, loss of life, or other appropriate quantified uncertainty.

In many situations, likelihoods and consequences are categorised and the scores are added. Neither the categorisation, nor the decision to add, should be undertaken arbitrarily. Appendix 2 of Beer & Ziolkowski (1995) discusses this and notes that if the categorisation is logarithmic, then addition of a likelihood score and a consequence score corresponds to addition of the logarithms of the scores. The reason being that the addition of logarithms corresponds to the multiplication of the numbers represented by the logarithms.

A4.5.1.1 Likelihood or consequence

The meaning of the word "risk" as used in the WQAP is not immediately clear. To attempt to deconstruct the meaning ascribed to it in the WQAP, let us consider two possibilities - risk as likelihood, and risk as consequence.

A4.5.1.2 Risk as likelihood

The WQAP may be using the word risk as the chance of something happening. Thus, the risk of sediment pollution is determined by the increase in sediment loading since 1850. The idea that "the risk of pollution is high if the sediment load has increased twelve-fold since 1850" has predetermined the consequence (pollution) and is using the high risk to indicate a high probability. Similarly, the idea that "the risk of pollution is high if the fertiliser load in 1990 exceeded 14 kg N/ha" treats high risk as synonymous with high probability.

A4.5.1.3 Risk as consequence

Beer (2000) pointed out that a precautionary principle approach to risk assessment treats the risk as having a probability of occurrence equal to unity. Let us assume that this approach was adopted in the WQAP; in that case, when the WQAP states that the risk of sediment pollution is determined by the increase in sediment loading since 1850, it may be interpreted as meaning "there is a risk of high pollution if the sediment load has increased twelve-fold since 1850". The word risk then refers to the consequence (because the probability equals unity), so that risk becomes synonymous with consequence. Similarly, the idea that "there is a risk of high pollution if the fertiliser load in 1990 exceeded 14 kg N/ha" treats high risk as synonymous with the consequence (high pollution).

A4.5.2 Transparency

Even though the statements "the risk of pollution is high if the sediment load has increased twelve-fold since 1850" or even "there is a risk of high pollution if the sediment load has increased twelve-fold since 1850" may both be valid ways of using the term "risk", a more substantive question is whether the statements themselves are, or are not, correct. Should it be an eight-fold, a twelve-fold, a sixteen-fold, or some other -fold that determines the category of high risk? The question is difficult to answer, but the real concern is that the WQAP appears to assign these boundaries arbitrarily. Appendix 2 of the WQAP details the methods used to estimate the amount of sediment, but the basis used to determine the number of categories or the category boundaries remains unspecified.

This lack of transparency in the WQAP applies to the sediment, phosphorus and nitrogen analyses, and extends, as has already been mentioned, to the risk assessment used to prioritise catchments.

A4.5.3 Risk Analysis

Table 3 of the WQAP denotes the risk calculus used to obtain a risk estimate for phosphorus and nitrogen. In general such a risk calculus attempts to combine estimates of likelihood and consequence.

A4.5.3.1 Risk as probability

If, in the WQAP, the term "risk" is used to denote a probability, then the risk calculus is incorrect. In this case, the risk calculus of Table 3 of the WQAP needs to obey the rules for the combination of probabilities. It does not.

Provided that the two events are independent, then the combination of the two risks is, mathematically, the multiplication of two probabilities. Probabilities are constrained to have values that are always below unity. Thus the product of two categories must always produce a category that is equal to, or lower than, the lowest of the two categories being combined. High combined with Low must produce Low. To demonstrate this quantitatively, assign 0.3 to Low, 0.6 to Medium and 0.9 to High. Then the combination of High and Low is 0.3 x 0.9, which is less than 0.3. In this case, the appropriate risk calculus is given in Table A4.6 below.

Table A4.6: Risk calculus if the axes refer to risks as probabilities.

	Low	**Medium**	**High**
Low	Low	Low	Low
Medium	Low	? (Low or Medium)	Medium
High	Low	Medium	High

The risk calculus used to derive the risk assessment of Table A4.5 above (Table 1 of the WQAP) is also invalid if the risk estimates correspond to probabilities. Three rankings of Medium, as in the case of the Barron River, cannot be combined to yield an overall ranking of High.

A4.5.3.2 Likelihood and consequences

If one axis of the risk matrix represents likelihood and the other represents consequences, and the categorisation is based on a logarithmic progression of categories, then a typical risk matrix would be as shown in Table A4.7 below. The general concept is similar to that of Table A4.6 above.

