Understanding the economics of improved management practices and systems on sugarcane farms

Reef Plan Action 4: Gap Analysis Report

Final Version December 2016

Queensland Government

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Executive Summary

There is growing scientific evidence that indicates terrestrial runoff from adjacent catchments is a major cause of declining marine ecosystem health in the Great Barrier Reef (GBR) lagoon. Queensland accounts for approximately 95 per cent of Australia's raw sugar production and more than 85 per cent of Queensland's' production occurs in the GBR catchments of the Wet Tropics, Burdekin and Mackay Whitsunday. The widespread adoption of best management practices (BMPs) by landholders is a key mechanism in addressing terrestrial runoff concerns, however, achieving the required water quality improvement targets is set to be a major challenge to industry. Improved management practices must also maintain or improve on existing production and profits if they are to achieve widespread adoption.

There are currently three different improved practices frameworks: 1) The Paddock to Reef programme categorises sugarcane practices according to the risk to water quality and is used to measure adoption data for the Reef Report Cards; 2) GBR natural resource management (NRM) bodies have developed their own improved practice frameworks for water quality reflecting the differences in farming systems and landscapes between the regions; and 3) The industry-led Smartcane BMP accreditation programme 'based on productivity, profitability and overall sustainability'. These frameworks, while all in place to improve water quality leaving sugarcane farms, are not always aligned due to their differing purposes and definitions of various categories of practices. The practices included in the NRM frameworks have been regularly reviewed and updated to reflect the latest science and economic information available both in terms of research and application in the field. To be listed as best practice in the NRM frameworks, an improved practice should be 'widely promoted by industry to achieve current and future industry expectations and community standards' (DAFF 2013b: 2).

In addition to pressure to improve the water quality leaving their properties, sugarcane growers face a number of challenges to their business environment. These challenges include: volatility as a price taker on the world market subject to exchange rate movements and barriers to trade, industry restructuring, as well as significant risks from adverse weather conditions and pest and disease outbreaks. These factors affect economic performance differently from year to year but also vary from region to region.

In the studies that reviewed improved practices focused on nitrogen application rates, Six Easy Steps (6ES) consistently outperformed Nitrogen (N)-Replacement on production and gross margin analysis. However, widespread adoption of 6ES, as currently defined, is unlikely to deliver the required reductions in nitrogen to meet the water quality targets. Modelling has estimated widespread adoption of 6ES will only deliver a reduction in dissolved inorganic nitrogen (DIN) transported to the GBR of 15 – 30 per cent. There is some agronomic evidence that N-Replacement yields in the longer term are not that disparate from 6ES, however, there is no economic analysis on these results to indicate the impact on profitability (Thorburn et al. 2011a, b; Webster et al. 2012). More recently research has shifted focus to improved nitrogen use efficiency (NUE) by utilising enhanced efficiency fertilisers, site specific nutrient management and changes to farming system management (for example, longer fallows and crop rotation).

Published studies on pesticides reviewed for this report find that targeted application with specialised spraying equipment as part of an integrated weed management programme will increase pesticide efficiency. However, the cost of spray equipment may prevent this being an economically viable option. In particular, some precision spraying pesticide technology is only cost effective in very specific circumstances of weed type and coverage.

There are a number of agronomy decision support tools available to growers that incorporate information generated from the economic and agronomic studies on management practices and their impact on water quality. This report categorises them into two types: 1) Individual advice and 2) more

general advice. While there are a number of tools already available in both these categories such as the Queensland Department of Agriculture and Fisheries (QDAF) Improved Practices Catalogue and the Farm Economic Analysis Tool (FEAT), there is uncertainty around what tools growers are using and how they are using them to enhance the adoption process of improved management practices. Research into the uptake of these tools, raising awareness of what tools exist and further development of tools to increase their usability would be all contribute to increasing adoption of best management practices for water quality outcomes. In particular the development of an economic decision support tool focusing on improved NUE has the potential to enhance adoption.

The most recent frameworks released by the GBR NRM bodies, Paddock to Reef program and Smartcane include using block, farm or sub-district yield potential as best or aspirational practice instead of district yield potential in the 6ES. However, there is a paucity of studies that include an economic analysis of this practice. Sugar Research Australia (SRA) has also highlighted this in their recent review into NUE as an area for more research (SRA 2015).

Economic studies on nutrient management over the past ten years have almost exclusively focused on nitrogen application rates and the interaction with other parts of the farming system, in particular fallow management, application method and tillage. There is little information on the use of site specific nutrient management as a whole system, including irrigation as a critical vector for the transportation of nutrients and chemicals, the interaction with other nutrients and identifying production constraints, along with their implications for economics and water quality. In the studies reviewed with an economic analysis, N-replacement did not convincingly provide comparable production and profit results to 6ES. The data collected in these studies often prevented a statistical analysis of the significance of the results, as such a combination of more statistically robust studies looking at N-replacement compared with industry practice and alternative innovative ways to reduce the rate of nitrogen should be considered.

There were a few studies that included timing and placement of nutrients, however, it was not clear from the results how important these are to economic performance and water quality outcomes – more studies on these other aspects of nutrient management would aid in clarifying the importance from an economic and environmental perspective. This review also supports the findings of previous studies that more work needs to be undertaken with respect to relatively new and emerging herbicides as much less is known about their behaviour and fate than older herbicides.

Very few field studies reviewed in this report included a water quality outcomes component. Where research features practices that are aspirational or innovative, some measure of the associated water quality benefits would greatly enhance their value. All of the studies included for review in this report that modelled a shift from a category of practices were based on management practices as defined in previous versions of the NRM ABCD frameworks and Paddock to Reef Water Quality Risk Framework. An update of these studies to reflect current categorisation of best and aspirational practices would provide insights to the economic impact of these changes at a regional scale.

This report has identified a number of high priority targets for future economic work, including continued collaboration with project partners to provide economic expertise in research trials in order to validate the profitability, risk and cost-effectiveness of the adoption of new management practices. In particular research trials that:

- Use site specific (block, farm or sub-district) yield in 6ES for nutrient management.
- Use relatively new and emerging alternative herbicides.
- EEF or alternative forms of nutrient management (other than 6ES).
- Investigate fallow crops in rotation with cane and fallow length.
- Effective use of mill mud.
- Investigate the influence of different irrigation systems in transporting excess nutrients and chemicals into water pathways to the GBR.

- Evaluate the profitability of shifting from conventional furrow irrigation management to BMP furrow irrigation management with different soil types (i.e. cracking clay and non-sodic duplex), water sources (i.e. channel and bore) and farm designs (i.e. row lengths, gradients and recycle pits).

Other areas for future economic work include:

- Evaluation of improved management practices as part of a whole-of-farm system to provide a greater understanding of their interactions and combined impact on social, economic and environmental outcomes. Using specific case studies to better understand the economic implications in a commercial setting for management practices identified as having water quality outcomes.

- The continued provision and enhancement of decision support tools to enable growers to develop individual advice on the adoption of improved management practices. This includes the update regional FEAT files for the Burdekin Delta, BRIA, Mackay and Tully areas to support industry BMP and continued development of FEAT files for other regions (e.g. Herbert) to facilitate understanding of the cost-effectiveness of management practices classified as innovative that have water quality outcomes.

- Update the Improved Practices Catalogue and measure how often it is accessed. Review how it is used by industry and how it can be improved to increase use.

- Review the potential for a Decision Support System for NUE – a tool which would provide an economic analysis of specific NUE practices under a set of specified farm enterprise characteristics. Any work on a Decision Support System for NUE will need to be collaboratively undertaken between government, industry and NRM bodies to ensure that if such a tool is developed it is relevant and the final product is able to be regularly updated and maintained so that it remains relevant.

- Update the Paddock to Reef Monitoring & Evaluation studies that undertook economic analysis of moving between categories of ABCD cane management practices for the cane growing regions in the GBR catchments based on 2009 best management practices (with the Wet Tropics being a high priority).

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Abbreviations and acronyms

ABARES	Australian Bureau of Agriculture, Resource Economics and Science
AEB	Annualised Economic Benefit
AGDA	Australian Government Department of Agriculture
APSIM	Agricultural Production Systems Simulator
AUD	Australian Dollar
BMP	Best Management Practice
BRIA	Burdekin River Irrigation Area
BSES	Bureau of Sugar Experimental Stations
CCS	Commercial Cane Sugar
CSIRO	Commonwealth Scientific and Industry Research Organisation
DIN	Dissolved Inorganic Nitrogen
DSS	Decision Support System
EAA	Economic Annualised Annuity
EEF	Enhanced Efficient Fertilisers
FEAT	Farm Economic Analysis Tool
GBR	Great Barrier Reef
GBR Taskforce	Great Barrier Reef Water Science Taskforce
GCTB	Green Cane Trash Blanket
GD	Grower Developed
GPS	Global Positioning System
ICE	Intercontinental Exchange
IPC	Improved Practice Catalogue
MWI	Mackay Whitsunday Isaac
N	Nitrogen
NPV	Net Present Value
NQDT	North Queensland Dry Tropics
NRM	Natural Resource Management
NUE	Nitrogen Use Efficiency
OHLP	Overhead Low Pressure irrigation system
PEH	Pre-Emergent Herbicide
PNR	Partial Net Return
PSII HEq	Photosystem II Herbicide Equivalent
QAO	Queensland Audit Office
QDAF	Queensland Department of Agriculture and Fisheries
QDEHP	Queensland Department of Environment and Heritage Protection
QGSO	Queensland Government Statisticians Office
QSL	Queensland Sugar Limited
RBA	Reserve Bank of Australia
SIRP	Sugar Industry Reform Programme
SRA	Sugar Research Australia
RDC	Sugar Research and Development Corporation
USD	United States Dollar
VRA	Variable Rate Application
WQ	Water Quality
WOF	Whole of Farm

WQIP	Water Quality Improvement Programme
6ES	Six Easy Steps

1. Introduction

The Great Barrier Reef (GBR) is an iconic world heritage area which scientific studies have shown to be negatively affected by terrestrial run-off from adjacent catchments containing pollutants such as nutrient and pesticide concentrations (The State of Queensland, 2013b). Both the Australian and Queensland governments have undertaken numerous measures to improve the water quality entering the GBR, including: the implementation of Reef Water Quality Protection Plans (Reef Plan) since 2003 (each set out actions over five year timeframes); the Reef Rescue programme which provided funding to landholders to move to improved practices with respect to water quality (2008 – 2013)[1]; the introduction of the Reef Regulations in 2009 to apply minimum standards for using nutrients and pesticides for sugarcane producers in the Wet Tropics, Burdekin and Mackay Whitsunday regions; the development of the Reef 2050 Long Term Sustainability Plan (Reef 2050 Plan) (Australian Government 2015) to guide long term protection and management of the GBR; the establishment of the Reef Trust to provide targeted investment in delivering the Reef 2050 Long Term Sustainability Plan and the establishment of the Great Barrier Reef Water Science Taskforce (GBR Taskforce) in 2015 to provide advice to the Queensland Government on prioritising investment of $90 million over five years to achieve water quality targets set out in Reef Plan and the Reef 2050 Plan.

