BEST MANAGEMENT PRACTICES IN THE SUGAR INDUSTRY FOR IMPROVING WATER QUALITY AND THEIR ADOPTION IN THE MACKAY WHITSUNDAY REGION

by

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This publication is the result of research during 2007 commissioned by the Consortium for Integrated Resource Management (CIRM) and carried out by a research team through the Institute for Sustainable Regional Development at Central Queensland University. It builds on CIRM's earlier state-wide work in 2005 and 2006 which investigated current and future research and development (R&D) that would help achieve the strategies laid out in the Reef Water Quality Protection Plan,

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EXECUTIVE SUMMARY

Concerns about the health of the Great Barrier Reef and associated coastal areas of eastern Queensland have led to an increased focus on the quality of river run-off. A wide range of activities in the Reef catchments contribute pollutants to the Great Barrier Reef World Heritage Area but diffuse sources from agricultural and land uses are significant. The pollutants include sediments, nutrients and chemicals from cropping (mainly sugar cane) and grazing land.

Initiatives over the last 20 years by the sugar industry, government, technical agencies and natural resource management groups have identified practices that can provide both economic and environmental benefits, with a range of technical and support mechanisms on offer for introduction.

It is difficult to identify specific levels of off-site exports on a farm-by-farm basis or to specify how changing a farm management practice will translate into an improvement in water quality. A response by industry has been to identify sets of generic best management practices (BMPs) that are based on sound biophysical principles, have both production and environmental benefits and whose adoption should lead to overall reductions in exports from agricultural land.

In 2005 the Consortium for Integrated Resource Management (CIRM) (see Appendix 1) published a compendium of current research and development being undertaken to achieve improved water quality, under the framework of the Reef Water Quality Protection Plan (Reef Plan). This was followed by a CIRM report in 2006, seeking to determine the major information needs to achieve the strategies in that plan. These reports can be found on the CIRM website at <www.cirm.org.au>.

This study builds on CIRM's earlier investigations. Taking a regional approach, it identifies (i) important BMPs for sugarcane production in the Mackay Whitsunday region that are important for improving water quality; (ii) the factors that are fostering or inhibiting adoption; and (iii) the priorities for further investment in and development of BMPs.

The findings suggest decisions about adoption or prioritisations of BMPs need to be based on four considerations:

- the level of environmental benefits involved
- the net private costs and production trade-offs involved
- the barriers to adoption or changes in management practices
- the appropriate support or encouragement mechanisms available.

The effectiveness of BMPs in addressing catchment-scale environmental issues relates closely to their level of adoption but factors influencing adoption and incentives to adopt are complex, necessitating the consideration of both 'program factors' (e.g. new industry initiatives) and 'landholder factors' (e.g. need for new machinery).

Issues relating to adoption of BMPs are discussed under the headings: industry structure; private and public benefits; social and non-financial constraints; technical reasons; information and knowledge barriers; and attributes of sustainable practices.

There is a range of different policy options available to government, industry, scientific, and natural resource management groups to support and improve the adoption of BMPs and this report suggests that one way of viewing these policy options is to regard them as a continuum from voluntary engagement to regulatory controls. Options include (in increasing order of intervention):

- provision of better information
- use of suasion, information and support mechanisms to change attitudes and norms, and to promote engagement and take-up
- use of incentives and support mechanisms
- use of market-like mechanisms, such as purchases of environmental services to provide more direct incentives
- changes in property rights
- more targeted planning and approvals mechanisms
- direct regulation.

In order to make the link between farm actions and environmental goals clearer, this report describes BMPs in terms of environmental outputs to be gained; it groups BMPs into packages that are relevant to landholders, and identifies different levels of potential improvement to be reached. Combinations of actions appear as packages that address soil management, nutrient management and herbicide management. A four-class or classification system has been developed for these BMP packages. Each class represents overall improvement in farm management and overall progress towards target area goals, rather than the adoption of specific practices. Different stages of improvement have been classified as A, B, C, or D.

A workshop with canegrowers from the Proserpine region indicated that more than half of those growers believed they were likely to move to a B-level practice in this classification (industry recommended BMPs) within 3–5 years. This suggests a mixture of suasion, information and support strategies may be sufficient to encourage adoption to this standard. There was much less interest in moving to Class A standards, with less than half of the growers indicating that they would move to an A rating (future BMPs achievable with more precise technology and farming techniques) within 5 years. Economic reasons (additional costs and few production gains) were identified as key reasons for not changing quickly. This suggests that direct financial incentives and/or regulation may be required to encourage more rapid adoption.

Findings from the workshop also indicate that BMPs likely to be associated with net production benefits (where it may be easier to encourage adoption) are green cane trash blanketing, variety selection, soil health analysis, and nitrogen management. BMPs likely to be associated with net production costs (where adoption may be more difficult to encourage) are sediment traps, precision farming, controlled traffic and river and stream bank stabilisation. BMPs likely to be least acceptable are double-row harvesting, chemical ripeners and integrated pest management. BMPs with reasonable levels of acceptability but with negative production outcomes include river and stream bank stabilisation, precision agriculture and sediment traps. These BMPs may require specialised support packages.

Table 1 presents a number of conclusions and recommendations aimed at identifying where specific knowledge gaps exist, while highlighting solutions to the social and economic barriers to adoption as they relate to cane growing in the Mackay Whitsunday region. The table offers a mix of conclusions and recommendations under four headings: research priorities, categorisation and identification of BMPs, relevance of BMPs on farm and off, and mechanisms to encourage adoption.

It is intended that this report will be used by research providers, management agencies, industry groups and funding bodies such as regional NRM bodies, Commonwealth and State Governments to inform future effort in enhancing adoption practices, while guiding further investment in research in the Reef catchments, relating to land management impacts on water quality.

Table 1. Conclusions and recommendations arising from this report

Issue	Conclusions and recommendations
Research priorities	Greater attention needs to be paid to collecting scientific and technical information about the links between changes in farm management actions and impacts on water quality.
	A combination of modelling and monitoring at paddock, subcatchment and regional scales is required to establish the relationship between adoption of BMPs and improvement in water quality.
	An audit mechanism for defining adoption of BMPs spatially and temporally is required.
	A mechanism for prioritising BMPs that deliver different types of water quality improvements (e.g. sediment reductions versus nutrient reductions versus chemical reductions) needs to be developed.
	A detailed investigation into the impediments to change in the Mackay Whitsunday region needs to be carried out and strategies to overcome these impediments need to be developed.
Categorisation and identification of BMPs	A number of 'leading-edge' BMPs for soil, nutrient and chemical management are associated with precision farming techniques, careful assessment and record keeping, and specific within-block treatments. There are typically economies of scale in improvements across several BMPs at the same time.
	BMPs for water quality actions on farms should be packaged into groups with a simple rating system to facilitate engagement with farmers. Suggested groupings are: soil management, nutrient management, chemical management and irrigation and waste water management.
	Reduction in the loss of soluble nutrients can be best achieved by closely matching soil fertility and fertiliser application rates to the crop requirements and other available nutrients.
	The loss of residual pesticides can be most effectively reduced by using those with alternative active ingredients, enabling lower application rates and alternative application strategies such as banding and precision application.
	The widespread adoption of minimum/zero tillage in fallow, rotational and cane cropping lands will give the greatest reduction in sediment, particulate nitrogen and particulate phosphorus losses from caneland in the Mackay Whitsunday region.
	Tailwater recycling and the construction of detention basins to trap first flush storm water and irrigation run-off will also reduce losses of soluble nutrients and sugar.
	Extra environmental benefit can be achieved by the use of managed grassed headlands, drains and filter strips. However, unless the delivery of material to these areas is reduced by better soil management practices, their sediment trapping abilities are soon overwhelmed.

Issue	Conclusions and recommendations
Moving beyond a focus at the single farm	A focus on a broad range of BMPs within groups (such as soil management BMPs) should be maintained to maximise relevance and participation, and to generate cost-effective engagement. In some cases it may be more cost-effective to implement BMPs across multiple farms. Separate BMPs may be required for development issues, where there may need to be an interface with the development process and approving bodies. These are particularly those relevant to risks of acid sulfate soils, water storages and biodiversity impacts Collaboration with sugar mills and other relevant stakeholders may be important, particularly for: improving the effectiveness of mill waste reuse (particularly mill mud and boiler ash); improving the efficiency of transport systems and reducing loss of cane juice; and the provision of GPS base stations to encourage precision farming.
Mechanisms to encourage adoption	Various strategies can facilitate the adoption of BMPs. A mixture of different support mechanisms should be used depending on the level and speed of uptake required, and the different trade-offs that might be involved. The choice of an implementation strategy should be sensitive to the level of environmental benefits involved, the net private costs and production trade-offs involved, and other barriers to adoption or changes in management practices. The selection of the appropriate policy instrument to encourage adoption of BMPs should be based on the levels of private and public benefits involved. A range of information, encouragement and support mechanisms may be sufficient to move growers to Class B standards (industry recommended standards). More direct financial incentives and targeted support mechanisms may be required to achieve adoption of Class A standards. Voluntary mechanisms are generally seen by most stakeholders as preferable to regulation but should not lead to inaction.

1. INTRODUCTION

In 2005, the Consortium for Integrated Resource Management (CIRM), through its Reef Catchments Working Group (RCWG), completed a detailed analysis of research and development relating to the Reef Water Quality Protection Plan (Reef Plan) (State of Queensland and Commonwealth of Australia, 2003). The RCWG, which included both R&D users and R&D providers from 18 organisations, first produced a compendium of current R&D being undertaken to support the Reef Plan (Prange et al., 2005), then later that year, a detailed analysis of R&D needs and priorities for future research to support the Reef Plan (Clark et al., 2006) was published.

Clark et al. (2006) suggested more work was needed to develop new models for water quality processes, including the translation of that information into knowledge that would lead to comprehensive, well-understood decision-making tools for land managers and policy makers. A clear understanding of community needs and aspirations was also required, to provide insight into the factors that encourage or inhibit the uptake of new and existing improved management approaches intended to sustain good water quality.

In particular, Clark et al. (2006) identified the need for refinement and evaluation of current best management practices (BMPs), especially in relation to their contribution towards minimising adverse downstream impacts. It was argued that before commissioning new reef-related research on diffuse pollutants, a synthesis of what was already known of BMPs and their adoption by land managers ought to be a priority. Of those land practices operating within the reef catchments, sugar cane was selected as the focus of this work, due to the pre-eminent role the industry plays in the region.

The RCWG was aware that uncertainty remained on what BMPs were available, their rates of adoption, and their consequential benefits to downstream water quality.

To address these shortcomings, CIRM commissioned, in 2007, a research team from Central Queensland University (CQU) to:

- identify BMPs in the cane industry relevant to achievement of Reef Plan goals
- assess the impacts on water quality that would be generated by the adoption of the various BMPs
- identify production trade-offs (economic incentives and barriers) that might be associated with the different BMPs
- identify other social, knowledge and attitudinal factors that might limit adoption of the different BMP practices.

