



Future research and development needs to improve water quality in the Great Barrier Reef catchments



A report prepared by the Reef Catchments Working Group for the Consortium for Integrated Resource Management

By Robin Clark and the CIRM Reef Catchments Working Group



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List of abbreviations and acronyms

AIMS	Australian Institute of Marine Science
BMP	Best management practice
BSES Ltd	(previously) Bureau of Sugar Experiment Stations
CIRM	Consortium for Integrated Resource Management
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CQU	Central Queensland University
DEH	Commonwealth Department of Environment and Heritage
DO	Dissolved oxygen
FBA	Fitzroy Basin Association
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GU	Griffith University
JCU	James Cook University
NRM	Natural resource management
QDNRMW	Queensland Department of Natural Resources, Mines and Water
QDPI&F	Queensland Department of Primary Industries and Fisheries
QEPA	Queensland Environmental Protection Agency
QFF	Queensland Farmers Federation
R&D	Research and development
RCWG	Reef Catchments Working Group
Reef Plan (RWQPP)	Reef Water Quality Protection Plan
UQ	University of Queensland



Executive summary

It is now widely accepted that sediment and nutrient loads in the majority of rivers flowing into Australia's Great Barrier Reef catchments have changed in type and composition and have increased significantly since European settlement. These loads are having a demonstrable, adverse effect on river and near-shore water quality and on the health of near-shore coral reefs. The primary source of sediment is from grazing lands in the Burdekin and Fitzroy River catchments, while fertiliser use on cropping land is a major contributor of nutrients in the Wet Tropics catchments (Baker, 2003).

The studies and processes leading to this report sought to determine the major information needs for wise management of the river catchments whose waters impact on the World Heritage-listed Great Barrier Reef. Several of the river catchments are also within the Wet Tropics World Heritage Area.

This work was initiated by the Consortium for Integrated Resource Management (CIRM) which sponsored the Reef Catchments Working Group (RCWG) to collate and review the current research and development (R&D) activities in the Reef catchments and identify and report on further R&D needs and priorities to support the Reef Water Quality Protection Plan (Reef Plan). Drawing on the power of its collaborative partnerships, the RCWG focussed on those R&D activities that would improve water quality in rivers flowing to the Great Barrier Reef. The RCWG aimed to facilitate implementation of the Reef Plan's research-related strategies through improved communication and cooperation between policy development officers, resource managers, research providers, community bodies and industry bodies.

A significant amount of research work has already been completed, and much is currently in progress, in trying to understand the natural and human systems and processes at work that link land use to water quality and reef condition.

The first phase of the RCWG's work, to identify and collate current R&D activities relevant to the Reef catchments up to March 2005, has already been reported in the document entitled "*Current research and development in the Great Barrier Reef catchments*" (Prange 2005a). This comprehensive report can be found on the CIRM web site at <www.cirm.org.au>. The next stage, to identify R&D needs and priorities for future research, is the topic of this report.

The findings of the current report suggest that much more work is needed to develop new models of water quality processes and then translate that information into knowledge that leads to comprehensive, well-understood decision-making tools for land managers, industry and policy makers. Also needed is a clear understanding of community needs and aspirations and of the factors that encourage or inhibit the uptake of new management approaches. In the short term, improved methods and protocols for water quality monitoring are also required. Most importantly, the vast array of information collected from monitoring and modelling projects needs to be assembled and analysed, with the results clearly communicated to the community. Reporting on selected performance indicators is seen as essential to determine whether the individual and collective effort going towards improving water quality is actually having a positive impact on water quality, the viability of contributing catchments and on the condition of the Reef.

These research needs have been captured using a conceptual model which illustrates how the various research activities fit within an environment of continuous learning and adaptive management. The R&D needs identified are summarised in Table E1.

The priority areas for research listed in this report are aimed at filling the identified knowledge gaps for the next 3–5 years. It is anticipated that another research gap analysis will be required within five years to identify research needs to the year 2020.

Table E1: Summary of identified R&D needs

Program area	Research theme*	Research area
1 Refining the problem (understanding the systems)	1. Determining the quantitative impacts of climatic variability and changes in land use and land and riverine management practices on water quality in Reef catchments and on Reef condition. (Links to Reef Plan strategies – D5, D8, F1, G3) Research type: Biophysical, social, economic Scale*: All scales	1.1 Progress and enhance research on landscape condition and processes, and their linkages at multiple scales. 1.2 Develop or refine catchment and catchment-to-reef models to integrate appropriate catchment datasets to assess condition and trend, ecosystem health and ecosystem thresholds. 1.3 Further develop tools and techniques for natural resource management and risk assessment (eg: risk assessment tools). 1.4 Develop integrated economic models with environmental cost/benefit: a) at a property scale through regional planning; and b) at a regional scale through economic assessment.
2 Setting priorities	2 Determining priority areas for natural resource management actions. (Links to Reef Plan strategies – F9, H1, H3, H4, H5) Research type: Biophysical, social, economic Scale: Catchment to reef, GBR-wide; regional and catchment	2.1 Develop tools for the identification of points of intervention (i.e. to determine hotspots/hot drivers). 2.2 Assess biophysical, social, economic and cultural values of priority near-shore reefs, seagrass, estuaries, wetlands and riparian areas. 2.3 Build capacity for priority setting processes (e.g. to use models within decision frameworks).
3 Finding solutions	3. Identifying best management methods and tools that minimise downstream impacts on water quality. (Links to Reef Plan strategies – A1, A3, C3, D5, F4, G4) Research type: Biophysical, social, economic Scale: Property; subcatchment; regional and catchment	3.1 Further develop, refine and evaluate best management practices (BMPs) for landholders. 3.2 Define benefits and costs associated with implementation of BMPs. 3.3 Identify factors of successful community- and government-driven solutions.

Table E1: Summary of identified R&D needs (continued)

Program area	Research theme	Research area
4 Facilitating implementation	<p>4. Developing pathways for adoption.</p> <p><i>(Links to Reef Plan strategies – A1, A4, C3, D8, F7, G2)</i></p> <p>Research type: Social, economic</p> <p>Scale: All scales</p>	<p>4.1 Develop and evaluate tools, technologies and mechanisms for adaptive management practices.</p> <p>4.2 Investigate factors encouraging or inhibiting changed management practices.</p> <p>4.3 Evaluate the effectiveness of engagement processes for natural resource management.</p>
5 Monitoring conditions and trends	<p>5. Improving the effectiveness and efficiency of monitoring programs.</p> <p><i>(Links to Reef Plan strategies – F3, I4, I5, I6, I7)</i></p> <p>Research type: Biophysical, social, economic</p> <p>Scale: All scales</p>	<p>5.1 Develop or refine appropriate indicators of change (biophysical, social, economic and cultural) (i.e. what to monitor, and at what scale).</p> <p>5.2 Develop or refine monitoring programs to reflect the needs and aspirations of different stakeholders (i.e. what to monitor).</p> <p>5.3 Develop or refine monitoring methods and protocols to improve quality and comparability of data through the application of agreed procedures and techniques (in regard to data capture, sample analysis, data assessment and innovative methods).</p>
6 Evaluation	<p>6. Evaluating performance and effectiveness of plans and investments.</p> <p><i>(Links to Reef Plan strategies – F1, F2, I9)</i></p> <p>Research type: Biophysical, social, economic</p> <p>Scale: All scales</p>	<p>6.1 Develop assessment methodologies for performance reporting.</p> <p>6.2 Assess and develop reporting techniques for effective communication with diverse stakeholder groups.</p>

* Scale: The relevant scale of research could be one or more of the following:

- Catchment to reef, Great Barrier Reef-wide
- Regional and catchment
- Subcatchment
- Property



1

Introduction

In December 2003 the Australian and Queensland Governments released the Reef Water Quality Protection Plan (Reef Plan) with the goal to reverse the decline in water quality entering the Great Barrier Reef (GBR) within 10 years. This was in response to the need to protect the GBR as a World Heritage Area and as a healthy functioning ecosystem for current and future generations. Some key details on the Reef Plan are provided in Appendix 1.

The Consortium for Integrated Resource Management (CIRM) partners and other organisations with an interest in the Reef (totalling 18 organisations) considered that there was an immediate need to determine what information needs were necessary to achieve the Reef Plan's goal of halting and reversing the decline in water quality entering the Reef within 10 years (RWQPP, 2003). This analysis could then be used to determine what additional research and development (R&D) had to be undertaken to be able to meet the Reef Plan's long-term objectives.

These 18 organisations, which included both R&D users and R&D providers, formed a working group to collectively develop the future R&D needs, required solely to support implementation of the Reef Plan. The Reef Catchments Working Group (RCWG) was formed under the sponsorship of CIRM to undertake this activity. Additional information on CIRM and the RCWG is provided in Appendix 2.

A significant body of R&D linked to the Reef Plan has already been or is being undertaken. The first stage of the RCWG's work was to prepare a document that listed the current R&D being undertaken to support the Reef Plan (Prange, 2005a). The RCWG also considered the research gaps identified by Baker (2003) and the Productivity Commission (2003) for the Reef Catchments. It was also decided that the future R&D priorities should be directly linked to the nine key strategies detailed in the Reef Plan (see Appendix 1).