The application of both nitrogen-based fertilisers and pesticides is an integral part of the commercial sugarcane farming system.[2] Land used for sugarcane growing in the GBR catchments (1.3 per cent) is estimated to contribute 56 per cent to the estimated anthropogenic loads of dissolved inorganic nitrogen (DIN) delivered to the GBR lagoon (Australian Government 2014).

Over the last 20 years the Queensland sugarcane industry has faced a number of pressures that have impacted on the business environment and farm profitability. Some of these pressures include increased international competition, industry deregulation, increasing input costs, pest and disease outbreaks and extreme weather events. Many of these external factors along with relatively weak world sugar prices for a prolonged period of time have highlighted the need for industry to innovate and develop farming practices that improve production and profitability (Devlin et al. 2012). Some of these practices, such as controlled traffic, minimum tillage and more targeted use of nutrients and pesticides have benefits for reducing run-off from farms.

The most recent Reef Report Card for data collected over 2013-14 estimates that the reduction in annual average DIN load between 2009 and 2014 was 17 per cent and the reduction in annual average pesticide load between 2009 and 2014 was 30.5 per cent — both well short of the targets set in Reef Plan 2009, especially the nitrogen reduction target of 50 per cent. The area of sugarcane levels managed using BMP at June 2014 was 30 per cent for pesticides, 13 per cent for nutrients and 23 per cent for soil management across the GBR – the target for 2018 is 90 per cent adoption across all categories (State of Queensland 2015).

The latest version of Reef Plan (2013) 'remains predominantly focused on working with landholders to address diffuse sources of pollution from broad scale land use' (State of Queensland 2013a:11). In particular, it aims to help landholders move to best practice as defined by water quality risk frameworks to meet the revised land management and water quality targets for 2018. While these revised targets have been based on estimated load reductions that can be achieved through the advancement of scientific knowledge, Reef Plan 2013 acknowledges that the nitrogen target may not be achievable 'using current best practice alone and may require new thinking and approaches in the Wet Tropics and Burdekin regions'

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[1] Reef Plan (2009) was accompanied by a $375 million investment over five years by Australian and Queensland governments to facilitate actions to pollutant load reduction targets and another $375 million has been committed over five years for the 2013 Reef Plan (The State of Queensland 2013a).

[2] Nitrogen is a highly mobile nutrient that can be removed from the soil and lost to watercourses through runoff and deep drainage, and to the air through denitrification (Biggs et al., 2013). Diuron, Atrazine, Hexazinone and Ametryn have been identified as herbicides commonly found in water sampling that pose the greatest risk to the health of reef ecosystems (Davis et al., 2013). These herbicides are known as PSII pesticides, designed specifically to inhibit photosynthesis in plants.

(State of Queensland 2013a:18). This finding is repeated in the GBR Taskforce report released May 2016, with the Taskforce recommending the establishment of an Innovation Fund to support the development of promising new technologies and a Reef innovation network to facilitate collaboration amongst stakeholders from diverse backgrounds to explore new solutions (State of Queensland 2016).[3]

It has been estimated that 100 per cent adoption by industry of current best practice for nitrogen application, 6ES (using district yield potential) will only deliver a 15 -30 per cent reduction in DIN transported to the GBR from catchment agriculture (QDEHP 2014: 12; Thornburn and Wilkinson 2013; Waters et al. 2014). This highlights the importance of Reef Plan's Action 4 to 'increase understanding of farm management practices and systems, economics and water quality benefits' and specifically for the sugarcane industry to identify 'the most critical, cost effective and profitable management practices and systems' as well as where there are gaps in the research around such management practices that can achieve the goals and objectives of Reef Plan 2013 (The State of Queensland 2013a: 26).

1.1 Reef Plan 2013 and Reef 2050 Plan

Reef Plan 2013 links the targets to load reductions expected using best practice land management for water quality outcomes, defines actions over a five year period and focuses on working with industry through extension, incentives and best management practice programmes to accelerate the uptake of practices that improve the quality of water leaving the farm (The State of Queensland 2013a: 7):

Reef Plan's long term goal:	to ensure that by 2020 the quality of water entering the reef from broad scale land use has no detrimental impact on the health and resilience of the Great Barrier Reef.
Land management and catchment targets:	1. 90 per cent of sugarcane, horticulture, cropping and grazing lands are managed using best management practice systems (soil, nutrient and pesticides) in priority areas.
	2. Minimum 70 per cent late dry season groundcover on grazing lands.
	3. The extent of riparian vegetation is increased.
	4. There is no net loss of the extent, and an improvement in the ecological processes and environmental values, of natural wetlands.
Water quality targets 2018:	1. At least a 50 per cent reduction in anthropogenic end of catchment dissolved inorganic nitrogen loads in priority areas
	2. At least a 20 per cent reduction in anthropogenic end of catchment loads of sediment and particulate nutrients in priority areas
	3. At least a 60 per cent reduction in end of catchment pesticide loads in priority areas.

[3] Other recommendations from the GBR Taskforce report included: 1) Review [Reef water quality] targets in 2016, feeding into the review of the Reef Water Quality Protection Plan; 2) Substantially improve communication and information to build understanding of the pressures on the reef and to support management practice and social change; 3) Invest in more effective, targeted and coordinated extension to support large scale land management practice change; 4) Establish greater use of incentives and market approaches to support water quality improvements; 5) Implement staged regulations to reduce water pollution throughout the reef regions; 6) Fund additional long-term and finer-scale catchment monitoring, modelling and reporting for improved decision making and adaptive management; 7) Implement two, well facilitated major integrated projects (MIPs) in pollutant 'hot spot' areas to evaluate the most effective combination of tools to inform the design of future programs; 8) Develop a strategic investment plan and establish reef-friendly public-private partnerships and 9) Simplify and strengthen governance and clarify roles and responsibilities within and between the Queensland and Australian Governments (State of Queensland 2016).

To achieve these targets and consequently the long term goal, Reef Plan 2013 specified nine key actions grouped under three priority work areas:

1. Prioritising investment and knowledge – prioritise, coordinate and integrate programmes to maximise reef water outcomes.

2. Responding to the challenge – Landholders adopt management systems that maximise reef water quality improvements while maintaining and enhancing resilience, business performance and environmental outcomes. Government policies and programmes that support Reef Plan 2013 goals and targets are maintained.

3. Evaluating performance – The efficiency and effectiveness of Reef Plan is measured through monitoring, evaluation and reporting.

The objective of Reef Plan 2013's Action 4 is to 'increase understanding of farm management practices and systems, economics and water quality benefits' (The State of Queensland 2013a: 26). As the agency responsible for reporting on Reef Plan Action 4, the Queensland Department of Agriculture and Fisheries is required to 'review existing commodity specific management practices and identify the most critical, cost effective and profitable management practices and systems' every two years and 'use this information to prioritise investment' in those identified management practices and systems at a regional/catchment scale. Understanding the economic implications of a change in management practices, particularly on grower profitability, is often critical in determining the rate of adoption in agriculture. Recent research indicates that farm management practices in sugarcane growing with high adoption rates tend to have a positive relationship with grower perceptions about their impact on profitability (Thompson et al. 2014). Demonstrating that practices identified as having water quality benefits are also profitable and have minimal impact on productivity is essential to improving the water quality leaving farms.

In 2015 the Reef 2050 Plan was released, and is now the overarching framework for the protection and management of the GBR. As well as incorporating the Reef Plan 2013, the Reef 2050 Plan also addresses six other themes of biodiversity, ecosystem health, heritage, community benefits, economic benefits and governance. Its vision is to ensure the GBR continues to improve on its Outstanding Universal Value every decade between now and 2050 to be a natural wonder for each successive generation to come (Australian Government, 2015b). While incorporating the water quality targets from Reef Plan 2013 for 2018, Reef 2050 Plan also put in place more ambitious water quality targets for 2025 (Australian Government 2015: 43):

- On the way to achieving up to an 80 per cent reduction in nitrogen
- On the way to achieving up to a 50 per cent reduction [of sediment in priority catchments]

The Reef 2050 Plan is to be reviewed every five years, however, the water quality targets that form the basis of Reef Plan 2013 and form a part of the Reef 2050 Plan are scheduled to be reviewed in 2016 (The State of Queensland 2016).