The cane growing region of eastern Queensland from Proserpine to Sarina (known in the sugar industry as the Central Region) was chosen as the focus region. Figure 1 shows the region’s location and its proximity to the Great Barrier Reef World Heritage Area.

This report derives from an unpublished report to CIRM by Rolfe et al. (2007) and it represents a compilation of new and existing knowledge on current BMPs for sugarcane farming, with emphasis on practices that lead to improved water quality. It will inform strategic policy makers and land managers about issues that relate to and impact on extension, policy development and regulatory responses outlined in the Reef Plan, and will also contribute to a shared understanding by all stakeholders of the knowledge needed to support the implementation of enhanced property-level management practices. For completeness, the report includes a précis of local water quality issues and related BMPs. The report is also intended to be relevant to current and proposed investments in R&D by Commonwealth, State, local and regional stakeholders.

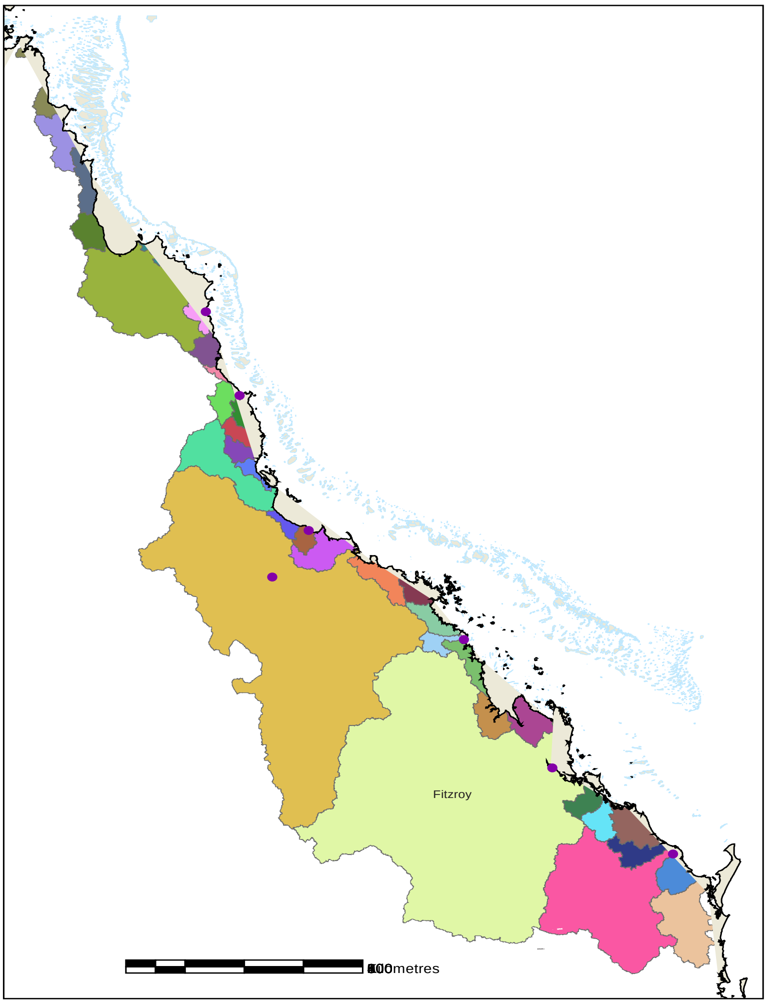

Figure 1: Coastal Queensland catchments covered by the Reef Plan
The Central (cane-growing) Region is centred on Plane Creek, Mackay and Proserpine (map courtesy of Reef Plan)

2. METHODOLOGY

A desktop study was conducted to identify BMPs for sugarcane production in the Mackay Whitsunday region that are important for improving water quality. To do this, close collaboration occurred between CQU researchers and staff from the Mackay Whitsunday NRM Group, followed by workshops with sugarcane growers in the Mackay and Proserpine areas to gather some primary data.

A five-part methodology was employed. The key components were:

- a desktop review in 2007 of published and grey literature relevant to water quality and sugarcane growing in eastern Australia, particularly in the Central Region of coastal Queensland
- identification and evaluation of relevant BMPs for sugarcane farming, from workshops conducted in late 2006 by the Mackay Whitsunday NRM Group with interested scientists, industry representatives and policy makers
- in-depth review of literature and evaluation of BMPs by the research team, including the likelihood of adoption and the expected success of the BMPs in achieving enhanced water quality outcomes
- two workshops with a small selection of canegrowers and other stakeholders from Mackay and Proserpine in mid-2007 to test the developed scenarios and to “score” perceptions of economic and social barriers to adoption in the region
- a multi-authored report for distribution by CIRM, complete with a synthesis of the key findings and supported by conclusions and recommendations.

Two key limitations of the project findings should be noted. These are that the results are focused on a small sample of canegrowers in the Mackay Whitsunday region and the work has largely been drawn from a desktop audit.

3. BACKGROUND

3.1 Queensland’s Central Region

This cane growing region on the coastal plains east of the Great Dividing Range extends from Eden Lassie Creek between Bowen and Proserpine in the north to Flaggy Rock Creek near Camilla in the south. The four main hydrological basins are the Proserpine, the O’Connell, the Pioneer and the Plane. In 2005, 9.8 million tonnes of cane were harvested from 114,880 ha, yielding 1.3 million tonnes of sugar (CANEGROWERS, 2006). This represents 30 per cent of Queensland’s canegrowing area and 27 per cent of the cane harvested in Queensland. Disease and drought have reduced the amount of cane harvested in the Central Region over the last four years (CRSG, 2007). Cropping in the Mackay Whitsunday region (mainly sugar cane) accounted for approximately 85 per cent of agricultural production in the area (Rohde et al., 2006a).

There are 1,664 canegrowers the Central Region (184 in the Proserpine area; 1,250 in the Mackay area; 230 in the Sarina area) (QDPIF, 2007). Moreover, the region supports six raw-sugar mills (Proserpine, Pleystowe, Marian, Farleigh, Racecourse and Plane Creek), run by three different entities (Proserpine Cooperative, Mackay Sugar and CSR). CSR also operates a distillery in Sarina. The growers obtain their technical support and advice mostly from BSES Limited (BSES), the regional CANEGROWERS organisation and (to a lesser extent) environmental protection and natural resource management agencies. Many of the growers provide supplementary irrigation from surface water storages and from groundwater. Nitrogen-phosphorus-potassium (NPK) fertilisers are commonly used while sugar mill and distillery wastes are returned to some farms.

3.2 Water quality issues

The quality of water draining from the eastern seaboard of Queensland has the potential to impact on environmental resources in the Great Barrier Reef World Heritage Area. A wide range of industries in the Great Barrier Reef catchment contribute pollutants and sediments to the Reef (Haynes et al., 2001; Haynes and Michalek-Wagner, 2000; Moss et al., 1992). However, the main sources of pollutants appear to be from diffuse sources such as from agriculture (Productivity Commission, 2003). The pollutants include sediments, nutrients and chemicals from cropping and grazing land in catchments adjacent to the Great Barrier Reef World Heritage Area (Mitchell et al., 1996; Furnas, 2003, Productivity Commission, 2003; State of Queensland and Commonwealth of Australia, 2003). For the central Great Barrier Reef, 40 per cent of external nitrogen (N) and 55 per cent of external phosphorus (P) inputs are believed to derive from land-based sources (Furnas et al., 1995).

There is evidence that nutrient loads are now several times greater than pre-European levels. Sediments with enriched nutrient levels are emerging as being detrimental to coral reef organisms (Fabricius, 2005) and are reaching and impacting on seagrasses, inshore reefs and marine animals (Furnas, 2003, Fabricius et al., 2005, Wolanski and De'ath, 2005).While these effects are mainly felt by coastal fringing reefs, deleterious changes to mid-shelf reefs are likely to occur in the future unless processes are put in place to manage land-based pollutants (Furnas et al., 1995).

The Reef Plan's goals are to reduce the amount of pollutants from diffuse sources entering the Reef and to rehabilitate and conserve areas of the Reef catchment that are influencing the levels of waterborne pollutants (State of Queensland and Commonwealth of Australia, 2003). Agricultural industries relevant to the achievement of these outcomes include cattle grazing, sugar cane, horticulture, cotton and cereal cropping. The Reef Plan has a range of strategies and actions to achieve its goals, including support to rural landholders to adopt BMPs. A good example in the Australian sugar industry is the self management of acid sulfate soils in northern New South Wales (Beattie et al., 2001). In addition, Reef Plan Action D8 requires the identification of nutrient management zones that will provide a focus for improving land management practices and reduce nutrient export (Brodie, 2007; QDPIF, 2007).

3.3 Sugar cane and water quality in the Central Region

Sugar cane is grown on about 400,000 hectares in Queensland but accounts for only around one per cent of the total area of the Great Barrier Reef catchments (Productivity Commission, 2003). Nevertheless, its intensive land use in areas with high rainfall and its close proximity to the coast mean that the industry is often identified as one of the key contributors to water quality impacts (QDPIF, 2007). Sugarcane production is estimated to account for about 75 per cent of applied N and 35-40 per cent of applied P in the coastal zone of Queensland (GE Rayment, Department of Natural Resources and Water, pers. comm.).

The coastal waterways in the Central Region have been assessed as having poor water quality, with high levels of nutrients, excessive turbidity and the presence of agricultural chemicals being the main problems, but low dissolved oxygen and cyanobacterial blooms are also a problem in some locations (Brodie, 2004). There is significant delivery of sediments to the Reef lagoon from the catchments of rivers across the Mackay Whitsunday region (Mitchell et al., 2005; McKergow et al., 2005).

Rohde et al. (2006b) reported that results of Sednet/ANNEX modelling indicated that hillslope erosion was the dominant source (85 per cent) of sediment supplied to streams, with the majority of this being exported to the coast due the relatively short, steep streams (where there are no major water storages). The region discharges approximately 0.25 kt/km^2/yr of sediment to the Great Barrier Reef, with the highest land-use contributions from grazing and cane (47% and 20% of the land use area respectively).

Total phosphorus load exported to the coast was estimated at 1700 t P/yr and was dominated by particulate phosphorus (associated with sediment). Total nitrogen exports to the coast were estimated at 7700 t N/yr split evenly between particulate and dissolved fractions. Dissolved inorganic nitrogen (DIN), comprising 30 per cent of the modelled total nitrogen load, was associated with the relatively large area of cane (Rohde et al., 2006b). Water quality monitoring in the 2004–05 wet season recorded high losses of dissolved inorganic nutrients (especially nitrates and phosphate) and persistent herbicide detections (particularly atrazine, Diuron and hexazinone) from sugarcane subcatchments (Rohde et al., 2006a). Multiple estimates including those by Moss et al. (1992), Furnas (2003) and Brodie (2004) have previously identified excess nutrients and agricultural chemical contaminants as major water quality issues in this region.