This report is the culmination of the second stage of the RCWG's activities and identifies the R&D needed for implementation of the Reef Plan strategies and actions.



2

Methodology

2.1 Scope of the report

This report is focused on the R&D needed for implementation of the Reef Plan strategies and actions. It includes biophysical, social and economic research for addressing the adverse impacts of diffuse land-sourced pollutants on water quality in the Great Barrier Reef catchments. Research related to point sources of pollution from activities such as mining, urban development or aquaculture is not considered, although it is acknowledged that these activities may also have an impact on water quality and reef health. Other impacts on the Reef, such as climate change and oil spills, are also outside the scope of the study.

This scope is consistent with the scope of the Reef Plan. The R&D needs identified in this report will relate to and impact upon extension, policy development and/or regulatory responses outlined by the Reef Plan, but this work does not deal specifically with these considerations.

For the purposes of this report, the 'Great Barrier Reef Catchments' covers:

- a) to the seaward extent—coastal and marine ecosystems (estuaries, mangroves, seagrasses and near-shore coral reefs) that may be affected by freshwater discharges and the sediments and nutrients they contain, from rivers flowing to the Great Barrier Reef Region between Cape York in the north and the Burnett-Mary River systems to the south; and
- b) to the landward extent—the catchments of all the rivers that discharge to the east coast of Queensland in that defined north-south spread of coastline.

Figure 2.1 (next page) shows the extent of the reef, the marine park boundary and the river catchments, as well as the hot spots and drivers identified by the Productivity Commission in its 2003 report.

2.2 Processes undertaken for R&D gap identification

The R&D needs identified in this report were developed through the following processes.

2.2.1 Formation of the Reef Catchments Working Group

The Reef Catchments Working Group (RCWG), a multidisciplinary/cross-sectoral working group, was established by CIRM in June 2004 to report on R&D gaps and needs. Additional background on the role of the RCWG and its membership is provided in Appendixes 2 and 3.

2.2.2 Review of previous research gap analyses

The RCWG reviewed several past research reports which identified research gaps and needs. Most significant were the findings from the Baker Report (Baker, 2003) and the Productivity Commission's report on industries, land use and water quality in the Great Barrier Reef Catchments (Productivity Commission, 2003). The main findings from these reports are outlined in Appendix 4.



Figure 2.1: Hot spots and hot drivers in the Great Barrier Reef

2.2.3 Compilation of current R&D activity

A summary of over 350 R&D projects recently or currently being undertaken, which addressed or were related to diffuse pollution from broadscale land use in the Reef catchments was compiled. This first phase of the RCWG's work culminated in March 2005 with the production of a document titled *"Current research and development in the Great Barrier Reef Catchments"* (Prange, 2005a). The document provided a valuable resource to inform natural resource managers, research providers, industry and the community of the breadth and location of R&D activity currently in progress in Queensland's Reef catchments. Copies of this document can be found on CIRM's website at <www.cirm.org.au>.

2.2.4 Mapping of current R&D projects against previously identified R&D gaps

To determine what progress had been made since 2003, the RCWG mapped the current R&D (Prange 2005a) against the identified R&D gaps and needs from the Baker and Productivity Commission reports (Baker, 2003; Productivity Commission, 2003). This process demonstrated the breadth of research activity in the Reef catchments and showed that most of the identified R&D needs had been covered to some extent through the R&D currently being undertaken. However, the mapping approach proved to be of limited use in identifying specific research gaps due to the fact that many of the relevant projects were still underway and the research results were not yet available.

2.2.5 Workshops to develop preliminary R&D needs

The RCWG was conscious that there were still critical areas of research required to give greater confidence to natural resource managers making decisions with respect to the Reef. Using the scientific expertise of both Working Group members and other key stakeholders in the Reef catchments, the key science gaps and knowledge needs were collated and distilled at a series of workshops held in March, April, July and August 2005.

The RCWG identified several preliminary R&D needs that were supported by both regional natural resource management (NRM) bodies and other stakeholder groups (see Appendix 5). These represented areas of research that Working Group members considered were not being adequately addressed under current R&D activities and met the criteria for prioritisation shown in Attachment 6. Details of the ranking process can be found in the report by Prange (2005b), and accessed on the CIRM website www.cirm.org.au.

The results of the gap analysis showing preliminary R&D needs and the links to the Reef Plan strategies were then discussed with regional bodies, industry groups, management agencies and research providers for further comment and refinement.

Initially the preliminary R&D needs and gaps were identified directly against the strategies of the Reef Plan. However there was considerable overlap of R&D needs across the strategies. Therefore a conceptual model was developed to categorise the R&D needs.

The conceptual model described in Section 3 (Figure 3.1) provides an adaptive management framework for collating and linking research projects (biophysical, social and economic). The model demonstrates the flow of research information through six phases – *refining the problem, setting priorities, finding solutions facilitating implementation, monitoring conditions and trends, and evaluation*.

The R&D needs were then categorised against these six phases or program areas.

2.2.6 Circulation of discussion paper

A discussion paper (CIRM, 2005) detailing proposed research themes and research areas within six program areas was developed. The discussion paper, which was released for comment and invited response from a broad range of stakeholders during October–November 2005, elicited submissions from 16 organisations, all of which are listed below:

Burnett–Mary Regional NRM Group
Burdekin Dry Tropical Coasts NRM Group
BSES Ltd
Commonwealth Scientific and Industrial Research Organisation
Department of Environment and Heritage
Great Barrier Reef Marine Park Authority
Griffith University
James Cook University
Leucaena Network
Queensland Department of Housing, Local Government and Planning
Queensland Department of Natural Resources, Mines and Water
Queensland Department of Primary Industries and Fisheries
Queensland Environmental Protection Agency
Queensland Farmers Federation
Reef Cooperative Research Centre
University of Queensland

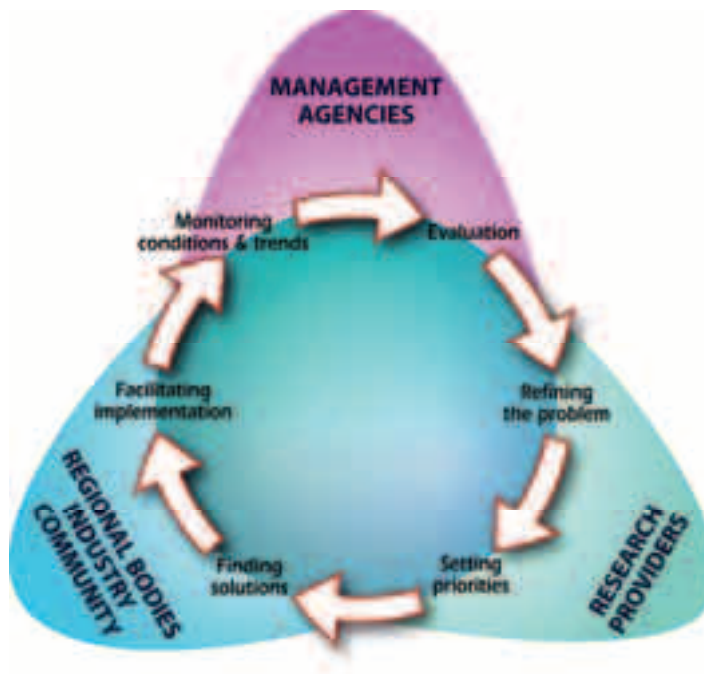
2.2.7 Finalisation of report

This final report takes into account the comments and suggestions received during the consultation phase of the discussion paper.

3

Conceptual framework

To provide a process for collating and linking research projects (biophysical, social and economic) related to improving water quality in the Reef catchments, the RCWG developed a conceptual framework, shown in Figure 3.1. Six phases are described – refining the problem, setting priorities, finding solutions, facilitating implementation, monitoring conditions and trends and evaluation.



Monitoring conditions and trends

- Improving effectiveness of monitoring programs
- Reflecting community needs and aspirations
- Determining what/how to monitor (biophysical, social, economic)

Facilitating implementation

- Developing pathways for adoption
- Establishing partnerships
- Facilitating change at community and institutional levels
- Understanding the value of ecosystem services
- Cost–benefit analysis and incentives

Finding solutions

- Identifying best management methods and tools
- Includes developing models, decision support systems, feasibility studies, scoping trials etc.

Evaluation

- Developing indicators of performance
- Information collation and assessment
- Reporting outcomes

Refining the problem

- Understanding the systems
- Determining the correlation between land use, water quality and impacts on the GBR
- Using numerical and conceptual models

Setting priorities

- Developing targets
- Determining hotspots and hot drivers
- Includes assessment of biophysical, social, economic and cultural values

Figure 3.1: The conceptual model, with its six phases and particular areas of interest

The six phases in the model are called R&D program areas, and by using this framework the RCWG identified future R&D needs, sorting them according to each of the six program areas.

The first phase (Program 1 – refining the problem) is about undertaking research and refining models to better understand the natural systems and processes at work in order to establish and quantify the linkages between land-use practices, water quality and reef condition.

This information then feeds into priority setting processes (Program 2), which aim to highlight the key activities (hot drivers) that may be having a negative impact on water quality, and any sensitive areas (hot spots) which may be threatened as a consequence. This will enable research and management actions to be targeted more effectively toward priority areas.