1.2 Report objectives

In accordance with the Reef Plan Action 4 deliverables, the objective of this report is to:

> *Review existing commodity specific management practices and identify the most critical, cost effective and profitable management practices and systems*

with respect to the sugarcane industry (deliverable 1). In particular, the information compiled in this report specifically aims to:

- Examine the business environment in the sugarcane industry
- Provide a summary of the latest information available on the profitability on management practices that improve the quality of water leaving farms.
- Outline current economic projects in the sugarcane industry in particular the work by QDAF that contribute to the delivery of Action 4
- Identify information gaps around the profitability of priority management practices (best management practices and above)
- Outline the QDAF Action 4 project and identify opportunities for future work to address information gaps

The second deliverable of Reef Plan's Action 4:

> *Use this information* [from deliverable 1] *to prioritise investment of the most critical, cost-effective and profitable practices and systems at a regional/catchment scale*

The second deliverable is not within the scope of this report; however a number of studies identified in this report and technical expertise provided by QDAF economists have been used to prioritise investment through the development of Water Quality Improvement Plans by Natural Resource Management organisations in GBR priority catchments. Where information is available, or becomes available, this report will aim to deliver tools that assist in prioritising investment (second deliverable).

1.3 Report scope and approach

This report focuses on the sugarcane industry, in particular those issues directly relating to QDAF obligations as a lead agency for the delivery of Action 4.

Through Reef Plan 2009, significant work has been undertaken to identify the most critical commodity specific practices impacting on water quality, and critical areas needing improvements in management practices (i.e. Scientific Consensus Statement Update). This report will review the economics work in accordance with: Reef Plan 2013 priorities; and the critical practices identified and prioritised in the 2013 Paddock to Reef Monitoring and Evaluation Programme's management practice water quality risk framework and the most recent ABCD frameworks on management practices for water quality outcomes from the NRM bodies (see Appendices 1 and 2).

In particular, the report focuses on Wet Tropics, Burdekin and Mackay Whitsunday sugarcane growing regions. These regions were identified by the Reef Water Quality Protection Plan Prioritisation Project Report (Australian Government 2014) as having very high and high overall relative risk to water quality entering the reef with respect to nutrients and herbicides (see Table 1 below).

Regions with the very high and high overall relative risk to water quality entering the reef are the Wet Tropics and Burdekin sugarcane growing regions. While the Mackay Whitsunday region has an overall moderate risk, it is identified as having a very high priority ranking in herbicides and given past work undertaken within this region it is included in the scope of this report.

Table 1: Investment prioritisation for sugarcane

Catchment	Sub-catchment	Priority ranking combined	Priority ranking Nutrient	Priority ranking Herbicide
Wet Tropics	Johnstone	**Very High**	**Very High**	**Moderate**
	Herbert	**Very High**	**High**	**Very High**
	Mulgrave-Russell	**High**	**High**	**Low**
	Tully	**High**	**High**	**Low**
Burdekin	Haughton	**Very High**	**High**	**High**
Mackay Whitsunday	Pioneer	**High**	**Low**	**Very High**
	Plane Creek	**High**	**Low**	**Very High**

Source: adapted from the Reef Water Quality Protection Plan Prioritisation Project Report (Australian Government 2014) including only sub-catchments that had a moderate and above combined ranking and from Reef Plan (The State of Queensland 2013a) ranked the catchments according to relative risk overall (across all priority pollutants and regardless of industry) with the Wet Tropics as Very High, Burdekin as High and Mackay Whitsunday as Moderate.

To address the report objectives the following approach was undertaken:

1. A desktop review of sugarcane growing businesses and industry, the use of best management practices to address water quality concerns and studies on the cost-effectiveness and profitability of management practices by NRM bodies and Paddock to Reef Monitoring Programme that improve the quality of water leaving farms.
2. Identify gaps in knowledge on nutrient and pesticide management practices from the desktop review.
3. Compare gaps in knowledge with existing research programmes.
4. Consult with relevant experts and stakeholders on findings.
5. Identify opportunities to expand existing research programmes and/or undertake new work to address any remaining gaps.

The desktop review is presented over sections two, three and four of the report with the second section providing an overview of sugarcane growing businesses and industry, while section three looks at how management practices are being used to address water quality concerns and how the management practice frameworks have changed from 2009 to 2014, with a particular emphasis on whether new best and aspirational practices align with gaps in past and current research. Section four provides a review of nutrient and pesticide management practices and systems, specifically, economic studies that highlight the profitability of management practices categorised as ‘best practice’ and ‘innovative’ for water quality outcomes. Differences in regional areas and enterprise type are distinguished where applicable. This section also includes information on research currently being undertaken with an economic analysis component and an overview of some of the research into why farmers adopt management practices. Gaps in research and existing knowledge around best management practices for water quality outcomes are identified throughout the desktop review and summarised in section five. Throughout the writing of this report relevant experts have been consulted and on finalisation of the report it will be distributed to key stakeholders. Opportunities to expand existing research programs and/or undertake new work to address any remaining gaps are highlighted in the final section of the report.

2. Queensland sugarcane growing industry

Key Points

- Queensland accounts for approximately 95 per cent of Australia's raw sugar production and over 85 per cent of Queensland's production occurs in the Great Barrier Reef catchments of the Wet Tropics, Burdekin and Mackay Whitsunday.
- Raw sugar exports valued at $1 354 million and accounted for approximately 3.3 per cent of the value for total farm exports from Australia in 2013-14 – making Australia the world's third largest exporter in that year (ABARES 2014).
- The real price of sugar in Australia has been declining over the last 25 years. Over that same period, with the exception of diesel and possibly electricity, the cost of inputs in real terms to sugarcane production appear to be relatively flat on average, increasing in line with inflation.
- Sugarcane growers face a number of challenges from volatility as a price taker on the world market subject to exchange rate movements and barriers to trade, industry restructuring as well as significant risks from adverse weather conditions and pest and disease outbreaks. This affects economic performance from year to year but also from region to region.

While the focus of this report is on reviewing and identifying management practices and systems that deliver critical water quality benefits whilst maintaining grower profitability, it is important to first have an understanding of the economic environment in which sugarcane farming businesses operate in Queensland. An overview of the financial risks associated with the industry provides context to the business environment that growers operate in and the potential economic impacts that moving to improved practices for water quality benefits have for them. These factors play an important role for growers when considering adopting these improved practices.

Sugarcane is predominantly grown in high rainfall areas along coastal plains on Australia's eastern seaboard with Queensland accounting for approximately 95 per cent of Australia's raw sugar production —375 000 hectares were harvested and 30.5 million tonnes of cane crushed at an export value of $1 354 million in 2013-14 (ABARES 2014). In that year, sugar exports accounted for approximately 3.3 per cent of total farm exports by value from Australia (ABARES 2014). At a state level, the value of production attributed to sugarcane was 19 per cent of total crops and 10.4 per cent of total agricultural production value in 2012-13 (QGSO 2014). In 2013-14 Australia was the world's tenth largest producer of sugar at 4.43 million tonnes and the world's third largest exporter (ABARES 2014).[4]

Over 85 per cent of Queensland's' production occurs within the Great Barrier Reef catchments of the Wet Tropics, Burdekin and Mackay Whitsunday (see Table 2 and Figure 1). Consequently the sugarcane industry, and in particular the management practices growers have been using on their farms, have come under scrutiny as State and Commonwealth Governments have committed to address the declining health of the GBR attributed to agricultural run-off through the implementation of Reef Plans and other initiatives such as Reef Rescue water quality improvement grants, Reef Rescue Research and Development Programme and more recently Reef Trust.

[4] The order of sugar production in 2013-14 greater than Australia was: 1. Brazil 39.63 m/t; 2. India 26.00 m/t; 3. EU 17.26 m/t; 4. China 14.6 m/t; 5. Thailand 12.18 m/t; 6. US 7.68 m/t; 7. Mexico 6.47 m/t; 8. Pakistan 5.95 m/t; and 9. Russian Federation 4.78 m/t (ABARES 2014).

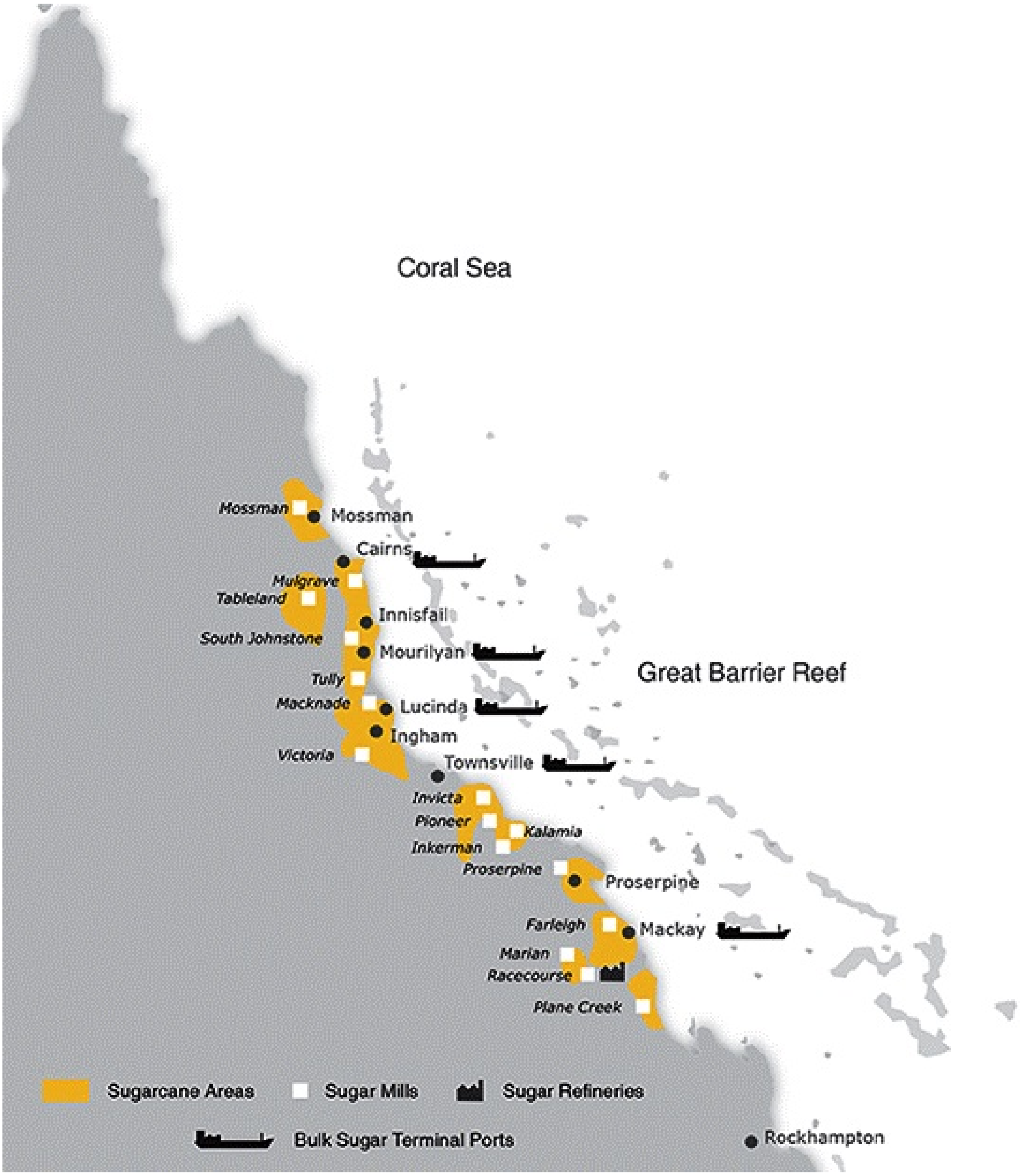
Table 2: Production figures for 2012 - 2014 for priority Great Barrier Reef Catchments