3.4 Efforts to improve water quality

Changes in management practices by agricultural producers are key activities in efforts to reduce water quality impacts. There have been significant advances in sediment and nutrient management practices in the sugarcane industry since the 1980s, particularly with the widespread adoption of green cane trash blanketing. The latter practice is credited with up to 90 per cent reduction in sediment movement off farms (Prove et al., 1995; Rayment, 2002). Green cane harvesting has increased from 30 per cent of land area in 1990 to 73 per cent of land area by 2005 (QDPIF, 2007).

There is evidence of a 20 per cent reduction in N and P fertiliser applications in sugarcane production in eastern Australia between 1996 and 2002 (Wrigley, 2005a). This has been attributed to changes in farming practices, particularly green cane trash blanketing, but may also be related to the closure of less viable cane farms when international sugar prices were at record lows in the early years of the 21st century. Estimated application rates for N and P on sugar cane in the Mackay Whitsunday region are shown in Figure 2.

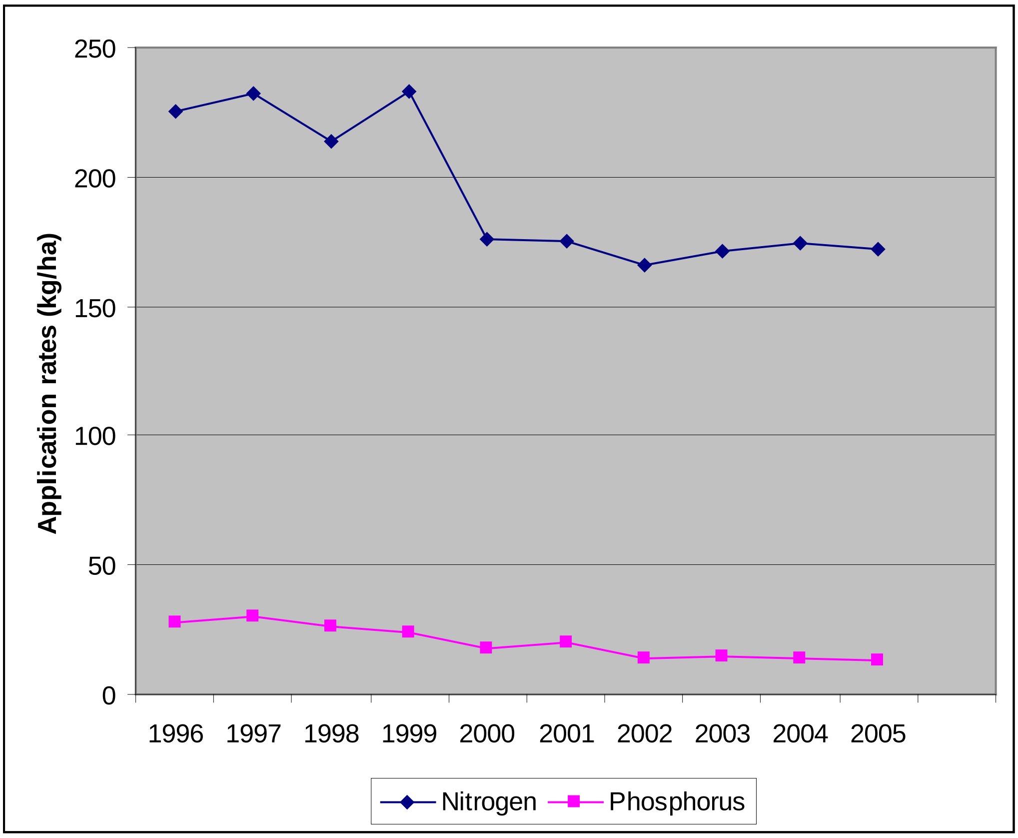

Figure 2. Application rates of N and P on sugar cane in the Central Region
(Kuhn, 2006, reported in QDPIF, 2007)

The Code of Practice for Sustainable Cane Growing in Queensland (CANEGROWERS, 1998) includes a range of recommended practices relating to all aspects of farm management and aims to assist growers in the environmentally sustainable development of both new and established farms. The Code includes recommendations for erosion reduction, minimising fertiliser application, efficiency in the use of irrigation water, as well as protection of streambank vegetation and the creation of artificial wetlands. This Code of Practice has been extended by programs such as Combining Profitability and Sustainability in Sugar (COMPASS), a self assessment of farming practices (Azzopardi, 2001).

The Rural Water Use Efficiency Initiative, a partnership between CANEGROWERS, BSES and the Queensland Department of Natural Resources and Water (NRW) has expanded its program of water efficiency to include on-farm management of nutrients and water quality monitoring.

The Sugar Yield Decline Joint Venture has developed a new cropping system involving minimum/zero tillage, controlled traffic and legume break crops (Garside et al., 2006). FutureCane, funded by the Queensland Government through the Department of Primary Industries and Fisheries (QDPIF) in partnership with BSES (QDPIF, 2005), aims to increase the adoption of an integrated farming system model comprising the farming system, business planning and financial management together with market and trade development of alternative crops. The Sugar Research and Development Corporation's

New Farming Systems aims to develop guidelines for controlled traffic and fallow management.

There are a number of nutrient management initiatives. The Six Easy Steps package establishes regional nutrient management guidelines with increased emphasis on testing nutrient levels and budgeting for crop nutrient needs (Schroeder et al., 2006). NRW's Safegauge for Nutrients and Soil Constraints and Management Package (SCAMP) enables growers to assess risks associated with the off-site movement of N. In addition, Bloesch and Rayment (2006) have reported two new environmental soil phosphorus tests particularly for cropping systems in coastal Queensland. Their use adds little to current soil testing costs.

The Natural Heritage Trust-funded Sugarcane Farm Management Systems Project aims to pull a wide range of existing farming practices together into an integrated program agreed by all sectors (Wrigley and Moore, 2006). These sustainable farming outcomes can be driven by regional focus groups developing environmental risk assessments and BMP registers (Wrigley, 2005b). FERTCARE is a national training and accreditation initiative provided by the Australian Fertiliser Services Association and the Fertiliser Industry Federation of Australia. It has been developed to improve the skills and knowledge of all individuals involved in the supply and distribution of fertilisers and to assist in optimising environmental stewardship, occupational health and safety, food safety and agricultural profitability.

4. BEST MANAGEMENT PRACTICES

4.1 BMPs for sustainable agriculture

Discharges from agricultural land generally originate from diffuse sources, as opposed to localised point sources. Their diffuse nature makes it difficult to identify the contribution of any particular industry or enterprise, or to specify how changing a farm management practice will translate into a specific improvement in water quality. As well, the linkages between actions, water pollution and any subsequent environmental damage are not always clear (Davidson, 2003).

Instead of addressing direct linkages for actions that may cause environmental problems on a case-by-case basis, a preferred approach for agricultural industries has been to promote a number of generic BMPs that are connected to environmental objectives through sound biophysical principles (Thorburn et al., 2007). Examples of BMPs that have been promoted include activities that maximise ground cover, protect riparian vegetation, and minimise soil erosion and the transport of chemicals and fertilisers into waterways. In some industries, such as irrigated cotton, BMPs have been formalised and extensive adoption campaigns have been run to facilitate adoption. In other industries, such as grazing, the promotion of BMPs has been low-key.

Some confusion exists, however, in the use of the term BMP. At any point in time within an industry there are a variety of practices adopted by individual enterprises. These will range from poor practice, to standard industry practices, to innovative practices developed by leading growers and/or researchers.

Practices recommended by industry bodies may be formalised within an industry-based farm management system or code of Practice. Best management practice can be used to refer to the leading edge of demonstrated innovative farming practice, but is also commonly used to refer to codified industry standards. Standards also change, as new technologies and practices are developed and established, so that over time innovative practices may become the new industry standards.

The range of benefits achieved by moving up this scale may relate to profitability, productivity and/or wider environmental benefits. For many growers, BMP has a production efficiency focus, while for researchers it may imply a focus on minimising environmental impacts. Maximising profitability and minimising environmental harm or risk is desirable but may not be practicable. Considerable debate resides in defining the thresholds and trade-offs that may exist between these benefits. Adoption of any specific practice by a grower is also contingent upon how that practice fits within their overall farming system and the environmental constraints of that particular farm. Within this document the term BMP is used to refer to practices that are considered to achieve water quality benefits within a profitable business enterprise in today's farming environment.

There are three key advantages of focusing on BMPs as a way to address environmental impacts from agriculture:

- it allows actions to occur where detailed scientific or technical information may not be available
- it focuses on the dual goals of improving efficiency for both production and environmental outcomes
- it summarises a number of technical issues into a format that is relevant to landholders.

Although BMPs may be an effective short-term solution to issues where scientific understanding is incomplete, it is important to improve information about how changes in management practices impact on water quality. Many scientific studies have focused on identifying water quality issues or understanding the impacts of poor water quality on natural resource assets (e.g. Fabricius, 2005). However, less attention has been given to identifying or predicting how changes in agricultural management practices will improve water quality parameters and address environmental issues. It follows that BMPs may need to be revised as more of this understanding becomes available.

For example, a combination of modelling and monitoring at paddock, subcatchment and regional scales could help to establish the relationship between adoption of BMPs and improvement in water quality. An audit mechanism for defining adoption of BMPs spatially and temporally is also required.

4.2 Existing BMPs for growing sugar cane

Numerous BMPs have been identified in different programs for improving environmental outcomes and improving water quality. The sugar industry's Code of Practice (CANEGROWERS, 1998) has 11 core categories of BMPs dealing with sustainable cane growing, including impacts relevant to water quality. These are summarised in Appendix 2. Roebeling and Webster (2007) identified both current and future BMPs relevant to sugarcane production in the Tully-Murray catchment in the North Queensland region. These are detailed in Appendix 3. Other summaries of BMPs have been published for the Douglas Shire (Roebeling et al., 2004) and the lower Burdekin (Davis, 2007; Thorburn et al., 2007).

A cane farm is a mosaic of different crop stages, each with different management practices, often interacting with different soil types and topography. Within the crop stages, different soil, fertiliser, chemical and irrigation management practices can be applied to improve water quality and the efficiency of production. There are also a number of landscape elements within farms, including not only the fields but also headlands and drains within and between fields, which can also be managed. Other issues to consider include the impacts of new developments, the disposal of mill wastes, and potential losses and impacts during transport of cane and mill wastes. Thus there are potentially a very large number of on-farm and nearby practices that could be given BMP status. Discussion of BMPs is best done by grouping BMPs on the basis of some common purpose.