Table A4.7: Risk calculus if the axes refer to probabilities and consequences. The categories in the risk matrix are then sometimes referred to as risk-weighted consequences.

	Low (p=0.01)	**Medium (p=0.1)**	**High (p=1)**
Low (1)	Ultra Low (.01)	Very Low (.1)	Low (1)
Medium (10)	Very Low (.1)	Low (1)	Medium (10)
High (100)	Low (1)	Medium (10)	High (100)

A4.5.3.3 Risk as consequence

If both of the risk categories in Table A4.3 of this report are taken as consequence categories then it becomes possible to envisage how the sum of two consequences combine to produce a result that is more severe than that of either one on its own.

However, with the actual risk calculus used in Table A4.3 above the situation is as follows. If a ranking of high indicates the certainty (or near certainty) of high pollution based, say, on the increase in load since 1850 then why should a low application of nutrient input in 1990 **lower** the risk rating? Surely the idea then is that "once polluted it remains polluted". In this case an appropriate risk calculus is that given in Table A4.8 below.

Table A4.8: Risk calculus if the axes refer to risks as consequences.

	Low	**Medium**	**High**
Low	Low	?	High
Medium	?	?	High
High	High	High	High

A similar problem exists with the risk assessment of Table A4.5 above (Table 1 in the WQAP). If the rankings refer to consequences then the overall assessment should be equal to, or higher than, the highest ranking in the group of three being used to determine the final risk level.

*A4.*5.4 Consistency

The inconsistency in the assessment of the Herbert and the Styx Rivers has already been noted. In the earlier discussion, this anomaly was noted in relation to other rivers rated with two medium risks and one high risk. When compared with the Barron River, the anomaly is even more glaring.

A4.6 Conclusion

It would appear, on the basis of the above discussion, that the risk approach used in the WQAP is not valid. If our understanding of the method that was used is correct, then the risk calculus is flawed. If a different method of risk assessment was used, then it has not been documented, in which case the risk analysis is flawed as a result of lack of transparency.

A4.7 References

AS/NZS 4360:1999 *Risk Management*, Standards Australia/Standards New Zealand.

Beer, T. (2000). Setting air quality standards: a case study of the Australian National Environment Protection Measure for ambient air quality. *Environmetrics*, **11**: 499-510.

Beer, T. & Ziolkowski, F. (1995) *Environmental Risk Assessment: An Australian Perspective*, Report 102, Supervising Scientist, Barton, ACT.

ATTACHMENT 5

Definitions

Definitions have been composed by member of the Panel, or have been extracted from other reports.

Acid sulphate soils	Soils or sediments containing highly acidic soil horizons or layers (actual acid sulphate soils), and iron sulphides or other sulphidic material that has not been exposed to air and oxidised (potential acid sulphate soils)
Agencies	State and Federal Government departments, statutory authorities, government-owned corporations, local governments
Adaptive Management	
Benthic	Associated with the bottom of the sea, stream or a lake
Biodiversity	The natural diversity of native wildlife, together with the environmental conditions necessary for survival. Includes regional diversity, that is, the diversity of the landscape components (landforms, soils, water, climate, wildlife and land uses) of a region and their functional relationships that affect environmental conditions within ecosystems; ecosystem diversity, that is, the diversity of the different types of communities formed by living organisms and the relations between them; species diversity, that is, the diversity of species; and genetic diversity, that is, the diversity of genes within each species (s10 *Nature Conservation Act 1992*)
Biological Diversity	Biodiversity
Bioregion	The primary level of land classification in Queensland, based on regional geology and climate, as well as major biota
Climate change	A change of climate, which is attributed directly or indirectly to human activity which alters the composition of the global atmospheres, and is in addition to natural climate variability observed over comparable time periods
Critical thresholds	Roger to supply
Coast	All areas within or neighbouring the foreshore (s 6 *Coastal Protection and Management Act 1995*)
Coastal waters	Queensland waters to the limit of highest astronomical tide (s 9 *Coastal Protection and Management Act 1995*)
Coastal wetlands	Tidal wetlands, estuaries, salt marshes, melaleuca swamps (and other coastal swamps), mangrove areas, marshes, lakes or minor coastal streams regardless of whether they are of a