The next two phases (Programs 3 and 4) in the process are tightly linked.

Program 3 – finding solutions – is about using science and stakeholder knowledge to develop best management methods and decision-support systems to assist landholders and policy providers in tackling specific hot spot/hot driver problems in priority areas. Developing and refining best management practices to reduce sediment runoff from grazing lands or nutrient inputs from cropping and horticulture would fall within this category.

Understanding motivational factors for change is the focus of Program 4 – facilitating implementation. Here, social and economic research is required to explain why some landholders are reluctant or slow to adopt new management methods. Determining the value of ecosystem services and cost-benefit analyses are needed to demonstrate to landholders and the broader community the economic costs and potential benefits of adoption of a particular action.

The last two phases relate to monitoring (Program 5) and evaluating (Program 6) the data to determine whether the changed land-use practices are having a positive impact on water quality and the Reef. Most importantly, it is about reporting on the findings and feeding that information back into the cycle to further refine NRM actions and future R&D.

In applying this conceptual model, it is recognised that although the most logical starting point is generally 'refining the problem', the phases do not always occur sequentially. For example, the work that contributes to finding solutions may highlight a need to reassess and enhance the priority setting processes. Similarly, there may be cross-linkages between projects and program areas that for the sake of simplicity are not shown in the conceptual model.

Different types of research are required in each of these programs, and R&D projects will be conducted in each program concurrently. For some issues, such as understanding the impacts of sugarcane farming, the research work will be well advanced in the cycle, while new issues may need some baseline data gathering just to define the problem.

The organisations involved in delivery of the Reef Plan's objectives will all have some interest in the six program areas of R&D illustrated in the conceptual model, and will likely have a particular and stronger interest in specific areas. For example, the major research providers are most likely to be interested in the R&D to refine the problem and to find solutions, while a regional body's interest is more likely to be in finding solutions and facilitating implementation. Management agencies may be particularly interested in monitoring conditions and trends, in evaluation and in refining the problem. The likely relationship of these three groups to particular program areas is also represented in Figure 3.1.

Table 3.1 below shows how the six phases of the conceptual model relate to the nine strategies described in the Reef Plan

Table 3.1: Broad relationship between the conceptual model phases and Reef Plan strategies

Conceptual model programs	Reef Plan strategies								
	Self-management approaches (A)	Education & extension (B)	Economic incentives (C)	Planning for NRM & land use (D)	Regulatory frameworks (E)	Research & information sharing (F)	Partnerships (G)	Priorities & targets (H)	Monitoring & evaluation (I)
Refining the problem				✓		✓	✓		
Setting priorities						✓	✓	✓	
Finding solutions	✓		✓	✓		✓	✓		
Facilitating implementation	✓		✓				✓		
Monitoring conditions & trends						✓			✓
Evaluation						✓			✓

4

What are the R&D needs for the Reef catchments?

The R&D needs identified through the processes outlined in Section 2.2 are discussed and categorised against the six program areas (i.e. the six phases of the conceptual model) in Sections 4.1 to 4.6. Each section provides:

- (a) The general research theme to address the program area.
- (b) A broad description of the program area needs
- (c) Specific R&D needs to be addressed
- (d) Anticipated products or outputs
- (e) Recommended pathways of adoption
- (f) Related R&D areas (i.e. links of the project area to Reef Plan strategies and actions)
- (g) Examples of specific R&D questions for each area, together with the research capability of the RCWG organisations and potential collaborations (presented in Tables 4.2 to 4.7).

The research themes and research areas for each program area are summarised in Table 4.1.

Table 4.1: Summary of identified R&D needs

Program area	Research theme*	Research area
1 Refining the problem (understanding the systems)	<p>1. Determining the quantitative impacts of climatic variability and changes in land use and land and riverine management practices on water quality in Reef catchments and on Reef condition.</p> <p><i>(Links to Reef Plan strategies – D5, D8, F1, G3)</i></p> <p>Research type: Biophysical, social, economic</p> <p>Scale*: All scales</p>	<p>1.1 Progress and enhance research on landscape condition and processes, and their linkages at multiple scales.</p> <p>1.2 Develop or refine catchment and catchment-to-reef models to integrate appropriate catchment datasets to assess condition and trend, ecosystem health and ecosystem thresholds.</p> <p>1.3 Further develop tools and techniques for natural resource management and risk assessment (e.g. risk assessment tools).</p> <p>1.4 Develop integrated economic models with environmental cost–benefit: <ol style="list-style-type: none"> a) at a property scale through regional planning; and b) at a regional scale through economic assessment. </p>
2 Setting priorities	<p>2. Determining priority areas for natural resource management actions.</p> <p><i>(Links to Reef Plan strategies – F9, H1, H3, H4, H5)</i></p> <p>Research type: Biophysical, social, economic</p> <p>Scale: Catchment to reef, GBR-wide; regional and catchment</p>	<p>2.1 Develop tools for the identification of points of intervention (i.e. to determine hotspots/hot drivers).</p> <p>2.2 Assess biophysical, social, economic and cultural values of priority near-shore reefs, seagrass, estuaries, wetlands and riparian areas.</p> <p>2.3 Build capacity for priority setting processes (e.g. to use models within decision frameworks).</p>

Table 4.1: Summary of identified R&D needs (continued)

Program area	Research theme	Research area
3	<p>Finding solutions</p> <p>3. Identifying best management methods and tools that minimise downstream impacts on water quality.</p> <p><i>(Links to Reef Plan strategies – A1, A3, C3, D5, F4, G4)</i></p> <p>Research type: Biophysical, social, economic</p> <p>Scale: Property; subcatchment; regional and catchment</p>	<p>3.1 Further develop, refine and evaluate best management practices (BMPs) for landholders.</p> <p>3.2 Define benefits and costs associated with implementation of BMPs.</p> <p>3.3 Identify factors of successful community- and government-driven solutions.</p>
4	<p>Facilitating implementation</p> <p>4. Developing pathways for adoption.</p> <p><i>(Links to Reef Plan strategies – A1, A4, C3, D8, F7, G2)</i></p> <p>Research type: Social, economic</p> <p>Scale: All scales</p>	<p>4.1 Develop and evaluate tools, technologies and mechanisms for adaptive management practices.</p> <p>4.2 Investigate factors encouraging or inhibiting changed management practices.</p> <p>4.3 Evaluate the effectiveness of engagement processes for natural resource management.</p>
5	<p>Monitoring conditions and trends</p> <p>5. Improving the effectiveness and efficiency of monitoring programs.</p> <p><i>(Links to Reef Plan strategies – F3, I4, I5, I6, I7)</i></p> <p>Research type: Biophysical, social, economic</p> <p>Scale: All scales</p>	<p>5.1 Develop or refine appropriate indicators of change (biophysical, social, economic and cultural) (i.e. what to monitor, and at what scale).</p> <p>5.2 Develop or refine monitoring programs to reflect the needs and aspirations of different stakeholders (i.e. what to monitor).</p> <p>5.3 Develop or refine monitoring methods and protocols to improve quality and comparability of data through the application of agreed procedures and techniques (in regard to data capture, sample analysis, data assessment and innovative methods).</p>
6	<p>Evaluation</p> <p>6. Evaluating performance and effectiveness of plans and investments.</p> <p><i>(Links to Reef Plan strategies – F1, F2, I9)</i></p> <p>Research type: Biophysical, social, economic</p> <p>Scale: All scales</p>	<p>6.1 Develop assessment methodologies for performance reporting.</p> <p>6.2 Assess and develop reporting techniques for effective communication with diverse stakeholder groups.</p>

* Scale: The relevant scale of research could be one or more of the following:

- Catchment to reef, Great Barrier Reef-wide
- Regional and catchment
- Subcatchment
- Property

4.1 Program 1 – Refining the problem

Much monitoring and modelling work has already been conducted in an attempt to quantify sediment and nutrient loads in rivers discharging to the Great Barrier Reef and to identify near-shore reefs most likely to be affected by such discharges (Devlin et al., 2001). While this work has been crucial in identifying and raising awareness of the risks to the health of the Reef, more detailed models are now required to better understand the processes at work and enable practical solutions for improving water quality to be developed at appropriate scales. For example, we don't yet fully understand the connection between surface water and groundwater systems, nor how nutrients move through the soil profile, nor the role of wetlands, floodplains and estuaries in trapping sediments and nutrients. We also have an incomplete knowledge of the critical levels for major water pollutants of near-shore coral reefs and other sensitive marine habitats.

This basic biophysical research is needed to provide the science foundation underpinning the development of natural resource management policy and sustainable management practices for industry and communities. It is recognised that our knowledge will never be complete, so we must use new knowledge as it becomes available in a cycle of continuous improvement. Research in these areas will provide the science base to support many Reef Plan strategies and actions, such as D5, D8, F1 and G3.

To date, much of the modelling has been based on biophysical parameters with little attention given to the social and economic implications of various modelling scenarios (Aitken, 2001). More sophisticated models are needed to take into account social dimensions such as population projections, shifts in land use over time and the economic impacts of adoption of sustainable land-use practices. The impact of changes in land use also needs to be factored into longer-term modelling scenarios. For example, what will happen to nutrient loads if 5% of canefarmers leave the industry to take up horticulture? Will the commercial prawn catch be affected if sediment loads are reduced by 10%? Integrated biophysical, social and economic models are needed to answer these sorts of questions.