Thorburn et al. (2007) identified four goals that aligned with the main water quality parameters of interest in irrigated sugarcane production in the Burdekin region. Best management principles were identified under each goal for each stage of the production cycle. This approach allows a collection of on-farm actions to be linked to specific water quality goals through detailed management principles. Their four goals were:

- Erosion management: aiming to reduce losses of sediments in run-off as well as chemicals attached to those sediments
- Nitrogen management: aiming to reduce the likely N concentrations in run-off and deep drainage
- Herbicide management: also aiming to reduce concentrations in run-off and deep drainage
- Water management: aiming to reduce the amount of water leaving farms through run-off and deep drainage, both pathways that impact on local and off-site water quality.

4.3 BMPs relevant to canelands in the Central Region

A list of BMPs for canelands in the Mackay Whitsunday region was generated through a workshop process with a range of cane industry stakeholders held in Brisbane in October 2006. The workshop was coordinated by Mackay Whitsunday NRM Group and the summary list of identified and future practices is shown in

Table 2. The BMPs are arranged into groups similar to those of Thorburn et al. (2007) for clarification purposes. The information provided in the table includes a summary of current practices (to provide a baseline), together with a range of potential BMPs. Within the groups of management practices, many BMPs are overlapping or nesting within more inclusive ones.

Important considerations in the selection of management actions are combinations of actions and how they relate to water quality outcomes. For example, some actions are only feasible when they occur in combination with others, such as some types of targeted fertiliser management that can only be implemented with adoption of precision farming techniques.

Table 2. Cane management practices and BMPs for the Mackay Whitsunday region

Management practice group	Cane management practices
Soil management	**Current practices** Fully cultivated plant cane and trash burnt Minimum till plant cane (residual herbicides) and trash burnt Fully cultivated plant cane and green cane trash blanketing Minimum till plant cane (residual herbicides) plant cane and green cane trash blanketing **BMPs** Annual soil management and action plan (including soil testing) Permanent bed controlled traffic, zero till plant cane Zonal tillage Permanent bed controlled traffic zero till plant cane with soil remediation between cycles Zero till fallow Detention basins and wetlands Filter strips, waterways and headlands GPS guidance Harvester optimisation
Fertiliser management	**Current practices** Surface granular NPK Underground granular NPK (side dress or stool split) Biodunder/*Liquid One Shot* applied at same rate as granular NPK Mill mud (+/- ash) applied at high rates once per crop cycle **BMPs** Annual nutrient management and action plan based on comprehensive soil testing and crop predictions and all sources of nutrients accounted for e.g. legumes, mill mud and irrigation water Schroeder (BSES) nutrient application rates (including soil testing, leaf analysis and NIR nitrogen analysis at mill) Thorburn (CSIRO) nutrient application rates (including soil testing, leaf analysis and NIR nitrogen analysis at mill) Mill mud application at low annual rate Legume fallow or crop rotations Variable rate application technology Split application of fertiliser Fertigation Slow release fertiliser products
Chemical management	**Current practices** Residual herbicides in plant cane and ratoons Knockdown herbicides for fallow **BMPs** Annual chemical management and action plan based on weed pressure and climate Application technology improved placement, timing 50 per cent banded residual herbicide strategy No residual herbicide strategy Precision herbicide strategy Fallow management, crop rotations

Management practice group	Cane management practices
Irrigation water management	**Current practices** Furrow (flood) irrigation High pressure overhead Other systems may include low pressure overhead, drip or trickle irrigation **BMPs** Annual water management and action plan based on soil types, crop stage, water allocation and climate Irrigation system audit and action plan to identify and address inefficiencies and losses Tailwater recycling Timing of irrigation with application of fertilisers and chemicals Irrigation scheduling based on soil types, crop stage and readily available water content Change flood or high pressure overhead irrigation to more efficient system – low pressure overhead, drip or trickle irrigation Effluent irrigation water to be kept on farm Saline water to be retained on farm Turbid water to be retained on farm

5. ADOPTION OF BEST MANAGEMENT PRACTICES

The effectiveness of BMPs in addressing catchment-scale environmental issues relates closely to their level of adoption by farmers. Lockie and Rockloff (2004) noted that factors influencing landholder adoption of BMPs and incentives are complex, necessitating the consideration of both ‘program factors’ and ‘landholder factors’.

The decision about adoption or prioritisation of BMPs should generally involve an assessment of the environmental benefits to be gained from adoption relative to the costs and level of support associated with implementation. Key factors to consider include:

- the level of environmental benefits involved
- the net private costs and production trade-offs involved
- the barriers to adoption of changes in management practices
- the appropriate support or encouragement mechanisms available.

5.1 Issues that enhance or impede adoption of improved management practices

Early studies about adoption rates of changes in farm management in Australia began in the 1940s and 1950s, with the research showing that the adoption of more sustainable agricultural management practices was often associated with socio-economic characteristics such as income, debt, education, and social participation (Productivity Commission, 2003; Cary et al., 2002). In the 1970s, several studies found the adoption of ‘environmental innovations’ cannot be predicted using the same variables as those associated with the adoption of ‘commercial innovations’ (Lockie and Rockloff, 2004). Some of the key issues relating to adoption rates are discussed next.

Industry structure

The sugar industry has a long history of production in Queensland and is characterised by a large number of small producers on family farms. As a consequence, many canegrowers have traditional or set farming practices and may be reluctant to change.

Private and public benefits

A key driver of adoption is likely to be the levels of private benefits accruing to the individual canegrower, normally through improvements in farm productivity and/or reductions in farm costs. The levels of private benefits are likely to vary with BMP as well as across and within enterprises, helping to explain the diversity of farm management practices within a regional area, as well as variations in BMP adoption rates. Financial and profit constraints are key reasons for slow adoption rates (Productivity Commission 2003; Lockie and Rockloff 2004; Rolfe 2006). Landholders will adopt new practices if real future benefits exist and any periodic or permanent loss of production is avoided so no financial losses are incurred. If practices are not 'adoptable' then simply increasing the levels of information or extension will not increase levels of uptake (Pannell et al., 2006). Some of the economic reasons BMPs may not be adopted include:

- costs of implementation
- capital investment required
- production losses involved
- scale of farm operation and existing financial constraints
- time and other financial contributions required by landholders.

Public benefits relate to the benefits the wider community receives from improvements in environmental outcomes. There may be very little correlation between the private and public benefits of BMP adoption, with the latter also varying both within and across BMPs. As the Productivity Commission (2003) noted, "those who take voluntary actions to limit discharges are rarely rewarded for the benefits they provide in the Reef lagoon, while those who degrade water quality are unlikely to bear any significant part of the costs they impose on others". For example, there may be significant environmental improvements (public benefits) associated with grass filter strips, but for the landholder who adopts them, these are likely to reduce the production area for farming and generate net production costs. This will be a disincentive to adoption.

Social and non-financial constraints

A number of landholder characteristics and social contexts appear to be important in explaining behaviour, including BMP adoption rates (Productivity Commission, 2003). Landholders do not act simply; they make land management decisions taking into account a complex mix of social and attitudinal factors, including historical patterns, personal circumstances, individuals' personal attributes (including values, goals, knowledge, age) and peer pressure (Rolfe, 2006; Lockie and Rockloff, 2004; Breetz et al., 2005; Productivity Commission, 2003). Landholder and non-financial factors that can be important include:

- BMPs may not align with farmer objectives and outlooks
- farmers may not trust the information provided
- attitudes to risk may limit trials and adoption of new practices
- farmers may not have all the skills required for some BMPs
- innovations and programs may require farmers to invest considerable time and effort
- there may not be peer group support for adoption of practices.

Technical reasons

Adoption rates may be linked to the complexity and technical requirements of the actions involved. BMPs that should be easier to implement are those that are small-scale, focused on a single item or issue, amenable to testing before full implementation, have relatively low cost, are not technically very complex, and do not require large amounts of time or other inputs. Therefore, BMPs that are large scale, complex, and require investments in technical skills and inputs are likely to have lower adoption rates. Some situations where adoption rates may be lower for technical reasons include:

- large-scale and complex changes required in farm operations
- incompatible fit with existing farm layout or operations
- transport costs may limit options (e.g. mill by-product disposal)
- cost-effective solutions may not yet be developed (e.g. cane juice loss during harvest and transport)
- legislative, bureaucratic or regulatory controls may limit certain actions or be a disincentive to others.

Information and knowledge barriers

Gaps in knowledge or information can be reasons for lack of adoption or slow adoption of BMPs. For example, some damage tends to occur with occasional extreme events such droughts, intense storms and cyclones. Because the linkages between management and land condition across seasonal variations remain poorly understood, management for different risks of extreme events is a complex task. Knowledge gaps may occur when:

- farmers have limited information and knowledge about BMPs
- there is limited technical information about specific adoption issues
- limited experimentation and rollout has been conducted to provide examples or to encourage adoption through action learning
- some BMPs are not very suitable for trialling on a small scale prior to full implementation
- the benefits of some BMPs are not always apparent
- farmers' attitudes to risk and uncertainty have not been satisfied by the clarity and/or amount of available information.

Attributes of sustainable practices

Cary et al. (2001) conducted a major study for Land and Water Australia into the drivers and constraints for the adoption of sustainable practices. They summarised the attributes of sustainable practices that have been found to be important in determining whether or not a practice is readily adopted. The attributes were:

- *Geographic applicability* – refers to relative appropriateness of a practice, in terms of whether it is effective or adapted to only specific localities or, more universally, across many localities.
- *Relative advantage* – the financial advantage or other convenience or personal advantage to the farm business or the adopter.
- *Risk* – refers to uncertainty about likely benefits or costs associated with a sustainable practice, uncertainty about the effectiveness of the practice, uncertainty as to when the benefits might be realised and uncertainty regarding the social acceptability of the practice.
- *Complexity* – implies that a practice comprises more than one or two simple elements and that its elements interact with each other and, in sometimes complicated ways, with elements of the farming system into which it is to be incorporated.
- *Compatibility* – the extent to which a practice fits in with existing farm practices, or with existing knowledge or existing social practice.

- *Trialability* – where practices can be implemented on a small or pilot scale, decisions can be more easily made about the value of a new practice without the risks associated with full implementation.
- *Observability* – practices whose impact or advantage is easily observable, or whose outcome is quickly realised, are more likely to be adopted.

On applying these to a nationwide list of sustainable practices, Cary et al. (2001) concluded:

- *There is no one sustainable practice which optimally comprises all the attributes* by being widely applicable, having high relative advantage to the landholder, low complexity, high compatibility, high trialability and observability, and low risk.
- *Very few sustainable practices have widespread or universal geographic applicability*. As a consequence, the identification, development and promotion of relevant sustainable practices need to be locality- or catchment-specific.
- *The sustainable practices with wider geographic applicability often provide only moderate relative advantage* to the landholder. The relative advantage will be different in different localities.
- *The level of relative advantage is rarely independent of commodity prices*. The relative advantage of many sustainable practices will be temporally dependent on the value of rural commodities produced as a result of using the practice. Low commodity prices in the broadacre industries have reduced the relative advantage of many sustainable practices.
- *The relative advantage and risk attributes are the least mutable in terms of feasible policy interventions*. Where relative advantage is low and risk is high, attempts to achieve wide-scale adoption will require large levels of external subsidy or insurance intervention. It will be more feasible to promote those sustainable practices which have higher relative advantage (and preferably lower risk) and to use policy interventions (such as extension and education programs) to overcome or ameliorate complexity and low compatibility and observability.