NRM region	Mill area	Tonnes of cane harvested from mill area (% of Australian total) 2012	2013	2014	Hectares harvested (% of Australian total) 2012	2013	2014
Wet Tropics	Mossman	508 867	587 295	1 141 393	7 100	7 580	13 981
	Tableland	745 356	850 479	330 345	7 227	7 865	3 682
	Mulgrave	1 148 780	1 343 399	1 031 222	11 850	14 675	11 555
	Innisfail	1 276 232	1 444 549	1 695 637	18 222	17 279	21 925
	Tully	1 774 157	2 335 509	2 436 860	23 911	26 122	27 747
	Herbert River	3 624 613	4 000 685	4 152 316	50 394	54 018	55 800
Wet Tropics	**Total**	**9 078 005 (30%)**	**10 561 916 (35%)**	**10 787 773 (33%)**	**118 704 (33%)**	**127 539 (34%)**	**134 690 (36%)**
Mackay Whitsunday	Proserpine	1 610 514	1 631 514	1 701 344	20 262	21 038	19 324
	Mackay	5 616 748	5 016 133	5 489 423	69 684	69 867	68 967
	Plane Creek	1 220 194	1 214 561	1 366 403	16 159	16 556	16 922
Mackay Whitsunday	**Total**	**8 447 456 (28%)**	**7 862 208 (26%)**	**8 557 170 (26%)**	**106 105 (30%)**	**107 461 (29%)**	**105 213 (28%)**
Dry Tropics	**Burdekin**	**7 479 187 (25%)**	**7 292 861 (24%)**	**8 061 406 (25%)**	**71 245 (20%)**	**71 402 (19%)**	**71 163 (19%)**
GBR catchments	**Total**	**25 004 648 (83%)**	**25 716 985 (84%)**	**27 406 349 (85%)**	**296 054 (83%)**	**306 402 (83%)**	**311 066 (84%)**
Australia	**Total**	**30 139 785**	**30 525 664**	**32 361 736**	**357 409**	**371 066**	**371 430**

Source: Canegrowers (2014b) and SRA (2015)

In addition to the pressures to adopt management practices with improved water quality outcomes for the GBR, in the past fifteen years the sugar growing industry has faced a number of challenges from other sources as well. As the industry is predominantly export focused it faces volatility as a price taker on the world market subject to exchange rate movements and barriers to trade — returns to growers were as low as $30 AUD per tonne of sugar in 2003-04 (Smith et al. 2014). There was restructuring and deregulation of the industry in the mid-2000s as well as significant risks from adverse weather conditions and disease outbreaks. The following paragraphs present more detail about regional and market characteristics and local industry changes that have shaped the context of the sugarcane industry over the period which governments have been developing policies to boost the adoption of practices that improve both profitability and water quality outcomes.

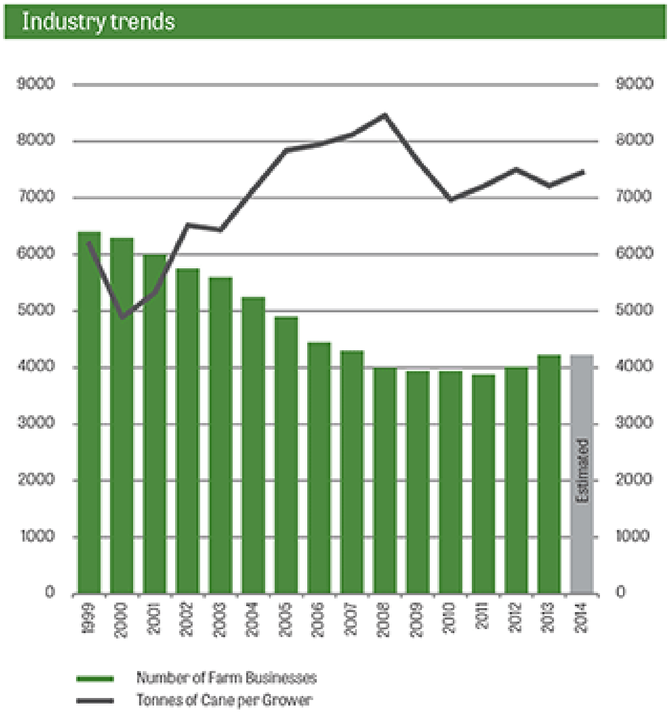
Figure 1: Map of Great Barrier Reef catchments sugarcane growing districts



Source: Canegrowers 2014a

In 2013 there were approximately 4000 sugarcane growing farms in Australia, averaging around 100 hectares in size (CANEGROWERS 2014). Over the past 15 years there has been a decline in the number of farm businesses growing sugarcane in Australia, from over 6000 in 1999 to 4000 in 2008 where it has hovered ever since (see Figure 2). At the same time that sugarcane growing farms were declining, the amount of sugarcane grown per grower was increasing, from around 6000 tonnes in 1999, peaking at 8500 tonnes in 2008 and sitting around 7500 tonnes since 2012 (see Figure 2).

Figure 2: Farm businesses and tonnes of cane per growers



Source: Canegrowers 2014

One factor that contributed to consolidation of farms was the restructuring of the sugar industry under the Sugar Industry Reform Programme (SIRP), whereby approximately $335 million was provided by the Federal Government to facilitate proposed reforms (Thompson et al. 2010).[5] Hooper (2008) reported that during the time of the SIRP, 2005-06 to 2007-08, the number of cane growers decreased by 15 per cent. However, an increase in tonnes of cane per sugarcane grower over this same period indicates that many sugarcane farms of growers exiting the industry have been consolidated into existing sugarcane properties rather than other land uses. Over the past 15 years the area harvested for sugarcane has varied between around 450 000 hectares in 2002-03 to just over 300 000 hectares in 2010-11 (ABARES 2015). Projections by the Australian Bureau of Agriculture, Resource Economics and Sciences (ABARES) sees sugarcane growing area staying close to 400 000 hectares over the next five years. Average sugar yield has ranged between approximately 10 and 13 tonnes per hectare over the last 15 years and is projected to remain over 12 tonnes per hectare in the next 5 years (ABARES 2015).

When trading raw sugar on international markets, Australian sugarcane growers are price takers, that is they are selling a product with little differentiation to that of other sellers in the market and there are many sellers so that if they tried to sell for a higher price than their competitors they would lose market share.

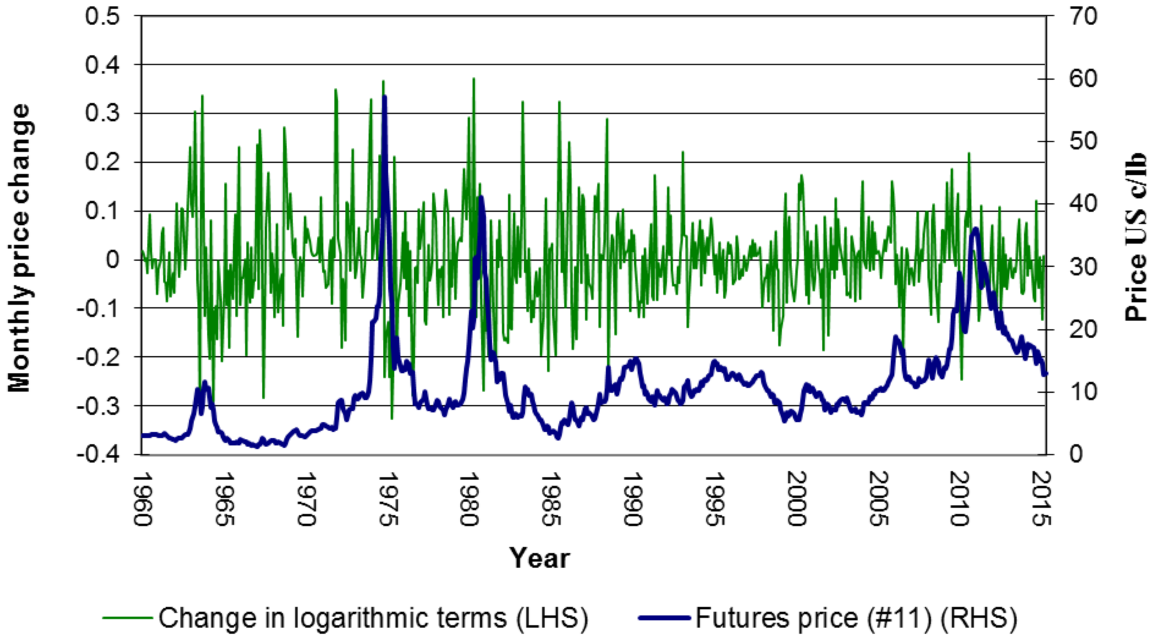
The Intercontinental Exchange (ICE) Futures US No. 11 contract for raw sugar is the predominant price setting tool for raw sugar around the world and is well recognised amongst sugar producers and traders (QSL 2011b). In fact, Queensland Sugar Limited (QSL) have stated that 'we price more than 90 per cent of all the sugar we export using this system' (QSL 2011b).[6] Figure 3 below illustrates the volatility in world

[5] Funding under SIRP was used for: Regional and Community Projects; Sustainability Grants; Income Support (including business planning for income support recipients);Business Planning (growers and harvesters);Business Planning (mills);Re-establishment Grants (growers and harvesters);Grower Restructuring Grants; Retraining; Crisis Counselling; and Intergenerational Transfer (AGDA 2015).