Similarly, risk-informed decision making using statistical modelling frameworks that enable both model uncertainty and error propagation to be accommodated are needed to improve the modelling of biophysical, social and economic factors in the Reef catchments. Another important aspect of refining the problem is considering the appropriate spatial and temporal scale for addressing the problems at hand. Modelling frameworks are needed that will enable the integration of data (e.g. remote sensing data, observational monitoring data, expert opinion, etc.) on appropriate spatial and temporal scales for reporting catchment and waterway condition. This also then leads to cost-effective monitoring efforts that provide for risk-informed decision making.

Gathering appropriate biophysical data to parameterise and calibrate landscape models can be a timely and expensive exercise. The use of remote sensing tools is seen as a cost-effective means of gathering a large volume of data over a large area in a short timeframe. The challenge is to develop remote sensing tools that will consistently provide meaningful data that can be used to interpret changes in the environment over time.

4.1.1 Key features of Program 1 – refining the problem

Research theme: Determining the quantitative impacts of climatic variability and changes in land use and land and riverine management practices on water quality in the Reef catchments and on Reef condition.

Description: Undertaking research and/or developing/refining numerical or conceptual models to obtain a better understanding and predictive capability of the dynamic linkages between climate variability and changes in land use and land or riverine management practices, water quality and the health of ecosystems in the Great Barrier Reef and its catchments.

R&D need to be addressed: Enhanced understanding and prediction of natural systems and processes in ecosystems of the Great Barrier Reef World Heritage Area and within Reef catchments.

Product or output: A dynamic predictive capability for the Reef catchments that enables the quantification of contaminant fluxes and the identification of their sources, under a range of climatic conditions and with changing land use and land or riverine management.

Pathways of adoption: Research results translated into plain English, related back to stakeholder specific questions. Calibrated water quality models for each Reef catchment, and ecosystem response models for the Great Barrier Reef. Integration of biophysical modelling alternative scenario results with social and economic impacts. Incorporation into agricultural planning policy development and water quality target setting. Integration and assessment of monitoring data.

Related research areas: Links to Reef Plan strategies and actions D5, D8, F1 and G3.

4.1.2 Specific R&D questions to be answered for Program 1

Examples of some of the specific R&D questions whose answers will help us to refine the problem of deteriorating water quality in the Reef catchments are shown in Table 4.2. Against these questions are an identification of the current and future capabilities of the RCWG research partners, and other potential collaborations that would prove beneficial.

Table 4.2: Sample R&D questions for Program 1, aligned with research capability of RCWG partners and potential collaborators

Research area (under the theme of climate variability and change)		Research capability		Potential collaborators
		Current	Future	
1.1	<p>Progress and enhance research on landscape condition and processes, and their linkages at multiple scales.</p> <p>For example:</p> <ul style="list-style-type: none"> • How do climatic variability and changes in land use and land/riverine management affect the generation, transport and processing of sediment, nutrients and other contaminants in the waterways of Reef catchments? • What is the contribution of groundwater processes to fluxes of nutrients and other contaminants discharged to the Great Barrier Reef World Heritage Area and what is their spatial extent? • What role do floodplains and estuaries perform in the biotransformation of sediment and nutrient loads as they move through the catchment? • What factors and processes influence the timelags between management change in Reef catchments and responses in downstream water quality? 	<p>GU JCU UQ QDNRMW QEPA CSIRO AIMS</p>	<p>GU JCU UQ QDNRMW QEPA CSIRO AIMS</p>	<p>Regional NRM bodies GBRMPA CSIRO DEH QDPI&F</p>
1.2	<p>Develop or refine catchment and catchment to reef models to integrate appropriate catchment datasets to assess condition and trend, ecosystem health and ecosystem thresholds.</p> <p>For example:</p> <ul style="list-style-type: none"> • What is the ecological response of estuaries and the Great Barrier Reef lagoon to anthropogenic change (e.g. hydrology, nutrients, sediment and temperature)? • What are the critical thresholds and recovery potential of catchment and reef ecosystems to major water quality changes? • What are the social, cultural and economic dimensions influencing catchment communities and how can these factors be integrated into catchment and catchment to reef modelling? 	<p>JCU UQ QDNRMW QEPA CSIRO</p>	<p>JCU UQ CQU QDNRMW QEPA CSIRO</p>	<p>Regional NRM bodies GBRMPA CSIRO DEH</p>
1.3	<p>Further develop tools and techniques for natural resource management and risk assessment.</p> <p>For example, we need to:</p> <ul style="list-style-type: none"> • Further develop statistical modelling frameworks to model uncertainty and error propagation • Further develop remote sensing tools for cost-effective data collection • Further develop isotope tracing of sediment/nutrient sources to obtain a better understanding of landscape processes • Further develop tools for risk assessment and risk management in Reef catchments. 	<p>JCU UQ CQU QDNRMW QEPA CSIRO</p>	<p>JCU UQ CQU QDNRMW QEPA CSIRO</p>	<p>GBRMPA CSIRO DEH</p>
1.4	<p>Develop integrated economic models with environmental cost-benefit:</p> <ul style="list-style-type: none"> • at a property scale through regional planning; • at a regional level through economic assessment. 	<p>CQU UQ QDPI&F CSIRO</p>	<p>CQU UQ QDPI&F Regional NRM bodies CSIRO</p>	<p>Industry representative bodies DEH CSIRO</p>

4.2 Program 2 – Setting priorities

Funding for R&D and on-ground management works has always been and will continue to be limited. It is therefore imperative that work is targeted at the areas of highest risk, greatest threat, or where it will have the most impact. Identification of hot spots, hot drivers and points of intervention is needed to direct funding toward priority areas. Some of this work has already been attempted.

The Reef Plan identifies ten priority catchments, based on a broad assessment of a number of factors including biophysical risk, social risk, development risk and risk to marine industries. The Productivity Commission Report (2003) suggested that the main causes of poor water quality on the Reef (hot drivers) are sediment runoff from grazing lands in the Burdekin Dry Tropics and Fitzroy Basin and nutrient-rich runoff from cropping and horticulture in the Wet Tropics catchments (see Figure 2.1). Mapping of fringing reefs, estuaries, wetlands and riparian areas to identify key sensitive habitats (or hot spots) is well under way. What is still missing however is a detailed assessment of the value of the hot spots, not only for their conservation significance, but also their economic importance for tourism and commercial fishing and social and cultural significance for Indigenous and non-Indigenous communities.

Also needed is a better understanding of the value of ecosystem services¹ and the social and economic drivers that influence land-use decisions and consequent impacts on water quality, and how these are changing over time. This detailed information needs to be combined with a better understanding of the source and fate of water-borne pollutants, thus enabling priority actions to be distilled. Such work would support Reef Plan strategies and actions F9, H1, H3, H4 and H5.

Decision-making criteria need to be established in order to give transparency to the priority setting process. Questions such as whether it is better to rehabilitate a degraded wetland or take preventative action to protect a pristine wetland, or where to best direct on-ground NRM actions, can then be addressed within a scientifically defensible decision-making framework.

4.2.1 Key features of Program 2 – setting priorities

Research theme: Determining priority areas for NRM actions.

Description: Determining priority areas for NRM actions, based on assessment of condition/values of key sensitive sites and risk assessment of threatening processes, land-use practices and social/economic capacity and impacts.

R&D need to be addressed: Targeting NRM actions and research activity toward priority areas.

Product or output: Enhanced assessment of aquatic ecosystems in the GBR World Heritage Area and in Reef catchments at risk from land-derived pollutants. A decision support system that integrates biophysical, social and economic factors to identify priority areas, actions or points of intervention on which to target NRM actions and future R&D.

¹ Ecosystem services are the transformation of natural features or resources (soil, plants and animals, air and water into things that we value, such as clean air, clean water, insect pest control, plant pollination etc. For more information refer to <www.esa.org/education/edupdfs/ecosystems-services.pdf#search='ecosystem%20services'>.

Pathways of adoption: Funding directed toward identified priorities by funding bodies.

Related research areas: Links to Reef Plan strategies and actions F9, H1, H3–H5.

4.2.2 Specific R&D questions to be answered for Program 2

Examples of some of the specific R&D questions whose answers will help us to set priorities for halting and reversing the decline in water quality entering the Reef lagoon are shown in Table 4.3. Against these questions are an identification of the current and future capabilities of the RCWG research partners, and other potential collaborations that would prove beneficial.