	saline, freshwater or brackish nature (s 10 *Coastal Protection and Management Act 1995*)
Coastal zone	Coastal waters and all areas to the landward side of coastal waters in which there are physical features, ecological or natural processes or human activities that affect, or potentially affect, the coast or coastal resources (s 11 *Coastal Protection and Management Act 1995*)
Conservation	The protection and maintenance of nature while allowing for its ecologically sustainable use (s 9 *Nature Conservation Act 1992*)
Contaminant	(a) a gas, liquid or solid; (b) an odour; (c) an organism (whether alive or dead), including a virus; (d) energy, including noise, heat, radioactivity and electromagnetic radiation; or (e) a combination of contaminants (s 11 *Environmental Protection Act 1994*)
Critical habitat	Habitat that is essential for the conservation of a viable population of protected wildlife, or community of native wildlife, regardless of whether special management considerations and protection are required (s 13 *Nature Conservation Act 1992*)
Cultural resources	Places or objects that have anthropological, archaeological, historical, scientific, spiritual, visual or sociological significance or value, including such significance or value under Aboriginal tradition or Torres Strait Island custom, within the coastal zone (schedule 2, *Coastal Protection and Management Act 1995*)
Cumulative impacts	Impacts that may be caused by or result from a number of separate successive and contibuting activities including (a) frequent and repetitive effects; (b) delayed effects; (c) effects that occur away from the source; (d) effects arising from multiple causes or sources; (e) combined potential effects of current development approvals, whether implemented or not (i.e. taking into account the 'latency' effect of current unimplemented approvals); (f) significant secondary effects; (g) interaction with other existing developments and uses; and (h) fundamental changes in system behaviour or structure (i.e. triggers and threshold effects are reached due to cumulative effects)
Ecoefficiency	Roger to supply
Ecologically sustainable development (ESD)	Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be improved
Ecosystem	A community of organisms interacting with one another and the environment in which they live
Eutrophication	Increase in the nutrient status of a water body, and

	consequently the rapid growth of plants, both natural and as a result of human activity
Foreshore	The land lying between high water mark and low water mark as is ordinarily covered and uncovered by the flow and ebb of the tide at spring tides (schedule 2 of the *Coastal Protection and Management Act 1995*)
GBR Catchment	A river catchment system where the waters of that system discharge into the GBR Region
High water mark	The ordinary high water mark at spring tides (schedule 2 of the *Coastal Protection and Management Act 1995*)
Incentive Instruments	
Integrated Resource Managment	
Integrity	The extent to which the natural values of the area in consideration are in their natural ecological, physical and aesthetic condition
Land	Includes land that is, or is at any time, covered by Queensland waters (schedule 2 of the *Coastal Protection and Management Act 1995*)
Landowner	A landowner, land manager, person or group of people with an interest in the planning area through special lease, mining claim, occupational licence, occupation permit, exploration permit, stock grazing permit, pastoral holding, permit to occupy, and trustees of land set aside for public purposes
Landscapes	Natural landscapes, cultural landscapes and seascapes
Mean high water springs	Long-term average of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of tide is greatest, at full and new moon
Monitoring	Routine counting, testing or measuring of environmental factors or organisms to determine their status or condition
Natural resources	The natural and physical features and processes of the coastal zone, including wildlife, soil, water, minerals and air (schedule 2 of the *Coastal Protection and Management Act 1995*)
Nature	All aspects of nature, including but not limited to: (a) ecosystems and their constituent parts; (b) all natural and physical resources; (c) natural dynamic processes; and (d) the characteristics of places, however large or small that contribute to (i) their biological diversity and integrity, or (ii) their intrinsic or scientific value (s 8 *Nature Conservation Act 1992*)
Nearshore reefs	
Pelagic	Associated with the surface or middle depths (as opposed to the bottom) of a body of water
Pest species	Plant and animal species that have established in areas