[6] QSL was the statutory single desk marketing authority up until 2006 when the Queensland government repealed their vesting powers and deregulated the marketing of Queensland raw sugar exports. However, it still handles the majority of raw sugar exports each year and has supply contracts to keep doing so up until 2017 (QSL 2011a). More recently sugarcane mills have

sugar prices over the period January 1960 to April 2015, with the green line measuring the monthly price change of raw sugar, and the blue line measuring the price of raw sugar in US cents per pound. Over the last 55 years, the price of sugar has varied between approximately 5 and 15 US cents per pound with periods of very high prices (approximately 35 to 55 US cents per pound around 1975, 1981 and 2012) and very low prices (approximately 2 to 5 US cents per pound around 1960 – 63, 1965 – 73, 1985).

Figure 3: World average monthly raw sugar prices, January 1960 - April 2015



Source: United States Department of Agriculture, 2015. (Original sourced from New York Board of Trade; Contract No. 11 – (free on board) stowed Caribbean port, including Brazil, bulk spot price plus freight to Far East).

The world raw sugar price from the ICE Futures US No. 11 contract is not the only factor that determines the price that growers receive. Growers can also hedge underlying exposure to price risk by participating in over the counter contract pools where the future delivery price is negotiated directly with customers such as the US Quota Pool, Guaranteed Floor Pool, Actively Managed Pool, Harvest Pool, 2 season Forward Pool and Shared Pool products offered by QSL in 2015. The price negotiated by such export marketers, fees incurred and exchange rates all affect the price that the grower receives.[7]

Figure 4 below shows Australian sugar prices in real terms from 1990-91 to 2013-14, taking into account inflation over this time period. It can be seen that the real price of sugar per tonne from 1990 is trending downwards, despite recent nominal increases to over AUD $500 per tonne in 2009-10 and 2011-12.

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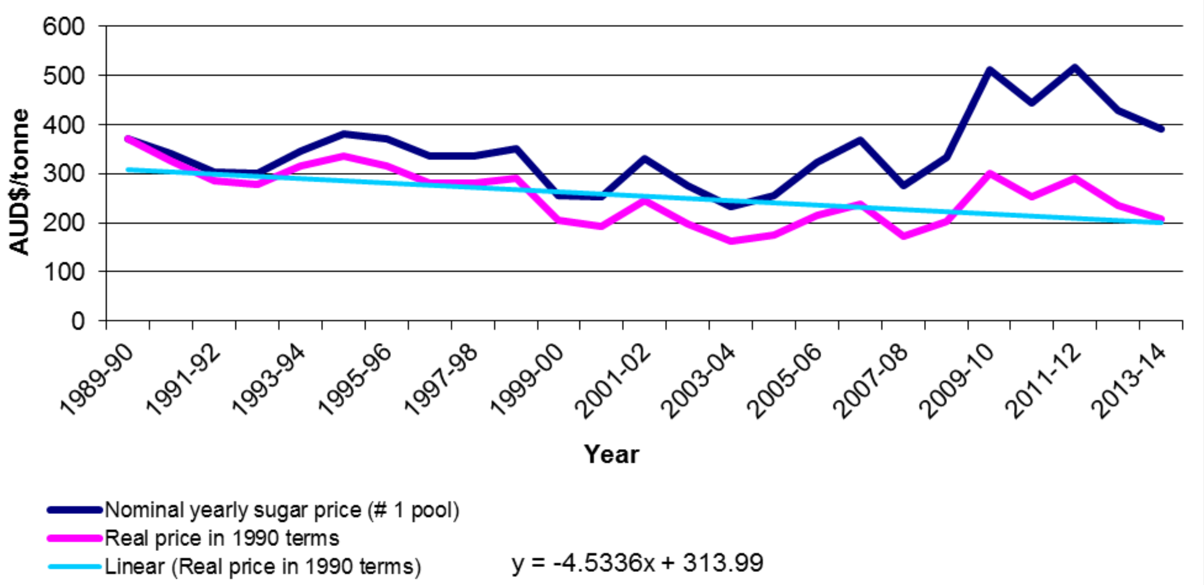
sought to market the export of raw sugar they have produced and concerns around transparency of pricing arrangements and market power saw a Senate Committee Inquiry established into 'Current and future arrangements for the marketing of sugar' on 4 September 2014 with final report released on 24 June 2015. The committee recommended 'the development and implementation of a mandatory sugar industry Code of Conduct acknowledging that, provided appropriate stakeholder consultation is undertaken, the work of the Sugar Marketing Code of Conduct Taskforce may provide a foundation upon which a Code of Conduct may be established'. The Queensland state government passed the *Sugar Industry (Real Choice in Marketing) Amendment Act 2015* in December 2015, enabling growers to choose who markets their sugar through the definition of 'grower economic interest' as well as providing for pre-contractual dispute resolution processes. Accessed on the 31 March, 28 July and 4 May at http://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Rural_and_Regional_Affairs_and_Transport/Sugar and https://www.legislation.qld.gov.au/LEGISLTN/ACTS/2015/15AC032.pdf accessed on 4 May 2016.

[7] As the Australian dollar is a floating currency, it can also be quite volatile. In the last 15 years one AUD has ranged between USD $0.50 to $1.10 (RBA 2015).

Figure 4: Australian sugar prices in real terms 1990-91 to 2013-14



Source: Australian sugar prices sourced from ABARES (2015) and QSL (2011-15). Prices deflated using Consumer Price Inflation (CPI) measures sourced from ABS (2015) (base year = 100 = 2012)

With around 80 per cent of sugar produced in Australia exported to international markets, the forecast value of sugar exports in 2014-15 is expected to be around $1.53 billion and increasing to $1.7 billion in 2015-16 (ABARES 2015). In 2013-14, Australia was the world's third largest raw sugar exporter with 3.4 million tonnes exported (Brazil and Thailand exported 25.6 and 7.75 million tonnes respectively) (ABARES 2014). The main importers of our raw sugar in 2013-14 were Indonesia (31.6 per cent), Republic of Korea (26.6 per cent), Japan (18.2 per cent), Malaysia (9 per cent), China (4.6 per cent) and Taiwan (3.9 per cent) (ABARES 2014). Although the Republic of Korea, Japan and Malaysia have always been important markets for sugar exports, the main importer of Australian sugar in 1995-96 was Canada, accounting for 17.8 per cent of exports that year (ABARE 1999: 20). The export market is now more focused on the growing demand for agricultural products from Asia.

This growing demand for raw sugar from Asia has also seen large foreign investment in the sugarcane industry from companies based in China (Tully Sugar Mill), Thailand (MSF mills) and Malaysia (Wilmar mills) in the last five years. This demand and increase in foreign investment may lead to further expansion of the industry.

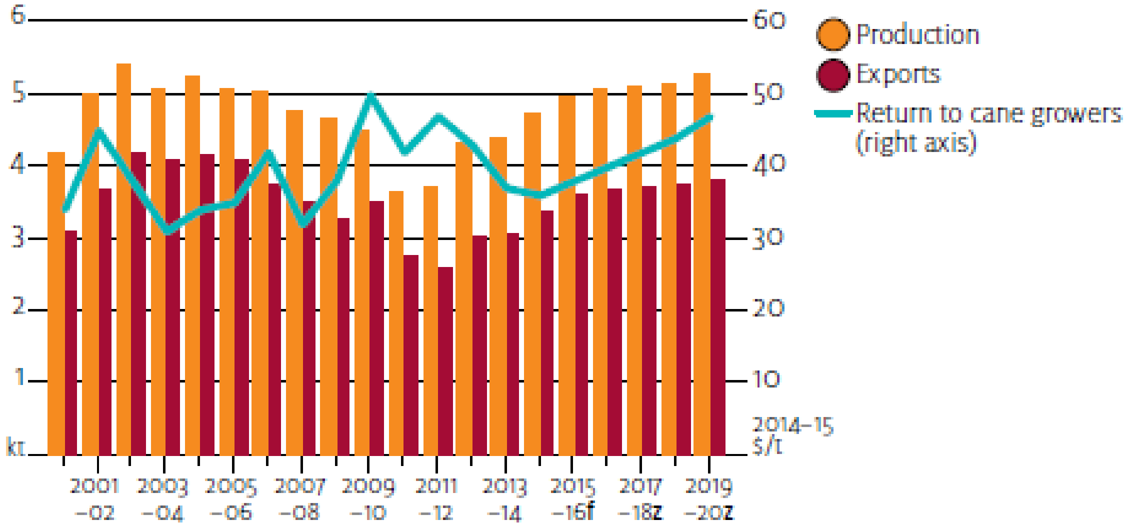
The Australian government provides limited and ad hoc budgetary assistance to the sugar industry. Examples include ongoing funding to the Sugar Research Australia (SRA), a portion of the $200 million in Reef Rescue payments to support industry to adopt management practices to improve environmental outcomes, disaster recovery assistance and in 2008-09 $4 million was provided under the SIRP for industry restructure (PC 2014:138). This is in contrast to other major producers of raw sugar in the world market where more consistent support is available in the form of minimum support prices (e.g. United States, India and Thailand) and quotas (e.g. European Union) (ABARES 2015).