Table 4.3: Sample R&D questions for Program 2, aligned with research capability of RCWG partners and potential collaborators

	Research area (under the theme of priority areas for QDNRMW action)	Research capability		Potential collaborators
		Current	Future	
2.1	<p>Develop tools for the identification of points of intervention (i.e. to determine hotspots and hot drivers).</p> <p>For example:</p> <ul style="list-style-type: none"> What ecosystems in the Great Barrier Reef World Heritage Area and in Reef catchments are most at risk from land-derived pollutants? How can decision making on priorities for NRM actions be optimised to take into account biophysical, social and economic factors? <p>Note that in order to determine hot spots we first need to finalise mapping of sensitive habitats, such as near-shore reefs, seagrass, estuaries, wetlands and riparian areas.</p>	JCU CQU UQ QDNRMW QEPA CSIRO Regional NRM bodies	JCU CQU UQ QDNRMW QEPA CSIRO Regional NRM bodies	GBRMPA QDPI&F Regional NRM bodies Industry representative bodies DEH CSIRO QDPI&F
2.2	<p>Assess biophysical, social, economic and cultural values of priority near-shore reefs, seagrass, estuaries, wetlands and riparian areas.</p> <p>For example:</p> <ul style="list-style-type: none"> What are the biophysical, social, economic and cultural values of key sensitive habitats, such as near-shore reefs or riparian zones? How can state-wide fisheries data be utilised to assess fisheries values at a suitable scale for regional condition assessment? 	JCU CQU UQ QDNRMW CSIRO Regional NRM bodies	JCU CQU UQ QDNRMW CSIRO Regional NRM bodies	GBRMPA CSIRO QDPI&F Regional NRM bodies DEH
2.3	<p>Build capacity for priority-setting processes (e.g. to use models within decision frameworks).</p> <p>For example, we need to:</p> <ul style="list-style-type: none"> Develop and refine tools for evaluating social, economic and environmental benefits and impacts of scenarios Further develop modelling capacity, including application and testing of new/improved models and tools Evaluate and apply innovative statistical techniques to assess quantitative and non-quantitative data (e.g. Bayesian techniques) Evaluate the effectiveness of the short-term modelling project in Reef catchments (e.g. SedNet scenarios). 	JCU UQ QDNRMW Regional NRM bodies CSIRO	JCU UQ QDNRMW CSIRO	QDPI&F DEH CSIRO QDPI&F

4.3 Program 3 – Finding solutions

Finding solutions and facilitating implementation are intricately linked activities, combining innovative science with stakeholder knowledge in all stages of development and delivery of best management methods and decision support tools.

The development of best management practices (BMP) and farm management systems for most agricultural industries in the Reef catchments is well advanced, with BMPs being continually improved and refined as new information becomes available (QFF, 2005; Kimball, 2005). A Public Environmental Report prepared by the sugar industry suggests that cane farmers have made significant improvements in sustainable farming practices in recent years (Wrigley, 2005).

The rate of uptake of sustainable farming practices in other industries is still not as well known. A joint study by Queensland's major agricultural industry representative bodies reports on industry's progress toward implementation of environmentally sustainable practices (Kimball, 2005). According to this report, the cotton industry is progressing well; with most growers changing management practices as a result of the industry's BMP program. An increasing number of growers have voluntarily undergone an independent audit of their management practices and received certification under the program. The grazing and horticulture industries are not so advanced but do have a number of training packages to encourage best management practices and are moving toward increased uptake of BMPs. While not within the scope of this report it is acknowledged that extension services provided to landholders can greatly assist in obtaining improved rates of uptake.

Much of the data on adoption rates for BMPs is supplied by individual industries. Overarching, independent monitoring of industry practices against an appropriate and consistent suite of performance measures would be helpful to assess industry's actual and ongoing commitment toward sustainable land-use practices.

Research in these areas would assist implementation of several Reef Plan actions such as A1, A3, C3, D5, F4 and G4.

4.3.1 Key features of Program 3 – finding solutions

Research theme: Identifying best management methods and tools that minimise downstream impacts on water quality.

Description: Developing efficient and effective systems and methods that contribute to policy and management decisions by government, industry and landholders. The focus of research would be on all industries and land uses in Reef catchments.

R&D need to be addressed: Developing simple and reliable tools to assist landholders, community groups and decision makers with management options that take into account environmental, social and economic issues.

Product or output: Assessment of currently available information on best management practices for each industry and identification of knowledge gaps and research priorities. Suite of tools for adoption or implementation by government, industry and landholders.

Pathways of adoption: Farm trials, scoping studies, cost–benefit analyses.

Related research areas: Links to Reef Plan strategies and actions A1, A3, C3, D5, F4 and G4.

4.3.2 Specific R&D questions to be answered for Program 3

Examples of some of the specific R&D questions whose answers will help us to find solutions for deteriorating water quality in the Reef catchments are shown in Table 4.4. Against these questions are an identification of the current and future capabilities of the RCWG research partners, and other potential collaborations that would prove beneficial.

Table 4.4: Sample R&D questions for Program 3, aligned with research capability of RCWG partners and potential collaborators

Research area (under the theme of best management methods and tools)		Research capability		Potential collaborators
		Current	Future	
3.1	<p>Further develop, refine and evaluate best management practices (BMPs) for landholders.</p> <p>For example:</p> <ul style="list-style-type: none"> • What innovative management practices are available for each industry to help minimise adverse impacts on downstream water quality at a range of scales? • How can decision-support tools such as SafeGauge be modified to manage nutrient use on cropping lands? • What are the optimal fertiliser application rates to just achieve maximum yield or plateau production while minimising adverse impacts on the environment? • What are suitable criteria on which to measure performance with respect to the uptake of best management practices across all agricultural industries in the Reef catchments? 	JCU CQU UQ QDNRMW QDPI&F CSIRO	JCU CQU UQ QDNRMW QDPI&F CSIRO	CSIRO Regional NRM bodies Industry representative bodies DEH
3.2	<p>Define benefits and costs associated with implementation of BMPs.</p> <p>For example:</p> <ul style="list-style-type: none"> • What are the economic costs and benefits of adoption of BMPs within a regional industry context? • What are the environmental costs and benefits of adoption and non-adoption of BMPs at a range of scales? 	CQU UQ QDPI&F CSIRO	CQU UQ QDPI&F CSIRO	Regional NRM bodies Industry representative bodies DEH CSIRO
3.3	<p>Identify factors for successful community- and government-driven solutions.</p> <p>For example:</p> <ul style="list-style-type: none"> • What are the best mechanisms for involving landholders and the community in the early development of BMPs and decision-support tools to improve the useability and engender greater ownership of the product? • What has been the impact of devolution of decision making from state to regional and local scales? • How do you measure the effectiveness of a successful community monitoring program such as Seagrass Watch? 	CQU UQ CSIRO	CQU UQ CSIRO	Regional NRM bodies DEH CSIRO QDPI&F

4.4 Program 4 – Facilitating implementation

In the past few years numerous projects have commenced or been completed exploring the underlying reasons and motivational factors contributing to landholder decisions with respect to BMPs (Richards and Aiken, 2004; Greiner, Herr and Stoeckl, 2003; Taylor et al., 2000). More work is still needed to gain a better understanding of the environmental and economic costs and benefits of sustainable land-use practices so that landholders and the broader community can make informed decisions. Such information could then be the basis for the development of well-targeted incentive programs, such as tax incentives or rate relief schemes, which would be tailored to the needs of a specific industry or community. Social and economic research, as applied to natural resource management issues, is still an emerging science that requires much more attention.

Communication and engagement with the community is a key factor in facilitating implementation of sustainable land-use practices. A dialogue between community members and researchers, policy makers and land managers enables local knowledge and expertise to be incorporated into best management practices and assists in increasing the community's understanding and acceptance of suggested changes to farming methods. Rather than being a top-down approach, this is a two-way process enabling the community and regional NRM bodies to influence R&D activities and promote change at both community and institutional levels.

Up until now, Indigenous communities who have a strong and enduring link with the land have not always been actively involved in these processes. We need to develop new ways of engaging with Indigenous communities to benefit from their traditional knowledge of land management and ensure their meaningful input to decision-making processes.

Research in these areas will support the Reef Plan, particularly strategies and actions A1, A4, C3, D8, F7 and G2.

4.4.1 Key features of Program 4 – facilitating implementation

Research theme: Developing pathways for adoption.

Description: Determining factors that influence the adoption of new management practices and developing/refining techniques to overcome impediments to change. The focus of research would be across all industries and land use.

R&D need to be addressed: Understanding motivational factors for change.

Product or output: Improved policies, programs and processes for engagement with the community to bring about change. Research results translated to address specific stakeholder questions.

Pathways of adoption: Consultative processes, institutional arrangements.

Related research areas: Links to Reef Plan strategies and actions A1, A4, C3, D8, F7 and G2.

4.4.2 Specific R&D questions to be answered for Program 4

Examples of some of the specific R&D questions whose answers will assist with implementing solutions for deteriorating water quality in the Reef catchments are shown in Table 4.5. Against these questions are an identification of the current and future capabilities of the RCWG research partners, and other potential collaborations that would prove beneficial.