5.2 Mechanisms to facilitate adoption

Adoption of new practices is typically a gradual process. It takes time for knowledge about new practices to transfer from researchers to producers, usually diffusing through early adopters and innovators to be gradually taken up by mainstream producers. As a general rule, many practices that have production benefits can take up to twenty years to be completely adopted across an industry. Because adoption rates can be slow, there is interest at a policy level in identifying strategies and support mechanisms that might facilitate adoption, particularly for BMPs that are more environmentally focused. For example, the New South Wales acid sulfate soil program was a four-year, state-wide approach involving all canegrowers in the state (Beattie et al., 2001).

A range of policy options is available to government, industry, scientific and natural resource management groups to support the adoption of BMPs. One way of considering policy options to support and improve adoption rates is to view them as a continuum between voluntary engagement mechanisms and regulatory controls. Options include (in increasing order of intervention):

- the provision of better information (can be across a range of media, demonstration and action learning mechanisms including participative research)

- the use of suasion, information and support mechanisms to change attitudes and norms and to promote engagement and take-up
- the use of incentives and support mechanisms
- the use of market-like mechanisms, such as purchases of environmental services to provide more direct incentives
- changes in property rights
- more targeted planning and approvals mechanisms
- direct regulation.

Details of these support mechanisms are outlined in Table 3.

Table 3. Mechanisms for supporting improved adoption rates of BMPs

Type	Mechanism	Attributes and examples
Voluntary	Information provision and education	Can change information and attitudes to different BMPs
	Encouragement and support mechanisms	Programs to engage landholders and support involvement in BMPs
	Local peer group learning programs	Use participative programs to increase awareness and understanding
	Decision support mechanisms	Development of paddock-scale nutrient management plans
	BMP guides and industry recommendations	Self-regulation by industry
	Financial and technical assistance	Grants and technical support offered to trial new mechanisms
Market-based systems	Conservation auctions and ecosystem service payments	Farmers tender for public funds, with most efficient bidders gaining contracts to change management actions
	Trading with point-source dischargers	System of trading nutrient credits, so industries might contract with farmers to make offset reductions
	Offsets	Farmers might negotiate trade-offs between different on-farm actions
	Conditional assistance	Assistance to farmers might be tied to the uptake of BMPs
Regulatory	Levies	Levy imposed on farm inputs (e.g. fertiliser) that create emissions
	Permits (e.g. registration of chemical use)	Permit system limits farm inputs or certain actions that have water quality impacts
	Contracts	Contracts between farmers and other industry sectors establish BMPs as a requirement to allow business to occur
	Planning and approval processes	Regulatory approval required to change processes or implement new developments
	Changes to property rights	Property rights are more tightly specified to identify allowable actions

5.3 Selection of policy instruments

Pannell (2006) discusses the selection of environmental policy instruments to encourage changes in land management on privately owned lands in order to enhance environmental conservation or natural resource management. The selection of the policy instrument is determined by the relationship between public and private benefits, as demonstrated in Figure 3.

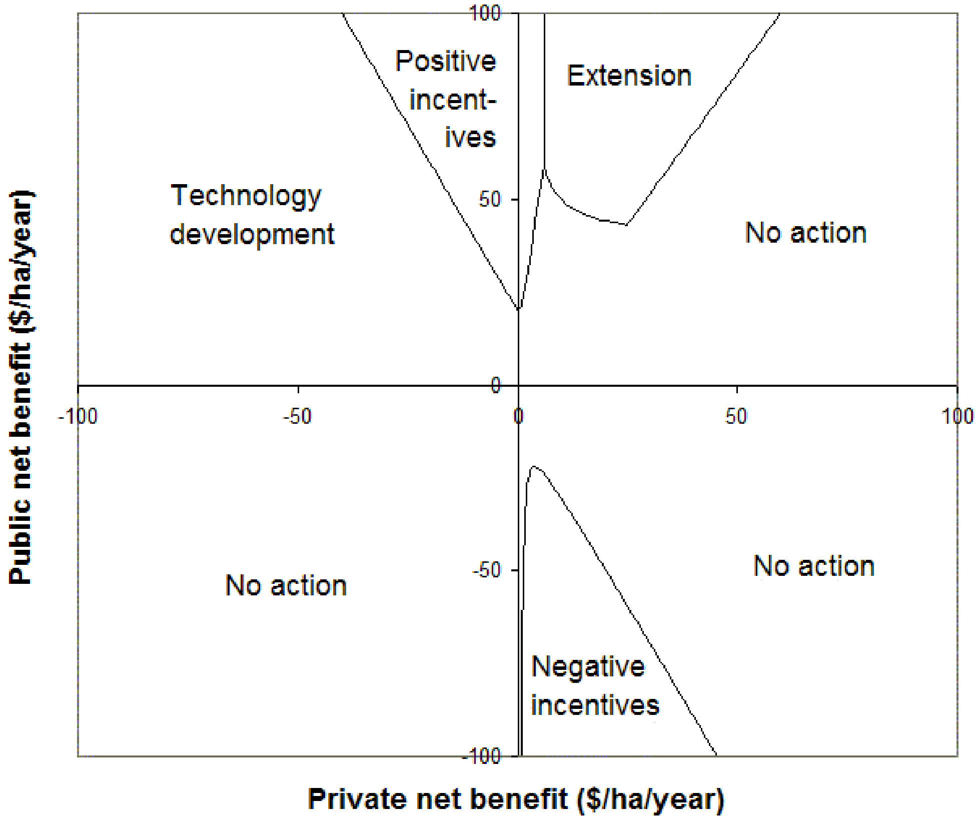

Figure 3. Efficient policy mechanisms for encouraging changes in land management on privately owned land (refined to account for lags to adoption and learning costs, and assuming that managers require a benefit:cost ratio >2) (Pannell, 2006)

Where there are positive public benefits but negative private benefits the development of better technologies or the use of positive incentives is appropriate. Where there are public benefits and limited levels of private benefits, then extension policies are more appropriate. Actions associated with high levels of both private and public benefits should not require any intervention because there should be sufficient private incentive to encourage change.

The higher-priority projects are those where private net benefits are closer to zero and/or public net benefits are more extremely positive or negative (Figure 3). Pannell (2006) discusses the influences of lag periods, learning costs and different cost-benefit ratios on this analysis.

5.4 Program factors influencing adoption

Lockie and Rockloff (2004) report that program factors are usually the predominant focus of participants' concerns regarding sustainable management programs. Landholders are not autonomous actors: their decisions to participate in different programs are taken in an environment that is complex and dynamic. Programs or support mechanisms that involve large transaction costs, increased risk and uncertainty, impact on perceived rights, or have complicated design characteristics, are likely to have lower levels of involvement (Rolfe, 2006). The characteristics of programs that influence landholders' participation can be summarised as follows (Vanclay, 1992; Productivity Commission, 2003; Lockie and Rockloff, 2004):

- *Complexity* – complex innovations and programs require greater management skill and detailed understanding of processes
- *Congruence* – programs need to be compatible with farm and personal objectives
- *Economics* – the greater the financial returns from an innovation, the greater will be its adoption
- *Risk and uncertainty* – landholders might not participate if the innovation involves a high financial risk. Similarly, a new management practice is more likely to be adopted if the advantages of the practice are observable
- *Capital implementation cost* – higher levels will tend to reduce adoption rates
- *Intellectual implementation cost* – innovations and programs may require landholders to invest considerable time
- *Flexibility* – ability of the program to be used in a variety of properties
- *Financial incentives* – offer of financial incentives or delay of payment
- *Duration and continuity of the program* – higher levels will tend to reduce adoption rates
- *Institutions* – legislative, bureaucratic and regulatory controls may limit certain actions or be a disincentive to others.

Above all, logistics, information, education and communications advances generally can accelerate the adoption of practices that would not otherwise be adopted quickly (Pannell, 2006; Lockie and Rockloff, 2004). Trust and communication are important factors for the program designers to ensure high levels of involvement, so these factors need to be considered in the design and rollout of new initiatives.

6. STRATEGIES FOR BMP ADOPTION IN THE CENTRAL REGION

There are varying rates of adoption of BMPs in sugar cane production across the industry. Some practices, such as green cane trash blanketing, have attained high adoption rates while others, such as precision farming techniques, are relatively new and currently have low adoption rates. The reasons why adoption rates differ across practices is not always clear. For example, while green cane trash blanketing had a very rapid uptake (with subsequent environmental benefits), recommendations to reduce fertiliser applications have resulted in slower uptake even though this practice should be associated with both environmental benefits and reduced farm costs. Clearly, reducing fertiliser applications is perceived as increasing the risk of less than optimum productivity/yield.

6.1 Previous studies of barriers to and incentives for BMP adoption

There have been four previous studies in the Mackay district dealing with the barriers to BMP adoption and the level of incentives needed to achieve high adoption rates. One of these studies involved asking canegrowers in workshops to assess the likely level of involvement and incentives needed to take up different BMPs in sugarcane production (Rolfe et al., 2005). The other studies were a review of the regional Sustainable Landscape Program (SLP) managed by the Mackay Whitsunday NRM Group, to identify key lessons from the rollout of the grant and tender program (Drewry et al., 2007, Rolfe et al., 2006), and a survey of canefarmers in the Mackay region about involvement in the SLP and BMP programs (Rolfe et al., 2006). The results of these studies are summarised below.

- A common outcome across the reviews was that there was large variation in the costs involved and incentives needed for individual farmers to adopt BMPs. This variation in cost is likely to be a consequence of differences across physical, climate, farming practices, social and individual farmer characteristics. One implication is that it will be very costly for some landholders to change management practices, while others may achieve change at low cost. These results mean it will be more cost-effective to focus only on those landholders with lower opportunity costs and it may be ineffective to use a fixed rate approach (as in devolved grants) to achieve management changes.
- There are differing costs associated with different BMP strategies. An analysis of bids in the SLP (Drewry et al., 2007) suggested that a BMP to reduce losses of nitrate-nitrogen would cost $52.50/ha/yr, a BMP to reduce losses of residual herbicides would cost $25/ha/yr, and a BMP to reduce losses of particulates (N, P and suspended sediments) would cost $65/ha/yr. These are estimated costs spread over 10 years. Although not directly comparable, Rolfe et al. (2005), as part of a hypothetical auction, reported that the incentive costs (with annual payments over five years) of establishing grass filter strips (and retiring land from cane production) would be $1,387/ha/yr, that of adopting minimum tillage mechanisms would be $128/ha/year and that of reducing fertiliser applications by 50 per cent would be $727/ha/yr.