These and other distortionary policies increase production beyond what the market would dictate without them, pushing world prices lower without the producers actually competing at the world price for their raw sugar. However, recent trade agreements with key trading partners in Asia are moving towards more favourable conditions for Australian growers exporting raw sugar.[8] ABARES projections for the next 5 years (see Figure 5) forecast both a production increase and higher returns to sugarcane growers.

Key points from the *Agricultural commodities: March 2015* for the sugar outlook to 2019-20 (ABARES 2015:72) were:

- World sugar prices are forecast to be lower in the short term, reflecting expected record world sugar stocks resulting from increased world production in 2014-15
- Over the medium term, higher world sugar consumption than production is projected to reduce world stocks. As a result the world stocks-to-use ratio for sugar is expected to decline over the medium term
- Reflecting expected higher Australian sugar production over the medium term, sugar exports are projected to reach 3.8 million tonnes in 2019-20.

Figure 5: Australian sugar production, exports and return to sugarcane growers



f ABARES forecast. z ABARES projection.

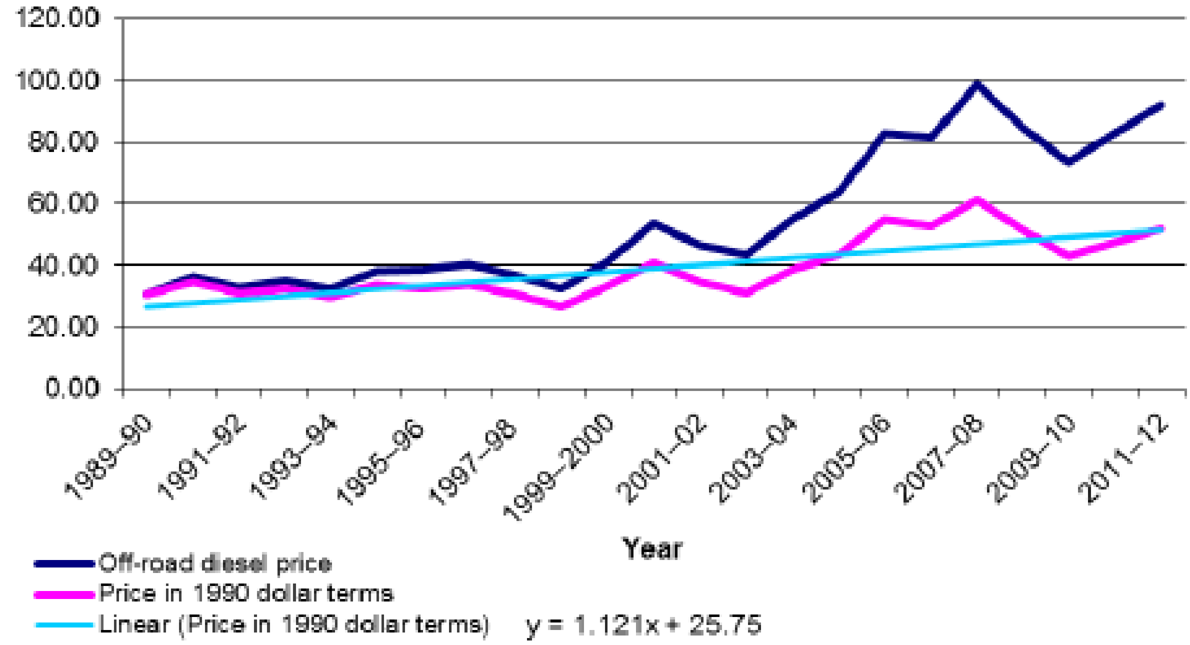
Source: ABARES (2015)

The price of raw sugar for export is just one variable that contributes to farm profitability –other contributors include farm production levels and input costs. Much has been written about cost-price squeeze in the agricultural sector, the phenomenon of declining output prices in the face of increasing input prices. The cyclical nature of commodity prices and the time lags involved for adjusting quantities supplied can often see the cost-price squeeze description more relevant at particular times in this cycle than others but the long term nature is less clear. Figure 4 from above shows that the real price of sugar in Australia has been declining over the past 25 years. Over that same period, with the exception of diesel (see Figure 6), the cost

[8] In the China-Australia Free Trade Agreement (ratified November 2014) sugar exports receive no tariff concessions or additional market access. China imports sugar under multilateral trade restricted quotas (TRQs), however, quotas are often binding and over quota tariff rates are applied (ABARES 2015: 23). The Japan-Australia Economic Partnership Agreement (ratified in January 2015) saw the 21.5 yen/kilogram tariff on high polarity raw sugar eliminated and a reduction of the domestic levy on commencement of the agreement (ABARES 2015: 31). The Korea-Australia Free Trade Agreement (ratified in December 2014) has tariffs to be eliminated on a wide range of agricultural commodities including sugar. In particular, the three per cent tariff on raw sugar was locked in at zero on commencement of the agreement – Korea has in recent years unilaterally applied a zero per cent tariff – and the removal of the 35 per cent tariff on refined sugar through equal annual reductions by 2031.

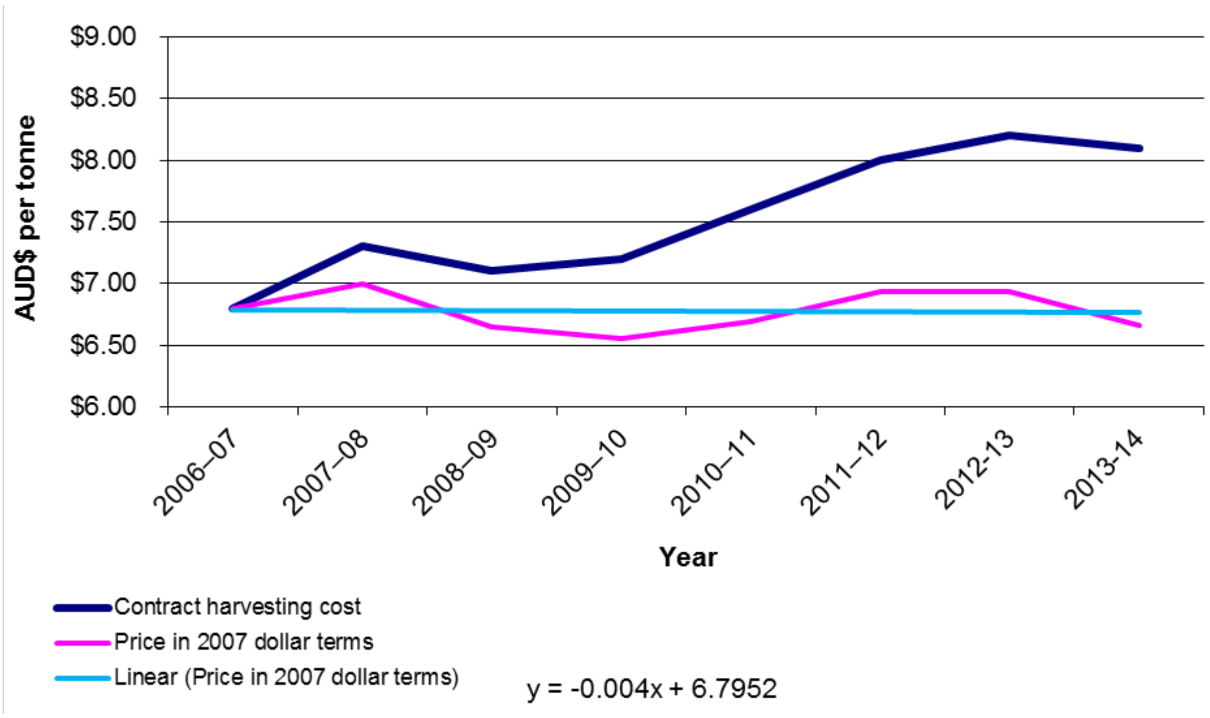
of inputs, in real terms to sugarcane production appear to be relatively flat on average increasing in line with inflation, such as harvesting costs in Figure 7. There was a spike in Urea (see Figure 8) and herbicide prices (see figure 9) around 2009 but these higher prices did not persist.