Table 4.5: Sample R&D questions for Program 4, aligned with research capability of RCWG partners and potential collaborators

Research area (under the theme of pathways for adoption)		Research capability		Potential collaborators
		Current	Future	
4.1	<p>Develop and evaluate tools, technologies and mechanisms for implementation of adaptive management practices.</p> <p>For example:</p> <ul style="list-style-type: none"> • What are effective mechanisms for embedding best management practices within local farming systems and evaluating their performance? • How can biophysical, social and economic factors be incorporated into simple-to-use and reliable models that provide management options to assist decision making? 	JCU CQU UQ QDNRMW QDPI&F CSIRO	JCU CQU UQ QDNRMW QDPI&F CSIRO	Regional NRM bodies Industry representative bodies DEH CSIRO
4.2	<p>Investigate factors encouraging or inhibiting changed management practices.</p> <p>For example:</p> <ul style="list-style-type: none"> • What are the adoption rates for BMPs in key industries, and what influences them? • Have landholders and industry needs been addressed in understanding the relationship between water quality and on-ground actions? • How do you evaluate the impact of incentive and adjustment packages on catchment communities? 	CQU UQ CSIRO	CQU UQ CSIRO	Regional NRM bodies DEH CSIRO QDPI&F
4.3	<p>Evaluate the effectiveness of engagement processes for natural resource management.</p> <p>For example:</p> <ul style="list-style-type: none"> • How do you evaluate the effectiveness of regional NRM arrangements and structures, e.g. institutional arrangements and communication networks? • How do you incorporate science into regional governance systems for regional planning and policy? • How can partnerships with Indigenous communities be strengthened to facilitate more effective involvement of Indigenous communities in NRM? • What management and partnership approaches and communication materials have a positive impact on attitudes and behaviour towards sustainable land-use practices? 	CQU UQ CSIRO	CQU UQ CSIRO	Regional NRM bodies DEH CSIRO

4.5 Program 5 – Monitoring conditions and trends

A vast amount of water quality and reef condition monitoring data has been collected over the years by government, industry and the community. Programs such as the Great Barrier Reef Marine Park Authority's inshore reef monitoring program and QDNRMW's ambient and community monitoring programs have contributed significantly to the body of knowledge on land-use impacts on water quality. At this stage some of the current datasets cannot be used to their maximum effect as they are not always compatible with other datasets. Also the temporal and spatial extent of the datasets currently limits the ability to report on natural resource condition and trend or use the data in catchment modelling.

We need to develop spatially balanced monitoring programs that accommodate differential monitoring effort through the region/s where monitoring data may be collected for a range of differing objectives. While spatially balanced monitoring designs can consider objectives from a number of monitoring programs with differing spatial and temporal scales, the incorporation of legacy sites ('permanent' sites established for the purpose of long-term monitoring) is also an option to maintain continuity of long historical sequences of data.

A more systematic and standardised approach to monitoring is therefore required in order to fully capitalise on the monitoring effort. This would also provide regional community coordinators and volunteers with a contextual framework in which to place local monitoring programs.

Data sharing protocols also need to be more universally established so that data can be made available to a variety of users for multiple purposes. This will avoid duplication in data collection and improve cost efficiency. Obviously there will be certain limitations on the use of some data, and the confidence levels and assumptions surrounding the data must be conveyed to potential users of the data. It is recognised that a well designed data collection, data analysis and data sharing framework needs to be developed and coordinated to maximise the usefulness of existing monitoring data. Engagement of statistical research expertise for monitoring program design, analysis and reporting (including visualisation of monitoring results) is critical to ensure a statistically robust and cost-effective design.

As previously mentioned, the acquisition of data to populate models and develop base water quality targets or set priorities is still a major concern, particularly for regional NRM bodies. A report by Webb (2004) highlighted the data capture requirements to support the Reef Plan. Large gaps still exist in these fundamental datasets (B. Powell, QDNRMW, pers. comm.).

While issues such as how we collect and store data are important, the primary consideration is what to do with the data. How do we make sense of what the data is telling us? This view is reflected in the Fitzroy Basin Association's Regional Investment Strategy, which states that "a significant risk to setting water quality targets is the potential inability to make sense of the data and this is the reason for the current lack of quantified targets" (FBA, 2004). Clearly we need information to enable us to make an assessment of water quality, catchment health and reef condition and to be able to monitor changes over time. Performance indicators that are easy to measure, meaningful and simple to interpret need to be developed.

Such research links strongly with Reef Plan strategies and actions F3, I4, I5, I6 and I7.

4.5.1 Key features of Program 5 – monitoring conditions and trends

Research theme: Improving the effectiveness of monitoring programs.

Description: Improving and refining monitoring data collection, data management, data assessment and modelling techniques to provide quality data and information which meets stakeholder expectations and can be used in evaluating performance. The focus of the research would be on biophysical, social and economic indicators.

R&D need to be addressed: Developing effective monitoring, modelling and assessment tools to quantify assessment of condition and trends in water quality, ecosystem health and the factors that influence them.

Product or output: Improved data collection processes and data sharing protocols.

Pathways of adoption: Government, industry and community cooperation and collaboration.

Related research areas: Links to Reef Plan strategies and actions F3, I4–7.

4.5.2 Specific R&D questions to be answered for Program 5

Examples of some of the specific R&D questions whose answers will assist in improving the effectiveness of monitoring systems in the Reef catchments are shown in Table 4.6. Against these questions are an identification of the current and future capabilities of the RCWG research partners, and other potential collaborations that would prove beneficial.

Table 4.6: Sample R&D questions for Program 5, aligned with research capability of RCWG partners and potential collaborators

Research area (under the theme of monitoring systems)		Research capability		Potential collaborators
		Current	Future	
5.1	<p>Develop or refine appropriate indicators of change (biophysical, social, economic and cultural) (i.e. what to monitor, and at what scale).</p> <p>For example:</p> <ul style="list-style-type: none"> • What suite of indicators could support State of the Region reporting of biophysical, social, economic and cultural condition and change? • What indicators are appropriate for remote communities, including Indigenous communities that are scientifically robust, technologically feasible and culturally appropriate? • To what extent can indicators be constructed to be applicable at different scales (spatial and temporal)? • What are the indicators of community capacity to change? • What indicators are most sensitive to change and what degree of change can reliably be detected? • What indicators and methods can be used to assess indicative trends in the short-to-medium term when change may not be immediately measurable? 	JCU CQU UQ QDNRMW QEPA AIMS CSIRO	JCU CQU UQ QDNRMW QEPA AIMS CSIRO	GBRMPA DEH CSIRO QDPI&F

Research area (under the theme of monitoring systems)	Research capability		Potential collaborators
	Current	Future	
<p>5.2 Develop or refine water quality monitoring programs to reflect the needs and aspirations of different stakeholders (i.e. what to monitor).</p> <p>For example:</p> <ul style="list-style-type: none"> • How do you develop monitoring programs that efficiently meet multiple objectives at multiple scales? • What monitoring strategies can landholders employ to provide feedback on the success of management practices in achieving water quality outcomes? • How do you improve the water quality improvement planning framework, particularly with respect to developing different ways of establishing environmental values and water quality objectives, and making these meaningful to the community? 	JCU CQU UQ QDNRMW QEPA Regional NRM bodies CSIRO	JCU CQU UQ QDNRMW QEPA Regional NRM bodies CSIRO	GBRMPA DEH CSIRO
<p>5.3 Develop and refine monitoring programs and protocols to improve the quality and comparability of data through the application of agreed procedures and techniques (in regard to data capture, sample analysis, data assessment and innovative methods).</p> <p>For example:</p> <ul style="list-style-type: none"> • What are the most appropriate and statistically robust data collection strategies (including on-ground, off-site and remotely sensed) and data analysis strategies to employ for understanding water quality change in pulse flow events? • What are the most appropriate sample handling and analysis methods for nutrients and suspended sediments collected in high flow events? • How do you relate catchment monitoring and modelling to estuarine and reef lagoon monitoring and modelling? • What monitoring is appropriate to improve the certainty of model parameterisation? • What are the most appropriate eco-toxicity testing procedures for representative organisms in the Great Barrier Reef environment? 	JCU CQU UQ QDNRMW QEPA AIMS Regional NRM bodies CSIRO	JCU CQU UQ QDNRMW QEPA AIMS Regional NRM bodies CSIRO	GBRMPA DEH CSIRO

4.6 Program 6 – Evaluation

There has been considerable R&D effort in the Reef catchments in recent years designed to progress the actions and strategies contained within the Reef Plan. It seems we now have a large volume of information, but still need to better determine how to address the impact of land-use practices on the Reef. It would be timely to gather together all the data and undertake an overview and comprehensive analysis of the R&D results measured against community needs and expectations and to synthesise and correlate all the findings. The results of this overview should then be reported back to the community in a manner that is easy to understand. Through a process of adaptive learning, the results should then go back into the cycle to refine future NRM actions and R&D and bring about change at a community and institutional level (refer to Reef Plan strategies and actions F1, F2 and I9).

Evaluating the performance and effectiveness of regional plans and investments is needed at several levels. Reporting on performance for accountability purposes may require a different set of measures than those needed for reporting resource condition and trend. Regional NRM bodies, for instance, need performance measures to identify short-term changes in order to determine the effectiveness of their regional investment strategies, while longer-term measures are needed to test the accuracy of predictive modelling tools or the impacts of changed land-use practices.

4.6.1 Key features of Program 6 – evaluation

Research theme: Evaluating the performance and effectiveness of plans and investments.

Description: Assessment, review and reporting of performance against the Reef Plan's strategies and actions.

R&D need to be addressed: Synthesis of data and information related to implementation of the Reef Plan's strategies.

Product or output: Easy-to-read reports and maps on the results and effectiveness of NRM actions, research and monitoring programs, including statements of catchment and reef condition and trends.