- The cost-effectiveness of different actions within programs varies widely (Rolfe et al., 2006). The 10 most highly ranked projects in the Stormwater subprogram of the SLP cost $67,940 and were modelled to capture 11,985 tonnes of sediment ($5.67/ton), 604 kilograms of phosphorus ($112.53/kg), and 3,838 kilograms of nitrogen ($17.70/kg). In comparison, the 10 lowest ranked projects cost $41,496 and were modelled to capture 539 tonnes of sediment ($77.05/ton), 32 kilograms of phosphorus ($1,283/kilo), and 231 kilograms of nitrogen ($179/kilo). These estimates provide some guide about the expected costs involved in reducing agricultural emissions.

- Key reasons for farmer involvement in the SLP were concerns about the farm future, interest in looking after the land and waterways, interest in improving productivity and congruence with existing farm management plans and operations. Financial support was an important but not overwhelming reason for involvement. The results suggested that the SLP program and financial support helped to speed up the adoption process.

6.2 Developing effective BMP packages

This review of BMP issues has identified that there is a very large number of existing and potential BMPs, that there may be some confusion between environmental and production goals, and that a number of interrelationships and overlaps exist within groups of BMPs. To simplify the concept and make the link between farm actions and environmental goals clearer, it was decided to improve the relevance and acceptance of BMPs by following three steps.

(1) Focus BMPs in terms of environmental outputs to be gained
Three target areas relevant to BMPs for water quality were identified:

- Soil management: reduce sediment and particulate nutrient loads
- Nutrient management: reduce nutrient concentrations in run-off and deep drainage
- Herbicide management: reduce residual herbicide concentrations.

(2) Package BMPs into groups that are relevant to landholders
Strategies to achieve improvements in each of the three target areas were identified. These were grouped into packages that contained a description of the combinations of actions, planning and record keeping that a farmer might undertake to achieve improvements in the relevant target area.

(3) Identify different levels of potential improvement to be reached
A four-class or classification system was developed for BMP packages. Each class represents overall improvement in farm management and overall progress towards target area goals, rather than the adoption of specific practices. Different stages of improvement were classified as A, B, C, or D. The classification of farming practices was developed as a way of communicating easily to farmers about the potential levels of improvements being sought. The levels in the classification are:

- D - traditional management practices that normally have both production and environmental inefficiencies
- C – basic adoption of some BMP actions
- B – current BMPs as generally recommended by industry
- A – future BMPs achievable with more precise technology and farming techniques.

A small workshop of stakeholders in Mackay in early 2007 was utilised to finalise the three BMP packages detailed in Tables 4–6.

Table 4. Packages of farming practices classified according to their contribution to improved nutrient management

Nutrient management	
Classification: D	**Classification: C**
Description: Based on historic application rates One rate for whole farm Application rates more than old BSES rates More than 180 kgN/ha for ratoons Records kept in head	*Description:* Basic Nutrient Management Plan, includes Soil testing One or two rates for the whole farm Application based on old BSES rates 180 kgN/ha for ratoons Records kept in daily diary
Planning and record keeping: None	*Planning and record keeping:* 1. Conduct soil tests 2. Choose fertiliser rates 3. Keep daily diary
Machinery costs: Surface or subsurface fertiliser box	*Machinery costs:* Subsurface fertiliser box
Classification: B	**Classification: A**
Description: Nutrient Management Plan based on six easy steps Variable rate between blocks Application rates based on new BSES rates Less than 160 kg N/ha for ratoons depending on soil type Records kept in paddock journal	*Description:* Nutrient Management Plan based on GPS yield, soil mapping and six easy steps Variable rate within blocks Application rates based on new BSES rates Average 120 kg N/ha for ratoons depending on soil type Records kept in computer database/paddock journal
Planning and record keeping: 1. Identify soil types/productivity zones for each block using existing soil maps 2. Develop nutrient management plan 3. Change fertiliser rates between blocks 4. Attend nutrient management course 5. Conduct soil tests 6. Do leaf analysis 7. Record yield 8. Keep records in paddock journal 9. Adjust nutrient rates for the following year if required	*Planning and record keeping:* 1. Identify soil types/productivity zones within each block using GPS yield and soil mapping 2. Develop GPS-based nutrient management plan 3. Apply variable fertiliser rates within blocks 4–7. Same as Class B 8. Keep records in computer database/paddock journal 9. Same as Class B
Machinery: Subsurface variable rate fertiliser box with manual rate control	*Machinery:* Subsurface variable rate fertiliser box with remote/automatic rate control and GPS guidance

Table 5. Packages of farming practices classified according to their contribution to improved herbicide management

<table>
<tr><th colspan="2">Herbicide management</th></tr>
<tr><td>Classification: D

Description: Based on historic application rates
One strategy for the whole farm
Often uses both full-strength residual and knockdown products
Records kept in head

Planning and record keeping:
None

Machinery costs:
Standard spray rig both high and low clearance</td><td>Classification: C

Description: Basic herbicide management plan
One or two herbicide strategies for the whole farm
Often uses both full–strength residual and knockdown products
Records kept in daily diary

Planning and record keeping:
Keep daily diary

Machinery costs:
Standard spray rig both high and low clearance</td></tr>
<tr><td>Classification: B

Description: Herbicide management plan based on weed pressure, soil types, crop stage and yield mapping
1. Implementation of new application technology for improved placement and timing to improve application efficiency, accuracy and to extend the window of opportunity
2. Knockdown herbicides replace residual herbicides where practical
3. Residual herbicides only used where weed pressure demands it
4. Variable herbicide strategies between blocks
5. Records kept in paddock journal

Planning and record keeping:
1. Identify weed types/pressure, soil types and productivity zones for each block using existing farm maps
2. Develop herbicide management plan
3. Change herbicide strategy between blocks
4. Attend herbicide management course
5. Monitor weed pressure
6. Record yield
7. Keep records in paddock journal
8. Adjust herbicide strategy the following year if required

Machinery:
Hooded sprayers, more accurate nozzles and high clearance tractors with manual rate control</td><td>Classification: A

Description: Herbicide management plan based on GPS, weed pressure, soil types, crop stage and yield mapping
1–3. Same as Class B
4. Variable herbicide strategies within blocks
5. Records kept in computer database/paddock journal

Planning and record keeping:
1. Identify weed types/pressure, soil types and productivity zones within each block using GPS yield and soil mapping
2. Develop GPS-based herbicide management plan
3. Apply variable herbicide strategies within blocks
4–6. Same as Class B
7. Keep records in computer database/paddock journal
8. Same as Class B

Machinery:
Hooded sprayers, more accurate nozzles and high clearance tractors with remote/ automatic rate control and GPS guidance</td></tr>
</table>

Table 6. Packages of farming practices classified according to their contribution to improved soil management

Soil management	
Classification: D	**Classification: C**
Description: Cultivated bare fallow Cultivated plant cane Zero till ratoons Records kept in head	*Description:* Minimum till bare fallow or legume fallow Cultivated plant cane Zero till ratoons Records kept in daily diary
Planning and record keeping: None	*Planning and record keeping:* Keep daily diary
Machinery: Standard equipment	*Machinery:* Standard equipment
Classification: B	**Classification: A**
Description: 1. Controlled traffic permanent beds 2. Zero till bare fallow or legume fallow 3. Zero till plant and ratoons 4. Headlands, drains and waterways managed as filter strips 5. Records kept in paddock journal	*Description:* 1. Controlled traffic permanent beds with GPS guidance of planting and harvesting operations 2. Zero till fallow, plant and ratoons 3. Headlands, drains and waterways managed as filter strips 4. Records kept in computer database/paddock journal
Planning and record keeping: 1. Identify soil types and productivity zones for each block using existing farm maps 2. Develop soil management plan 3. Keep records in paddock journal 4. Record yield 5. Adjust soil management plan the following year if required	*Planning and record keeping:* 1. Identify soil types and productivity zones for each block using GPS mapping 2. Develop soil management plan based on GPS mapping 3. Keep records in computer database/paddock journal 4–5. Same as Class B
Machinery: Standard wheel spacing on all equipment, bed former, zero till seed planter, zero till cane planter, harvester and haul-out vehicles	*Machinery:* Standard wheel spacing and GPS guidance on all equipment, bed former, zero till seed planter, zero till cane planter, harvester and haul-out vehicles

6.3 Attitudes of farmers in the Central Region to adopting BMPs

BMP options and issues were explored in two separate workshops. One workshop was held in Mackay in April 2007 with six people representing growers and stakeholders from the Mackay region, including representatives from CANEGROWERS, BSES, QDPIF and the Mackay Whitsunday NRM Group. Results of this workshop were used to finalise the designs for BMP packages described in Section 6.2. A second workshop was held with 12 canegrowers at Proserpine in June 2007 to provide more detailed responses to different BMP issues and to rate different BMP options. Outcomes of the Proserpine workshop with canegrowers are summarised here. Further detail is given by Rolfe et al. (2007).

Attitudes to standard BMPs

Participants were given a selection of BMPs and asked to rate them on a scale of 1–10 against four criteria:

- Knowledge of practice
- Operating costs to implement
- Production benefits
- Acceptability to farmers.

Participants were also asked to indicate which of the listed practices they had adopted. Adoption rates (as a percentage) are illustrated graphically in Figure 4, with the BMPs arranged in decreasing order of adoption, and a summary of all participants' responses is shown in Table 7.