Figure 6: Diesel prices 1990-91 to 2013-14 in cents per litre



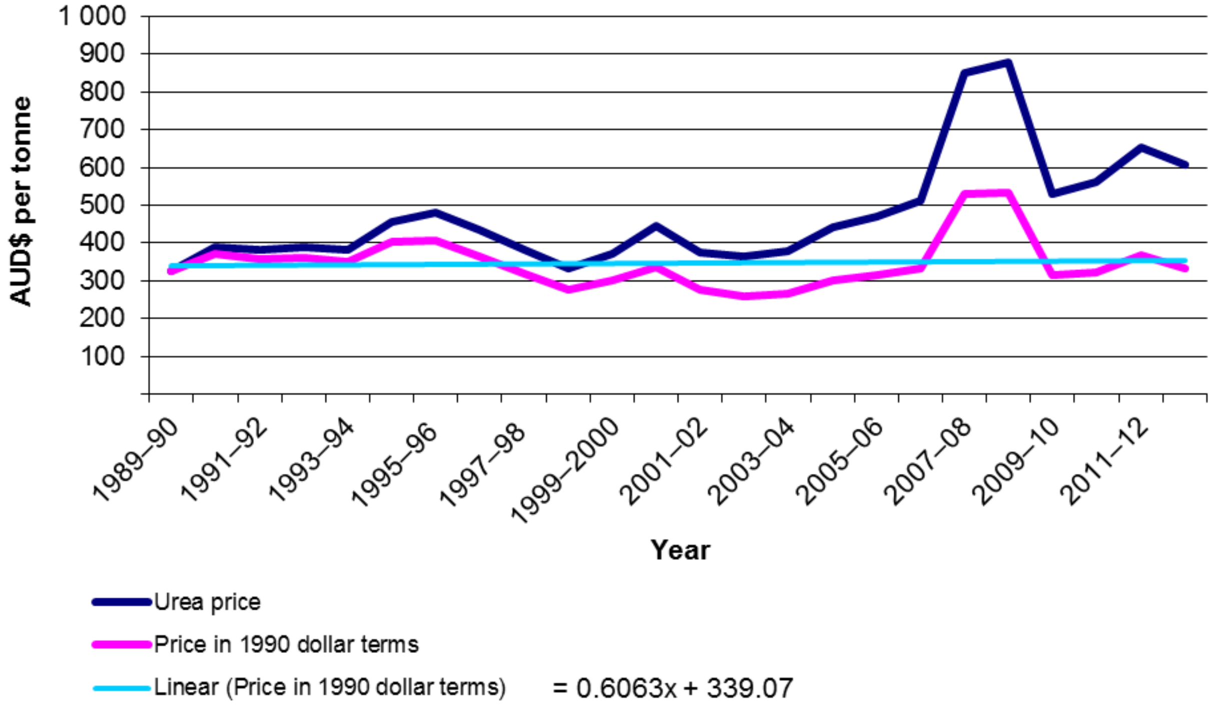
Source: Input prices sourced from ABARES 2014. Prices deflated using CPI measures sourced from ABS 2015

Figure 7: Contract harvesting prices (Herbert region), 2006-07 to 2013-14



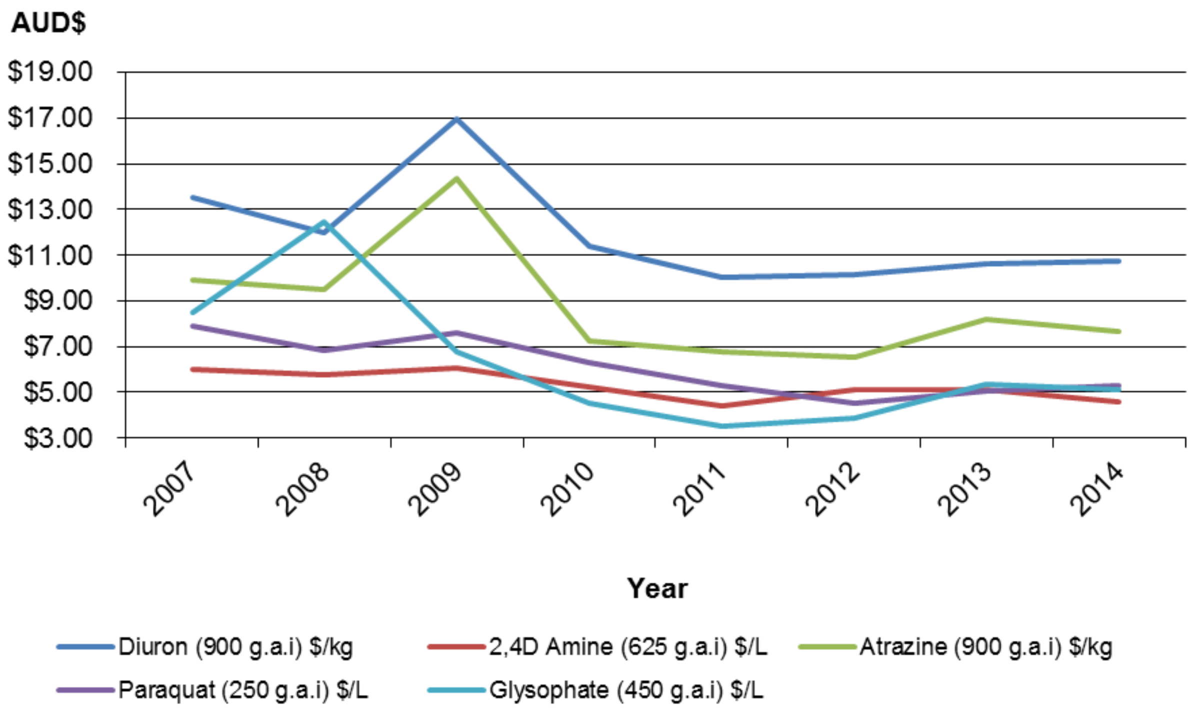
Source: contract prices sourced from private communication. Prices deflated using CPI measures sourced from ABS, 2015

Figure 8: Urea prices 1990-91 to 2012-13



Source: input prices sourced from ABARES 2014. Prices deflated using CPI measures sourced from ABS 2015.

Figure 9: Indicative herbicide prices in real terms 2007 to 2014



Source: Wholesale prices sourced from resellers in the Herbert region. Prices deflated using CPI measures sourced from ABS 2015.

Another input cost worth noting is the cost of labour, which is relevant for those farms that employ labour from outside the family unit or are corporately structured. The booming mining sector of recent years and the accompanying high wages offered have had flow-on effects for the agriculture sector, although this may be easing somewhat given the slowdown currently occurring in mining (Downes et al. 2014). For the Burdekin region which is heavily irrigated, there are also cost increases to the price of electricity and water to consider. In a report to CANEGROWERS in 2013, Carbon and Energy Market (CME) consultants found that the nominal rate of irrigation tariffs in Queensland had increased 90 per cent between 2008 and 2014 (CME 2013).

On the production side, Poggio et al. (2014) show that over a period of 10 years, yields varied from 63.9 to 98 tonnes cane per hectare in Tully, 95.3 to 129.7 tonnes cane per hectare in the Burdekin and 64.9 to 87.9 tonnes cane per hectare in Mackay. Unseasonal weather conditions disruptive to farming operations drive much of the production volatility, particularly in the Wet Tropics and Mackay Whitsunday regions (but can also be affected by pest and disease outbreaks such as Yellow Canopy Syndrome which has recently impacted on yields in all of the GBR catchments). This yield variation directly impacts on the economic performance of cane farming businesses. For example, Hooper (2008) reported a 40 per cent rise in farm base incomes in 2006-07 compared to the previous period and then a fall of 94 per cent the following year in 2007-08. As well as yearly variation, economic performance also varies from region to region. Collier (2014a) compares key economic data based on long term average production history and sugar price for the different sugarcane growing regions. The differences in the return on assets estimates generated from FEAT give an indication on the variation between the regions with the Burdekin Delta at 5.67 per cent per year, BRIA at 3.08 per cent per year, Tully at 2.82 per cent per year and Mackay at 2.14 per cent per year for representative 150 hectare farms.

The high level of volatility from many external factors in sugarcane production flow directly through to grower's income. As a result many sugarcane growers focus on ways to reduce or manage the risks from factors they can control in the production process. It is in this environment that Government agencies must make the case for moving to 'new' practices regardless of whether they are classified as best practice and even more so if they are still being proven as cost-effective and profitable (A practices).

3. Use of management practices to address water quality concerns

Key Points

- Scientific studies indicate that terrestrial runoff from adjacent catchments is a major cause of declining marine ecosystem health in the GBR lagoon and the widespread adoption of BMPs by landholders a key mechanism to addressing this decline.
- Improved management practices must also maintain or improve on existing production and profitability if they are to achieve widespread adoption.
- Since 2008 NRM bodies in GBR catchments have employed improved practice frameworks for water quality (ABCD frameworks) which reflect the differences in farming systems and landscapes between the regions. These provide a means of identifying where a farming system is at with respect to likely water quality outcomes and the options available for improvement.
- The ABCD frameworks have been updated a number of times since first introduced. There have mostly been downward revisions of practices (e.g. reclassification from B to C) as they become more widespread and technology develops. Most notably there were 14 reclassifications downwards in the North Queensland Dry Tropics ABCD framework between 2009 and 2013.
- The Paddock to Reef program developed a Reef Plan Water Quality Risk framework for sugarcane during 2013-14. This water quality risk framework is similar to ABCD frameworks although it is limited only to these practices that present the greatest water quality risk. These practices are also weighted to reflect the expected contribution to risk of off-site movement of pollutants.
- The more recent ABCD water quality frameworks from the NRM groups also saw the addition of many ‘new’ practices, some which were more detailed descriptions of previous practices and some which involved new methods such as using block yield potential in 6ES
- Smartcane BMP is the industry led best practice accreditation program launched in December 2013 and is ‘based on productivity, profitability and overall sustainability’. Participation in the Smartcane program is voluntary and the Queensland Audit Office found that as of June 2015 the number of farmers achieving accreditation is significantly below the targets set
- For a practice to be listed as a class B, best practice, in any of the frameworks, there should be sufficient research and on ground experience validating it’s water quality benefits and profitability to growers.

3.1 Water quality frameworks

Terrestrial runoff from adjacent catchments was identified as a major cause of declining marine ecosystem health in the GBR lagoon in both the 2008 and 2013 Scientific Consensus Statement Update reports. The widespread adoption of management practices, identified as delivering improved water quality outcomes, by landholders is a key mechanism to improving the health of the GBR ecosystem. For widespread adoption of these management practices to occur, they must not only address water quality concerns but also maintain or improve on existing profitability as explained in Section 2. The rest of this section describes the main frameworks that categorise management practices according to water quality outcomes or industry standard. These frameworks, while all in place to improve water quality leaving sugarcane farms, are not always aligned due to their differing purposes and definitions of various categories of practices. In this report, practices listed as best practice or aspirational are considered as those that are critical for improving the quality of water entering the GBR.