	outside of their naturally occurring distributions
Pollution	Pollution is defined as a deleterious change in the chemical, physical and biological qualities of an ecosystem due to human activity. Pollutants are the substances, structures or species that cause the pollution.
Precautionary principle	Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. (In the application of the precautionary principle, public and private decisions should be guided by: (i) careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment; and (ii) an assessment of the risk-weighted consequences of various options.) (National Strategy for Ecologically Sustainable Development 1992)
Primary industries	The growing of crops, grazing and fisheries
Regional Coastal Management Plan (RCMP)	A regional coastal management plan approved under the *Coastal Protection and Management Act 1995*)
Queensland waters	All waters that are within the limits of the State, or are coastal waters of the State (s 36 *Acts Interpretation Act 1954*)
Reef waters	Within this report the Panel considers Reef Waters to include The Great Barrier Reef World Heritage Area and intertidal waters adjacent to the WHA
Riparian	On the banks of and adjacent to a waterway or wetland
Run-off	Water discharged from the land that enters the sea either directly, or indirectly after passing through streams and rivers
Rural land uses	Land used including primary industries, within non-urban areas
Sewage treatment	*Primary treatment*. The first step in sewage treatment removes large objects by screens (filters) and sediment and organic matter in settling chambers *Secondary treatment*. After primary treatment, removal of biodegradable organic matter from sewage using bacteria and other micro-organisms, inactivated sludge or trickle filters. Also removes some of the phosphorus (30%) and nitrate (50%) *Tertiary treatment*. Removal of nitrates, phosphates, chlorinated compounds, salts, acids, metals and toxic organics after secondary treatment
Suspended solids	Any solid substance present in the water in an undissolved state, usually contributing directly to turbidity
Targets	*Aspirational Targets*. A vision by the community for a region *Resource Condition Targets*. Desired outcomes in the medium term of 10-20 years

	Management Action Targets. Desired outcomes in the short term of 1-5 years
Threatened species	Wildlife prescribed under the *Nature Conservation Act 1992* as presumed extinct, endangered or vulnerable
Tidal water	The sea and any part of a harbour or water course ordinarily within the ebb and flow of the tide at spring tides (schedule 2 of the *Coastal Protection and Management Act 1995*)
Trigger values	Roger to supply
Turbidity	The cloudy water conditions caused by suspended solids
Urban area	An area identified on a map in a planning scheme as an area for urban purposes, including residential, industrial, commercial, rural residential, major tourist developments, ports and future urban purposes
Water quality	The ecosystem health of aquatic systems (including surface, soil and underground waters), including processes affecting or involving the physical, chemical and biological characteristics of water
Water quality	For the practical purposes of this review, the Panel considered Water Quality to mean the physical, chemical and biological characteristics that sustain aquatic ecosystems and desired water uses. The Panel also took into consideration that water quality is socially defined depending on the desired use of the water. For example, uses such as drinking, recreation, fishing and habitat for aquatic organisms are normally associated with high levels of water quality, whereas water used for hydropower generation, industrial purposes and irrigation does not require as high standards.
Waterway	Includes a river, creek, stream, watercourse or inlet of the sea (s 5 *Fisheries Act 1994*)
Wilderness	An area that is substantially undisturbed by modern society, and remote at its core from points of mechanised access and other evidence of society; includes an area that provides a sense of wilderness, but does not necessarily contain all other wilderness values
Wildlife	Any plant or animal, as defined in the *Nature Conservation Act 1992*
Wetlands	Areas of fresh and salt water, over land, that are flooded all or part of the time

ATTACHMENT 6

Abbreviations

AEC	Anion Exchange Capacity
AIMS	Australian Institute of Marine Science
ANZECC	Australian and New Zealand Environment and Conservation Council
ASS	Acid Sulphate Soil
BOD, BOD_5	Biological Oxygen Demand
CEC	Cation Exchange Capacity
CEO	Chief Executive Officer
COMPASS	Combining Profitability and Sustainability in Sugar
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIN	Dissolved Inorganic Nitrogen
DNRM	Department of Natural Resources and Mining (Queensland)
DO	Dissolved Oxygen
EPA	Environmental Protection Authority
ESD	Environmentally Sustainable Development
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GBRCWQAP	Great Barrier Reef Catchment Water Quality Action Plan
ICM	Integrated Catchment Management
IDC	Inter-Departmental Committee
IPA	Integrated Planning Act 1997
IRM	Integrated Resource Management
MoU	Memorandum of Understanding
N	Nitrogen
NAP	National Action Plan
NAPSWQ	
NHT	Natural Heritage Trust
NHT2	
NLWRA	National Land and Water Resources Audit
NRM	Natural Resource Management
P	Phosphorus
PCB	Princess Charlotte Bay
PMP	Property Management Planning
QLD	Queensland
R&D	Research and Development

RCMP	Regional Coastal Management Plan
RNRM	Regional Natural Resources Management
RWQPP	Reef Water Quality Protection Plan
SS	Suspended Sediment
TEP	Transparent Exopolymer Particle
TN	Total Nitrogen
TOR	Term of Reference
TORs	Terms of Reference
TP	Total Phosphorus
WHA	World Heritage Area
WQAP	Water Quality Action Plan
WT	Wet Tropics