Pathways of adoption: Research results translated into plain English. Adaptive learning approaches. Incorporation into agricultural planning policy development, water quality target setting and R&D gap analyses.

Related research areas: Links to Reef Plan strategies and actions F1, F2 and I9.

4.6.2 Specific research questions to be answered for Program 6

Examples of some of the specific questions whose answers will assist in evaluating performance against the Reef Plan's strategies and actions are shown in Table 4.7. Against these questions are an identification of the current and future capabilities of the RCWG research partners, and other potential collaborations that would prove beneficial.

Table 4.7: Sample questions for Program 6, aligned with research capability of RCWG partners and potential collaborators

	Research area (under the theme of evaluating performance and plans)	Research capability		Potential collaborators
		Current	Future	
6.1	<p>Develop assessment methodologies for performance reporting.</p> <p>For example:</p> <ul style="list-style-type: none"> • How can catchment and marine assessment methods be integrated? • How do you combine diverse information sources including scientific and tacit knowledge? • How can the notion of uncertainty be explicitly considered and communicated in water quality and landscape health assessments? • What performance measures are needed to report on short-term and long-term change in Reef catchments (resource condition and community resilience to change)? • How do you evaluate the impact of investments, plans and actions for (a) accountability and (b) adaptive management purposes? 	<p>JCU CQU UQ QDNRMW QEPA AIMS CSIRO</p>	<p>JCU CQU UQ QDNRMW QEPA AIMS CSIRO</p>	<p>Regional NRM bodies DEH CSIRO QDPI&F</p>
6.2	<p>Assess and develop reporting techniques for effective communication with diverse stakeholder groups.</p> <p>For example, we need to:</p> <ul style="list-style-type: none"> • Consider stakeholder information needs when reporting on research activities • Investigate the use of reporting 'scorecards' for regional monitoring programs and develop transparent and scientifically defensible integrated assessment techniques that are suited to stakeholders' needs • Determine the effectiveness of using iconic entities (e.g. frog species, lung fish) for engaging community stakeholders. 	<p>JCU CQU UQ QDNRMW QEPA CSIRO</p>	<p>JCU CQU UQ QDNRMW QEPA CSIRO</p>	<p>Regional NRM bodies DEH CSIRO</p>



5

Conclusions and future directions

The RCWG's analysis of future needs for R&D to support the Reef Plan demonstrates that considerable research effort has already been applied across a broad range of topics in the Reef catchments, covering to some degree the research gaps identified in the Baker and Productivity Commission reports (Baker, 2003; Productivity Commission, 2003). Some of this research work is complete, while much is still underway.

In recent years significant inroads have been made in modelling landscape processes, developing best management practices for industry and understanding the community's resilience to change. The RCWG determined however that there were still many areas where our knowledge and understanding was not yet sufficiently refined to adequately address many of the research questions raised under the Reef Plan.

While R&D is required across all the program areas, the RCWG considered that a high priority should be placed on the synthesis, evaluation and reporting of current research and monitoring results, and in using that knowledge to feed back into the development of new natural resource management actions or future R&D.

While not strictly research projects as such, the RCWG considered that two areas – data capture and data sharing protocols – warranted further attention, and were integral to the successful delivery of science in the Reef catchments.

The timing of this work coincides well with the implementation of regional NRM plans and associated targets and investment strategies by regional NRM bodies. This report can also be used as input in the process of developing future research priorities by the CIRM partners and science providers, and by the newly formed Marine and Tropical Science Research Facility. The CIRM partners hope to develop a collaborative relationship with this facility that is mutually beneficial to both organisations and will result in positive natural resource management research outcomes.

It is intended that this final report will be used by research providers, management agencies and funding bodies such as regional NRM bodies and the Commonwealth Government to guide future investment in research in the Reef catchments for the next 3–5 years. It is anticipated that another research gap analysis will be required within five years to identify research needs to the year 2020.

Member organisations of CIRM and the RCWG will advocate and promote the report's proposed R&D themes and research areas in forums at appropriate times to link in with funding and research project proposal cycles.

It is envisaged that, by working together in collaborative partnerships, limited research dollars will be more effectively used to bring about positive outcomes for water quality in the Reef catchments and on the Great Barrier Reef.

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Appendix 1: What is the Reef Water Quality Protection Plan?

The Reef Water Quality Protection Plan (Reef Plan) is an overarching policy, planning and implementation document focussed on addressing pollution sources from broadscale land use in the catchments draining to the Great Barrier Reef – the Reef catchments (RWQPP, 2003). Launched jointly in December 2003 by the Australian and Queensland Governments, its goal is to 'halt and reverse the decline in water quality entering the Reef within 10 years'.

The Reef Plan has two key objectives:

1. Reduce the load of pollutants from diffuse sources in the water entering the Reef; and
2. Rehabilitate and conserve areas of the Reef catchment that have a role in removing water-borne pollutants.

Underlying these objectives are nine key strategies and associated actions. The strategies are:

- A – Self-management approaches
- B – Education and extension
- C – Economic incentives
- D – Planning for natural resource management and land use
- E – Regulatory frameworks
- F – Research and information sharing
- G – Partnerships
- H – Priorities and targets
- I – Monitoring and evaluation.

The Reef Water Protection Plan Annual Report 2004–05 provides a detailed summary of the progress and major investments made during 2004–05 against the Reef Plan's actions and strategies (see <www.deh.gov.au/coasts/publications/annual-report/04-05/index.html>). An independent audit on progress toward implementation of the Reef Plan was completed in July 2005 and will be repeated in July 2010. The annual report and Reef Plan audit describe the research, extension and policy or regulatory programs already undertaken to implement the Reef Plan.

Appendix 2: More about CIRM and the Reef Catchments Working Group

The Consortium for Integrated Resource Management (CIRM) is a voluntary collaboration of research providers and government agencies who share an interest in natural resource management in Queensland. CIRM's partners are:

Department of Natural Resources, Mines and Water (QDNRMW)
Department of Primary Industries and Fisheries (QDPI&F)
Environmental Protection Agency (QEPA)
James Cook University (JCU)
The University of Queensland (UQ)
Central Queensland University (CQU)
Griffith University (GU)
Commonwealth Scientific and Industrial Research Organisation (CSIRO).

CIRM's primary objective is to support and facilitate the planning, coordination and collaboration of R&D initiatives through:

- facilitating and enhancing cross-agency collaboration for the implementation of priority natural resource management initiatives;
- maximising the opportunities for science to form an effective and timely basis for policy development and natural resource management decision making; and
- ensuring holistic, systems-based approaches to natural resource management research.

To date, CIRM has established several working groups, drawing on its partners and other organisations, to progress the identification and implementation of R&D priorities. The focus of CIRM's current working groups includes:

Great Barrier Reef catchments
Social and community dimensions
Dryland salinity risk management
Inland aquatic systems
Native vegetation management
Water renewal in Queensland.

Further information on CIRM's contributions to science coordination can be found on the CIRM website at <www.cirm.org.au>.

CIRM's Reef Catchments Working Group (RCWG) was formed in October 2004 to collate and review the current R&D activities in the Reef catchments and to identify and report on further R&D needs and priorities to support the Reef Plan. Organisations represented on the RCWG are listed in Appendix 3 and include the CIRM partners plus other science providers, policy agencies and regional natural resource management (NRM) bodies. Inclusion of the regional NRM bodies was seen as particularly important, given their significant role in delivery of many aspects of the Reef Plan through their regional NRM plans and regional investment strategies².

²Regional NRM plans and regional investment strategies include three levels of targets – aspirational, resource condition and management action targets. To set appropriate targets, regional NRM bodies need timely and focussed R&D.

Appendix 3: Organisations and representatives on the Reef Catchments Working Group (as at November 2005)

Chair: Chris Robson, Queensland Department of Natural Resources, Mines and Water

Executive Project Officer: Robin Clark, Consortium for Integrated Resource Management

Working Group members:

Australian Institute of Marine Science	Miles Furnas/ Britta Schaffelke
Burdekin Dry Tropics Board	David Foster/Bob Frazer/ Ian Wight
Burnett–Mary Regional Group	Deborah Scott
Central Queensland University	Peter Stratford/ Alister Melzer
Australian Government Department of Environment and Heritage	Alexa Ryhorchuk
Commonwealth Industrial and Scientific Research Organisation	Sheriden Morris & Iain Gordon
Far North Queensland Natural Resource Management Ltd	David Green
Fitzroy Basin Association	Claire Rodgers
Great Barrier Reef Cooperative Research Centre	Russell Reichelt/ Jane Waterhouse
Great Barrier Reef Marine Park Authority	David Haynes/ Francis Verrier
Griffith University	Angela Arthington/ Roy Rickson
James Cook University	George Lukacs
Mackay Whitsunday Natural Resource Management Group	Ray Allan
Queensland Department of Natural Resources, Mines and Water (QDNRMW)	John Mullins/ Heather Hunter & Paul Lawrence/ Tony Pressland
QDNRMW (North Region)	John Ward/Lex Cogle
Queensland Department of Primary Industries and Fisheries	Adam West, Rob Coles & Anne Clarke
Queensland Environmental Protection Agency	Andy Steven
Rainforest Cooperative Research Centre	Richard Pearson
The University of Queensland	Ron Johnstone/John Mott

Appendix 4: Research gaps and needs from earlier reports

Baker Report, 2003

In 2002, as a precursor to the development of the Reef Plan, a panel of science experts was convened to report on the study of land-sourced pollutants and their impacts on water quality in and adjacent to the Great Barrier Reef. The panel, chaired by Dr Joe Baker, considered the existing body of science relating to the issue and determined that, although the extent of current knowledge was incomplete, there was sufficient evidence to suggest a strong correlation between changed land-use practices, water quality and the health of near-shore reefs (Baker, 2003). The panel was also asked to 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 Baker Report made seven recommendations regarding research capabilities, gaps and priority research needs. These were:

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 biophysical, 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 minimise the mobilisation 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 modelled 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 trialled 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 subcatchment 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 minimise 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 (Baker, 2003).