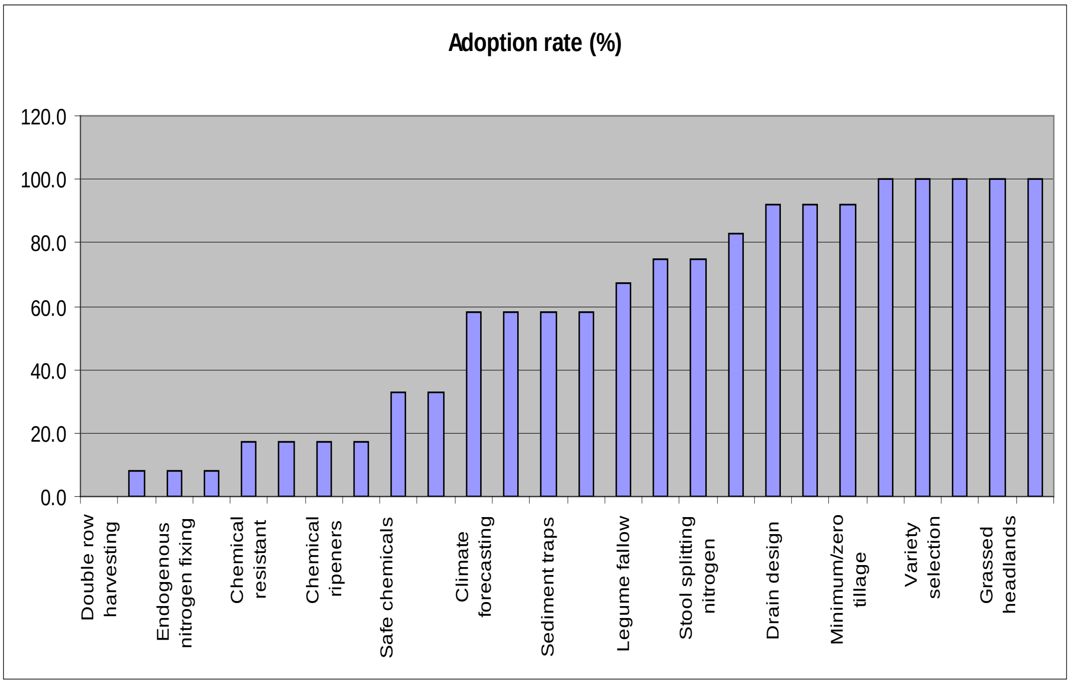

Figure 4. Adoption rates of BMPs by participants at Proserpine workshop

Table 7. Summary of Proserpine workshop participants' responses, showing mean ratings of BMPs against four criteria on a scale of 1 (low) to 10 (high), and adoption rates (%)

BMPs	Criteria				Adoption (%)
	Knowledge of practice	Operating costs to implement	Production benefits	Acceptability to farmers	
Green cane trash blanketing	9.4	2.4	8.1	9.3	100
Nitrogen management	6.8	4.3	7.0	6.6	100
Grassed headlands	8.7	3.5	3.7	7.1	100
Soil testing and amelioration	8.0	6.1	7.6	7.3	100
Variety selection	7.4	3.2	7.8	7.2	100
Minimum/zero tillage	8.5	3.8	6.2	7.1	92
Drain design	7.4	5.5	5.5	6.3	92
Block drainage	7.7	6.0	6.9	6.6	92
River and stream bank stability	6.7	5.1	3.1	5.7	83
Stool splitting nitrogen	7.7	5.3	7.0	6.9	75
Integrated pest management	4.3	4.4	5.2	4.0	75
Legume fallow	6.1	5.2	6.3	5.6	67
Sediment traps	6.3	7.1	4.1	6.4	58
Controlled traffic	6.8	8.2	5.6	5.0	58
Soil health analysis	4.6	3.9	8.1	7.1	58
Climate forecasting	4.6	2.5	4.8	5.0	58
Slow-release fertilisers	5.2	5.8	6.5	6.2	33
Safe chemicals	4.8	4.4	5.6	7.0	33
Denitrification inhibitors	2.6	6.0	5.5	6.0	17
GM varieties	3.4	6.8	8.6	5.4	17
Chemical-resistant varieties	2.5	4.7	7.3	8.0	17
Chemical ripeners	2.9	6.2	4.2	3.2	17
Precision farming/spatial crop imagery	2.0	9.0	6.3	7.3	8
Endogenous nitrogen fixing	2.1	6.0	5.5	6.5	8
Fertigation	2.6	5.7	6.0	5.0	8
Double-row harvesting	3.1	7.2	3.2	1.2	0

Despite the small sample, it is worthy to note that the first eight BMPs in Table 7 had adoption rates of over 90 per cent. They also had high scores for knowledge of the practice, indicating a strong relationship between adoption and knowledge. On the other hand, high adoption was not always associated with high production benefits or low costs to implement, indicating that some practices will be adopted without financial benefits, for example, grassed headlands and drain design.

Acceptability and knowledge were not always correlated. There were a number of BMPs with good acceptability but with low ratings for knowledge of the practice. Their adoption rates were also low. The differences between the ratings for acceptability and knowledge indicate a need for more information about the following practices:

- Chemical-resistant varieties
- Precision farming/spatial crop imagery
- Endogenous nitrogen fixing
- Denitrification inhibitors
- Soil health analysis

- Fertigation
- GM varieties
- Safe chemicals.

It is concluded that, while the concepts of the above practices were acceptable, their adoption levels were low, partly because of lack of knowledge and understanding.

More than half of the BMPs listed were rated as having high operating costs (rating score of five or more), which might be a barrier to adoption for some growers. A more realistic assessment of the relative cost of implementation and the potential impact on adoption is gained from the difference between the production benefit and operating cost.

Practices with the greatest net benefit (that is, production benefits exceed implementation costs by a factor of two or more points) were:

- Green cane trash blanketing (+5.7)
- Variety selection (+4.6)
- Soil health analysis (+4.2)
- Nitrogen management (+2.7)
- Chemical-resistant varieties (+2.6)
- Minimum/zero tillage (+2.4)
- Climate forecasting (+2.3).

If, as responses suggest, these BMPs are associated with net production (private) benefits, it should be easier to encourage adoption. However, they received a wide range of acceptability, knowledge and adoption scores, indicating financial return is not always the first consideration.

BMPs that appear to be associated with significant net production (private) costs (i.e. implementation costs exceed production benefits by a factor of two or more points), where adoption may be more difficult to encourage, are:

- Double-row harvesting (-4.0)
- Sediment traps (-3.0)
- Precision farming/spatial crop imagery (-2.7)
- Controlled traffic (-2.6)
- River and stream bank stability (-2.0)
- Chemical ripeners (-2.0).

Practices that received low ratings for acceptability (score ≤ 5 out of 10) and where adoption may therefore be most difficult to encourage were:

- Double-row harvesting (1.2)
- Chemical ripeners (3.2)
- Integrated pest management (4.0)
- Controlled traffic (5.0)
- Fertigation (5.0)
- Climate forecasting (5.0).

Of the practices in the last list above, double-row harvesting, which had the lowest overall rating for acceptability, also had a high cost to implement and low production benefit;

controlled traffic was perceived to have high implementation cost; and the remainder were generally at low knowledge levels.

Attitudes to BMP management packages

The second part of the Proserpine workshop focused on the new management packages and classification systems for nutrient, herbicide and soil management, as described in Tables 4, 5 and 6. Participants were asked to indicate which class they thought they were in for each management area and also to estimate which classes applied to the whole region.

Growers rated their management standards higher for soil and herbicide management than for nutrient management (Table 8). The majority of growers had C-rated practices (basic adoption of some BMPs), with up to one-third achieving B ratings (current BMPs as generally recommended by industry). Up to one-quarter of farmers may be engaged in practices with a D rating (traditional management practices). Nobody gave themselves an A rating in any category nor a D rating in herbicide management.

Growers generally rated the regional situation at a lower management standard than their own (these were the more proactive growers) and suggested 40-49 per cent of farmers were in the D category. There was recognition that one or two growers were already in Class A.

Table 8. **Proportion (%) of growers in each class according to their ratings of themselves and the region, from Proserpine workshop**

	Classification			
	A	B	C	D
Nutrient management				
Self	0	17	58	25
Region	1	11	39	49
Herbicide management				
Self	0	25	75	0
Region	2	10	41	49
Soil management				
Self	0	33	50	17
Region	3	12	47	40

When asked about the likelihood of adopting Class B and Class A standards, only one participant thought it was unlikely he would move to Class B, and at least half the participants thought it possible they would move to Class B in the next 3–5 years (Table 9). Although growers had rated their nutrient management standards lower than those for herbicide and soil management, they appeared to be more willing to improve their nutrient management practices, with 92 per cent likely to be in Class B in 3-5 years compared with 75 per cent each for herbicide and soil management.

There was much less interest in moving to Class A standards (Table 9). Nevertheless, it is possible that 75 per cent will be at Class A standard for nutrient management in 6–10 years. Corresponding figures for herbicide management and soil management were 67 per cent and 75 per cent respectively.

Table 9. Estimated proportion (%) of growers likely to move to Class B or Class A, from Proserpine workshop

	Time frame			
	Already implemented	Possible in 3-5 years	Possible in 6-10 years	Not likely
Nutrient management				
Moving to Class B	17	75	8	0
Moving to Class A	0	50	25	25
Herbicide management				
Moving to Class B	17	58	25	0
Moving to Class A	0	42	25	33
Soil management				
Moving to Class B	25	50	17	8
Moving to Class A	0	42	33	25

The lower interest in Class A standards was largely due of cost factors. The main impediments to adoption were quoted as:

- additional costs are too high (55%)
- I see little benefit for me (15%)
- makes management too complicated (10%)
- I don't have the technical skills (10%)
- takes up too much time (10%).

Participants were then asked to consider in more detail the economic impacts of moving to Class A standards, particularly the costs of fertilisers, chemicals and fuel, and then to estimate the net impact of Class A on productivity, operating costs and farm revenue.

There was more certainty about the positive impacts of Class A soil management changes and there was general agreement that these would increase productivity (67%), decrease operating costs (67%) and increase farm revenue (75%). Nobody thought that farm revenue would decrease. Under these conditions the use of financial incentives should be for short-term periods and focused on practice change.

There was uncertainty about the benefits of moving to Class A herbicide and nutrient management standards. There was a general belief that there would be increases in operating costs (75%). The opinion on the overall impact on farm revenue was mixed, with 33% of respondents thinking there would be a negative impact. This would imply that financial incentives may be needed for a longer period, either to compensate for lost revenue and/or until growers are reassured that there will not be negative impacts.

The results suggest that growers might adopt BMPs for nutrient management more readily than for herbicide and soil management. While a range of information, encouragement and support mechanisms may be sufficient to move growers to Class B standards, more direct financial incentives or regulation are likely to be required to achieve adoption of Class A standards.

7. CONCLUSIONS AND RECOMMENDATIONS

The overview and analysis detailed in the preceding sections allows the following recommendations to be drawn:

Issues relating to research priorities

- Greater attention needs to be paid to collecting scientific and technical information about the links between changes in farm management practices and impacts on water quality.
    - A combination of modelling and monitoring at paddock, subcatchment and regional scales is required to establish the relationship between adoption of BMPs and improvement in water quality.
    - An audit mechanism for monitoring adoption of BMPs spatially and temporally is required.
- Some mechanism for prioritising BMPs that deliver different types of water quality improvements (e.g. sediment reductions versus nutrient reductions versus chemical reductions) needs to be developed.
- A detailed investigation into the impediments to change in the Mackay Whitsunday region needs to be carried out and strategies to overcome these impediments need to be developed.

Issues relating to the categorisation and identification of BMPs

- A number of 'leading-edge' BMPs for soil, nutrient and chemical management are associated with precision farming techniques, careful assessment and record keeping and specific within-block treatments. There are typically economies of scale in improvements across several BMPs at the same time.
- BMPs for water quality actions on farms should be packaged into groups with a simple rating system to facilitate engagement with farmers. A suggested grouping is as follows:
    - soil management
    - nutrient management
    - chemical management
    - irrigation and waste water management.
- Reduction in the loss of soluble nutrients can be best achieved by closely matching fertiliser application rates to crop requirements and other available nutrients. Increased awareness of the soil's ability to retain or lose nutrients such as phosphate should also be factored in.
- The loss of residual herbicides and other chemicals can be most effectively reduced by lower usage of these chemicals through strategies such as banding and precision application in accordance with legal requirements. Alternatively, use of active ingredients that are effective but have low environmental impact can be considered.