Productivity Commission Report, 2003

Numerous research studies aimed at filling these research gaps and needs have been undertaken since 2002³. The Productivity Commission's research report on industries, land use and water quality in the Great Barrier Reef Catchment (Productivity Commission, 2003) provides a useful synthesis of much of the data available at that time. The Productivity Commission recognises cattle grazing as a significant source of sediment discharges, particularly in the dry catchments such as the Burdekin and Fitzroy, while cropping is noted as a major source of dissolved nitrogen, particularly in the wet catchments. The Report concludes that the reefs facing the highest risk from terrestrial runoff were the inner shelf reefs in the Wet Tropics and Whitsunday regions, while the inner and midshelf areas between Cape Upstart and the Daintree River faced a moderate risk.

In order to prioritise threats to water quality in the Great Barrier Reef (GBR), the Productivity Commission recommended further monitoring to enable an estimation of sediment discharges from smaller regions within the GBR catchments. It suggested that risk assessments for individual reefs should be linked back to the contributing discharge areas and land uses. Information on the current condition of near-shore reefs, such as the economic or cultural significance of reefs, was recommended, as was further research to obtain a better understanding of the role of wetlands in trapping sediments.

The Productivity Commission also conducted a preliminary benchmarking of the level of development and adoption of best management practices in several key industries, including sugar, beef and cotton production industries and found there was little data available on which to measure environmental performance.

³A comprehensive review of our knowledge of the source and fate of sediments and nutrients in Reef catchments, including management recommendations to improve water quality and minimise impacts on the Great Barrier Reef can be found in "Catchments and corals: Terrestrial runoff to the Great Barrier Reef" by Furnas (2003).

Appendix 5: Preliminary R&D needs

(ranked as high in both the stakeholder and regional bodies responses)

Reef Plan strategy ^a / Action ^b & NRM research theme ^c	Description
A1.2 & F4.2 <i>NRM Theme 5</i>	Develop effective tools to enable landholders to self-manage sustainability at property scale – e.g. targeted decision support tools, risk management information. <ul style="list-style-type: none"> • Project^d • Scale: regional (entrained into local management schemes)
A3.1 <i>NRM Theme 4, 5</i>	Investigate the effectiveness and efficacy of BMP models for industry-led action in achieving change on the ground. <ul style="list-style-type: none"> • Program^d • Scale: industry focus
A3.4 <i>NRM Theme 1</i>	Determine the impact of management practices (including all aspects such as riparian vegetation, road maintenance etc.) on water quality outcomes across industries and regions. <ul style="list-style-type: none"> • Program • Scale: across industries and regions / property focus
A3-8 & F3.4 <i>NRM Theme 5</i>	Develop useful and robust tools to assist land managers achieve cost effective monitoring and evaluation with an adaptive approach for sustainable NRM. <ul style="list-style-type: none"> • Program • Scale
A3.9 <i>NRM Theme 1, 5</i>	Develop models to assess the cumulative impact on water quality from the adoption of management practices (i.e. actual adoption rates versus targets). <ul style="list-style-type: none"> • Project • Scale
A4.3 <i>NRM Theme 4</i>	Define the benefits and costs associated with sustainable (BMP) land management. <ul style="list-style-type: none"> • Project • Scale: different scales required (property – on and off farm and regional)
B1.4 & D11.2 <i>NRM Theme 4</i>	Develop a process for the inclusion of indigenous values and understandings in NRM. <ul style="list-style-type: none"> • Project • Scale:
B2.1 <i>NRM Theme 4</i>	Integrate economic models with environmental cost/benefit: <ol style="list-style-type: none"> at a property scale through financial planning; and at a regional scale through economic assessment. <ul style="list-style-type: none"> • Program • Scale: property and regional
D5.1 <i>NRM Theme 1</i>	Undertake land resource and land capability assessment for priority areas at the required scale and identify mechanisms for change (if deemed unsuitable). <ul style="list-style-type: none"> • Program • Scale: across regions
D5.2 & F4.5 <i>NRM Theme 1</i>	Identify, prioritise and map areas of high conservation significance using biological assessment at the appropriate scale. <ul style="list-style-type: none"> • Program • Scale: across regions
D5.3 <i>NRM Theme 5</i>	Develop remote sensing tools/new techniques for land resource/risk assessment. <ul style="list-style-type: none"> • Program • Scale:
D5.4 <i>NRM Theme 4</i>	Investigate how to include social and economic aspects with biophysical R&D as part of agricultural planning systems. <ul style="list-style-type: none"> • Project • Scale:

Appendix 5 continued (ranked as high in both the stakeholder and regional bodies responses)

Reef Plan strategy ^a / Action ^b & NRM research theme ^c	Description
D8.1 <i>NRM Theme 1,2,3</i>	Undertake research to increase understanding of the movement of nutrients, sediments, pesticides etc. (for process understanding and to validate models) e.g. groundwater – surface water – coastal zone, how much, where is it going and how does it behave under various land types/management systems. <ul style="list-style-type: none"> • Program • Scale: across regions and land use
D8.2 <i>NRM Theme 1</i>	Update land use and land cover mapping and expand to include current management practices. <ul style="list-style-type: none"> • Project • Scale: Queensland wide
F1.1, F4.6 & G1–3 <i>NRM Theme 5</i>	Refine models (in a cost and resource efficient manner) to adequately parameterise the impact of changing land management practices. Data collection at individual property scale is vital. <ul style="list-style-type: none"> • Program • Scale: property level • Need to link property scale models to regional scale
F1.5 <i>NRM Theme 5</i>	Develop models of impact of management practices on water quality. <ul style="list-style-type: none"> • Project/Program? • Scale:
F3.1 <i>NRM Theme 1</i>	Contribute to existing monitoring efforts for condition and trends on grazing land and cropping lands. <ul style="list-style-type: none"> • Program • Scale: across regions and industries
F3.2, H4.1 & I7.3 <i>NRM Theme 1, 5</i>	Develop catchment models to integrate appropriate catchment datasets to assess and predict condition trend and ecosystem threshold. <ul style="list-style-type: none"> • Program • Scale: catchment
F3.3 & I7.3 <i>NRM Theme 1, 5</i>	Develop criteria and a framework for condition and trend assessment to interpret indicators of ecosystem health. <ul style="list-style-type: none"> • Project • Scale
F4.4 <i>NRM Theme 1</i>	R&D for landscape processes understanding e.g. isotope tracing of sediment/nutrient sources. <ul style="list-style-type: none"> • Project • Scale
H1.2 <i>NRM Theme 2</i>	Contribute to the improvement of baseline biophysical data/characteristics to develop water quality targets. <ul style="list-style-type: none"> • Program • Scale: across regions • Need upper catchment data (have significant amount of river mouth data); spatial and temporal gaps in data; year-to-year and other levels of temporal variation
H3.1 <i>NRM Theme 2</i>	Investigate the most appropriate ways to integrate the social, economic and biophysical outcomes of a range of initiatives into day-to-day practices (for waterways, wetlands, and riparian zones in good condition). <ul style="list-style-type: none"> • Project • Scale
I5.1 & I6.1 <i>NRM Theme 1</i>	Identify the most appropriate monitoring in the Reef Catchments to meet the needs of different stakeholders e.g. evaluate community monitoring for the social, economic and biophysical benefits or positive outcomes. <ul style="list-style-type: none"> • Project (periodic) • Scale
I9.1 <i>NRM Theme 5</i>	Develop appropriate monitoring methods to assess management systems (BMPs) in determining desired NRM outcomes. <ul style="list-style-type: none"> • Program/project?

Notes

a Reef Plan strategy – from the Reef Plan strategies A–I (see Appendix 1).

b Action – research needs described by the RCWG and numbered 1–10 (see Prange 2005b).

c NRM themes (Prange 2005b) are re-described as programs in Section 4 of this report.

d 'Project' indicates research able to be done within one research project; 'Program' indicates a suite of related research projects.

Appendix 6: Criteria for prioritisation of R&D needs

Criterion 1

Broad acceptance by majority of stakeholders

Criterion 2

R&D is a high priority for either:

- a) all of the Reef catchments
- b) a specific sector or region

Criterion 3

The R&D product lends itself to uptake by relevant stakeholders

Criterion 4

The R&D will deliver within the Reef Plan timelines and is strategically targeted towards future requirements