- The widespread adoption of minimum/zero tillage in fallow, rotational and cane crops will give the greatest reduction in sediment, particulate nitrogen and particulate phosphorus losses from caneland in the Mackay Whitsunday region.
- Tailwater recycling and the construction of detention basins to trap first-flush stormwater will also reduce losses of soluble nutrients and herbicides and dissolved oxygen reducing materials such as sugar juice, to waterways.
- Some extra environmental benefit can be achieved by the use of managed grassed headlands, drains and filter strips. However, unless the delivery of material to these areas is reduced by better soil management practices, their sediment trapping abilities are soon overwhelmed.

Moving beyond a focus at the single farm

- A focus on a broad range of BMPs within groups (such as soil management BMPs) should be maintained to maximise relevance and participation, and to generate cost-effective engagement. In some cases it may be more cost-effective to develop implement BMPs across multiple farms.
- Separate BMPs may be required for development issues, where there may need to be an interface with the development process and approving bodies. These are particularly those relevant to:
    - risks of acid-sulfate soils
    - water storages
    - biodiversity impacts.
- Collaboration with sugar mills and other relevant stakeholders may be important for particular issues, particularly:
    - improving the effectiveness of mill waste reuse (particularly mill mud and boiler ash)
    - improving the efficiency of transport systems and reducing loss of cane juice
    - the provision of GPS base stations to encourage precision farming.

Mechanisms to encourage adoption

- There are a range of different options to facilitate the adoption of BMPs. A mixture of different support mechanisms should be used depending on the level and speed of uptake required, and the different trade-offs that might be involved. The choice of an implementation strategy should be sensitive to:
    - the level of environmental benefits involved
    - the net private costs and production trade-offs involved
    - the barriers to adoption or changes in management practices.
- The selection of the appropriate policy instrument to encourage adoption of BMPs should be based on the levels of private and public benefits involved.
- It is likely to be easier in the Central Region to encourage adoption of BMPs for nutrient management than for herbicide and soil management.
- A range of information, encouragement and support mechanisms may be sufficient to move growers to Class B standards (industry recommended standards)

- More direct financial incentives and targeted support mechanisms may be required to achieve adoption of Class A standards (future BMPs achievable with more precise technology and farming techniques).

This report is intended for use by research providers, management agencies, industry groups and funding bodies such as regional NRM bodies, Commonwealth and State Governments to inform future effort in enhancing adoption practices, while guiding further investment in research in the Great Barrier Reef catchments, relating to land management impacts on water quality.

Member organisations of CIRM will advocate and promote the report’s findings and recommendations for future research investment in forums at appropriate times, to link with funding and research project proposal cycles.

It is envisaged that, by working together in collaborative partnerships, landholder efforts and limited research dollars will be more effectively used to bring about positive outcomes and offer a bright future for those in the sugar industry and for water quality in the Reef catchments.

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Appendix 1. What is CIRM?

"Tackling tomorrow's natural resource management challenges today"

Managing natural resources for sustainability and ecosystem health is increasingly part of the decision-making by government, research, community and industry stakeholders alike. Such decision-making requires an integrated approach for success. This can be a challenge, as competing interests and needs strive to be accommodated. Through its collaborative partnerships, the Consortium for Integrated Resource Management (CIRM) is tackling this challenge.

CIRM is an unincorporated joint venture of 10 organisations. It operates as a formal linkage for facilitating collaborative planning and coordination of research and development (R&D) initiatives. Strength through partnerships is the key to CIRM's success.

The consortium was formed in 1993 and now in 2007 has the following partners:

Department of Natural Resources and Water (Qld)
Department of Primary Industries and Fisheries (Qld)
Environmental Protection Agency (Qld)
James Cook University
University of Queensland
Central Queensland University
Griffith University
University of the Sunshine Coast
Queensland University of Technology
CSIRO.

It is a conduit for research by providing flexible, accessible pathways for collaboration and communication between the CIRM partners.

This approach is designed to:

- understand ecological, social and productive systems, and
- deliver multi-organisational agreement to invest in effective R&D related to those systems.

Appendix 2. Code of Practice for Sustainable Cane Growing in Queensland (CANEGROWERS, 1998)

Category	Description
2.1 Farm plan	Management tool to assist farm operation – should contain property details, soil information, topography, block layout, natural watercourses etc. Requirement of applications for new cane production area or expansion of existing cane area
2.2 Vegetation management	Manage native vegetation for wildlife corridors. Stream bank vegetation enhances wildlife corridors, improves instream habitat and stabilises the banks
2.3 Soil management	Conservation and maintenance of soil structure, fertility and biological characteristics
↘ Reducing Erosion	Use of minimum tillage farming systems and laser levelling to reduce potential of soil erosion
↘ Fertilisers and soil ameliorants	Use of essential cane nutrients to improve the condition and ground cover of crops
↘ Fertiliser application methods	Calibrate fertiliser applicator and apply fertiliser below ground, either stool split or directly beside the stool. For above-ground application, delay application until cane height of 50 cm and surface band applying close to the stool.
↘ Fertiliser application rates	Analytical testing of soils to determine nutrient status
↘ Use of mill by-products	Recycling and reusing mill mud (filter press) from mills to provide plant nutrition and soil conditioning
↘ Managing saline and sodic soils	Manage drainage systems, application of soil ameliorants including gypsum, retain harvesting residue, maintain adequate topsoil, adopt good irrigation management practices
2.4 Irrigation	Selection of the most suitable irrigation system is influenced by soil permeability, topography, water availability and cost
↘ Furrow irrigation	Furrow irrigation is less suitable than overhead low pressure or trickle systems on free-draining, highly permeable soils
↘ Overhead irrigation	Overhead irrigation systems need to be calibrated to soil type. Other factors to consider include green cane trash blanketing and climatic conditions including wind speed
↘Tailwater recycling	The installation of tailwater storage improves irrigation efficiencies, minimises run-off and traps sediments, nutrients and chemicals. The design of tailwater storages should ensure that off-farm run-off from irrigation does not exceed 10 per cent of irrigation inflow rates
↘ Irrigation scheduling / water efficiencies	Schedule irrigation with evaporation mini-pans and/or soil probes calibrated to stalk growth measurements and soil types
↘ Treated waste water	Effluent water should only be applied when it is of the appropriate quality, soils are appropriately permeable and groundwater is of sufficient depth to minimise contamination

Category	Description
2.5 Drainage	Drainage systems should be designed so that they do not significantly alter the nature of healthy streams, affect water quality or expose potential acid sulfate soils
2.6 Weed, pest & disease control	
➘ Integrated pest management	Adoption of integrated pest management strategies including biological and cultural controls
➘ Rat control	Application of integrated pest management strategies for the control of rats through minimising weeds in cane and surrounding grass harbourage areas
➘ Feral animals	Abide by relevant legislation when pursuing feral animals and obtain damage mitigation permits for the control of native animals
2.7 Fire management	Cane firing must be in accordance with the established local permit system. Every effort should be made to retain, incorporate or dispose of tops rather than burning. Green cane harvesting and trash blanketing should be adopted where compatible with profitable cane growing
2.8 Timing of operations and notifying neighbours	Time your farm management operations to minimise off-farm impacts
2.9 Fuel and dangerous goods – use and storage	Adhere to relevant codes and participate in approved training programs
➘ Storage and bunding	Store chemicals in accordance with relevant codes in a well ventilated, secure and child-proof area with impervious bunding
➘ Chemical use	Maintain comprehensive records of any usage of agricultural chemicals
➘ Managing off-site risks of spray drift and chemicals	Ensure that people and the environment are protected from potential harm from the use of agricultural chemicals
2.10 Waste management	
➘ Recycling	Where available, commercial recycling options should be utilised
➘ Chemical containers	Chemical containers must be disposed of as specified in relevant codes
2.11 On-farm monitoring	Maintain effective farm records to demonstrate sustainable cane growing practices including productivity records, soil tests, chemical usage, fertiliser use, tree plantings and survival rates

Appendix 3. BMPs for Sugarcane Production in the Tully-Murray Catchment

Table A2.1. Current BMPs in the Tully-Murray catchment (Roebeling and Webster, 2007)

Current BMPs	Description
Green cane trash blanketing	Harvest without burning and leaving the cane residue on the block for the duration of ratoons
Minimum/zero tillage	Apply no or minimum ploughing passes when preparing a block for planting
Legume fallow	Plant legumes zero till over the wet season at the end of a cropping cycle
Drain design	Establish shallow and grassed drains that are, preferably, spoon shaped
River and stream bank stability	Use a combination of rocks, groins, netting and vegetation to reduce the erosion of stream and river banks
Nitrogen management	Match N to crop requirements, while taking into account all sources of N
Stool splitting nitrogen	Underground application of N to ratoons using a stool splitter
Block drainage	Facilitate block drainage by avoiding low spots and assuring all headlands are lower than the blocks
Grassed headlands	Establish headlands at least 4 m wide and are at least 80% grassed
Sediment traps	Establish hollows in drainage networks specifically designed to trap sediments in drainage water
Soil testing and amelioration	Elementary chemical analysis of soils to assess crop nutrient requirements in cane blocks
Variety selection	Plant early, mid or late maturing variety according to paddock situation

Table A2.2. Future BMPs in sugarcane production for the Tully-Murray catchment (Roebeling and Webster, 2007)

Future BMPs	Description
Controlled traffic	Wider row spacing and controlled steering technology to prevent farm machinery from compacting stool area
Precision farming/spatial crop imagery	Within-block variable application of fertiliser and chemicals based on spatial within-block data
Enzyme nitrogen fixing	Enzymes that allow much of the crop's N needs to be derived from the atmosphere
Denitrification inhibitors	Chemicals that prevent N fertilisers from denitrifying before crop uptake
Double-row harvesting	Harvesting two cane rows (as opposed to dual row) in one pass
GM varieties	Varieties that have better productivity and improved resource use efficiency
Soil health analysis	Using soil health indicators in farming
Fertigation	More frequent applications of fertilisers and chemicals in irrigation water as the crop needs them
Integrated pest management	Using chemical, cultural, biological and physical control measures
Slow-release fertilisers	N fertilisers that are less prone to environmental losses
Safe chemicals	Chemicals that do not persist in the environment
Chemical-resistant varieties	Varieties that can be sprayed with general knockdown herbicides and not suffer
Chemical ripeners	Applications of chemicals to improve commercial cane sugar (CCS)
Climate forecasting	Using seasonal climate forecasters to time operations on farms