Paddock to Reef Monitoring and Reef Report Cards

The Paddock to Reef program (P2R) monitors and reports the adoption of best management practices in GBR catchments. These adoption data are primary inputs into paddock and catchment scale models; these models estimate the pollutant load (sediment, nutrient, and pesticides) reductions which may occur through the adoption of improved management practices on farms. Both the degree of adoption of best management practice systems and the consequent reduction in pollutant loads are key components of the GBR Report Cards[9] GBR Report Cards have been produced for every year since 2009, with the 2014 report the most recently released in September 2015.

The P2R water quality risk framework provides the basis for determining the adoption of best management practice systems. The P2R water quality frameworks are distinguished by the following features (McCosker 2016: 1):

- The suites of practices relevant to each pollutant are described in the frameworks. This does not mean all of the practices in the production system, only those practices that pose the greatest potential water quality risk through movement of sediments, nutrients, or pesticides off-farm.
- Not all practices are equal. The P2R frameworks allocate a percentage weighting to each practice depending upon its relative potential influence on off-farm water quality.
- The 'best practice' level is that targeted by Reef Plan investments.

Table 3 below describes how P2R categorises sugarcane practices according to the risk of water quality in relation to the Reef Plan 2009 ABCD framework.

Table 3: P2R classification of management practices in the cropping industries (sugarcane)

2013 Water Quality Risk	**Low**	**Moderate-Low**	**Moderate-High**	**High**
Description	Lowest water quality risk, commercial feasibility not well understood	Best Management Practice	Minimum Standard	Superseded
Previous Reef Plan 2009 "ABCD" nomenclature				
Sugarcane	A	B	C	D

Source: McCosker (2016)

Practices listed as moderate to low risk and lowest risks are the most critical for water quality outcomes (for more detail on practices listed under these categories for sugarcane see Table 15 in Appendix 1).

Natural Resource Management bodies and ABCD management practice frameworks

GBR NRM bodies have developed their own management practice frameworks for water quality, originally as part of the Water Quality Improvement Plan process prior to the Reef Report Cards being undertaken (Drewry et al. 2008). Table 4 below describes the categories, practices and desired outcomes for central region sugarcane practices.

[9] Between 2009 and 2013 adoption data was measured as the number of landholders who had adopted best management practices. In 2014 this was changed so that Paddock to Reef program collected data on the number of hectares under best management practices.

Table 4: Description of ABCD framework categories, practices and desired outcomes

Category	Description of practice	Effect on resource condition
Aspirational (A)	• New and innovative practices adopted by growers that require further validation to determine industry wide environmental, social and economic costs/benefits. • Validation requires R&D and if appropriate, some validated practices will become recommended best practice. • Development of Farm Management Plans and utilization of new and innovative technology.	• Validated practices likely to achieve medium to long term target resource condition goals if widely adopted. • Some practices may have good environmental outcomes which may not be universally endorsed as feasible by industry and community.
Best Practice (B)	• Currently industry promoted practices. • Widely promoted by industry to achieve current and future industry expectations and community standards. • Development of Farm Management Plans and utilization of common technology.	• Practices likely to achieve short to medium target resource condition goals if widely adopted.
Conventional (C)	• Common practices widely adopted by industry but meet only basic current industry expectations and community standards.	• Practices unlikely to achieve short term target resource condition goals if widely adopted.
Dated (D)	• Practices superseded or unacceptable by current industry expectations and community standards.	• Practices likely to degrade resource condition if widely adopted.

Source: DAFF (2013b)

The frameworks used by the GBR NRM bodies, known as ABCD frameworks, while similar to the one used for the Paddock to Reef programme, reflect the differences in farming systems and landscapes between the regions (see Appendix 2 for the ABCD frameworks for each GBR NRM body). The ABCD frameworks provide a mechanism for sugarcane growers to identify where their farming system is at with respect to water quality outcomes and the options available for improvement specific to their region.

Table 5 below compares the number of management practices under the headings of Nutrient, Pesticide, Soil Health and Water and Irrigation Management and Record Keeping found in each of the GBR NRM bodies ABCD frameworks for sugarcane. The management practices under these headings from ABCD frameworks are presented in Appendix 2. While this report has altered the format of ABCD frameworks to enable easier comparison of the content between the NRM regions in Appendix 2, in their original format they appear quite different. For example, the NQ Dry Tropics 2013 framework is presented as a table on a single page (see Table 16 in Appendix 2), Reef Catchments 2014 ABCD framework for the Mackay Whitsunday region is presented over seven pages (see Table 18 in Appendix 2) and the Terrain ABCD 2014 framework is presented in a checklist form over 15 pages (see Table 17 in Appendix 2).

Table 5: Comparison of practice management categories across water quality frameworks

Framework	Nutrient	Pesticides	Soil Health	Water & Irrigation	Record Keeping
Reef Catchments 2014	6	6	8	4	1
NQ Dry Tropics 2013	5	5	7	6	1
Terrain 2014	9	9 [(a)]	9 [(b)]	6 [(b)]	1
P2R WQ Risk 2013	3	3	5	3	n/a
Smartcane BMP 2013 [(c)]	4 [(d)]	8 [(e)]	7 [(d)]	14	1

Notes: (a) Terrain uses heading 'Weed Management'. P2R uses heading 'Herbicides'. (b) Terrain includes water and irrigation management practice categories under 'Soil Health' heading in their framework – separated out for comparative purposes here. (c) Management practice headings taken from Smartcane key modules only. (d) Separated out Smartcane key module heading 'Soil Health and plant nutrition' into separate headings for comparative purposes here. (e) Smartcane key module heading 'Pest, disease and weed management'.

Smartcane Best Management Practice (BMP)

In early 2012 CANEGROWERS received funding of $3.345 million from the Queensland Government to develop and deliver a best management practices accreditation program for sugarcane growing (Smartcane 2013) with the aim that this program would support transition away from the *Great Barrier Reef Protection Amendment Act 2009*.[10] The industry led Smartcane BMP programme launched in December 2013 and is 'based on productivity, profitability and overall sustainability' compared to the ABCD and water quality risk frameworks used under Reef Plan which are focused more towards water quality improvements (Smartcane 2013). The programme includes seven modules (below) that sugarcane growers complete to gain BMP accreditation (see Table 19 in Appendix 3 for a list of detailed practices under each module and their classification):

1. Soil health and plant nutrition (key module)
2. Pest, disease and weed management (key module)
3. Drainage and irrigation management (key module)
4. Crop production and harvest management
5. Natural systems management
6. Farm business management
7. Workplace health and safety management

An important point to note is that the Smartcane BMP program generally articulates practices relating to management issues at three levels:

- Below industry standard
- At industry standard
- Above industry standard

Participating in the programme is voluntary and growers can choose to undertake a self-assessment of how they comply with the modules with the choice of going further to undertake the accreditation process. The grower can undertake training through the programme with Smartcane BMP facilitators supported by

[10] The Great Barrier Reef Protection Amendment Act 2009 regulates the water quality impacts of all commercial sugarcane farming in the Burdekin Dry Tropics, Mackay Whitsunday and Wet Tropics catchments (Queensland Government 2013). Specifically, sugarcane growers are required to: calculate and apply no more than the optimum amount of nitrogen and phosphorus fertilser to achieve the district yield potential; keep records of soil test results, how the optimum rate was calculated, the rate applied and method used to apply fertiliser; hold recognized training qualifications in chemical handling, preparation, application, transport, storage and weed control; observe mandatory requirements when using certain herbicides and implement an Environmental Risk Management Plan.

industry and government officers, to improve their knowledge in certain areas to assist achieving module accreditation (Smartcane 2013). Modules denoted as key are those which were required to be completed for accreditation by a given number of growers for the rollback of the Reef Regulations when the Smartcane BMP programme was first introduced in 2013.

It is important to highlight that the *Great Barrier Reef Protection Amendment Act 2009* remains in place and recommendations in the Great Barrier Reef Water Science Taskforce (the Taskforce) final report released in May 2016 included keeping regulations as part of the policy mix (The State of Queensland 2016: 61). The Queensland Government has recently agreed in principle to all ten recommendations made in the Taskforce's Final Report (Queensland Government 2016).

3.2 Changes to ABCD framework management practices

Consensus on what constitutes best management practice is constantly evolving. That is, some practices may initially be regarded as best practice or innovative, but eventually are superseded by new thinking or innovations. The reverse can also occur with practices listed as 'aspirational' proving not to be commercially viable. Since 2009 the Reef Catchments NRM has had the Mackay Whitsunday (MW) region ABCD framework updated three times, Terrain NRM has updated the Wet Tropics ABCD framework at least four times while NQ Dry Tropics has updated the Burdekin's twice. A comparison between the 2009 and most recently available frameworks for the MW, Burdekin and Wet Tropics regions was undertaken and the main changes are summarised below in Table 6.

There has been minimal upward reclassification of recommended management practices over the past five years with three practices moving up from B to A class in the Reef Catchments framework and one practice from C to B-class and another from B to A-class in the Terrain framework. Interestingly, the practices that moved up a class in the Reef Catchment framework were completely different to the practices that moved upwards in the Terrain framework. The reasons for upward reclassification were not found in the literature reviewed. The NQ Dry Tropics framework did not reclassify any practices upwards.

Only two management practices moved down from A to B-class and one from B to C-class in both the Reef Catchments and Terrain frameworks over five years – again, completely different practices in each region made the downward reclassification. In contrast, the NQ Dry Tropics framework had 14 downward reclassifications – one C to D, five B to C, and eight A to B reclassifications. The gradual reclassification of certain management practices downwards is consistent with the outcomes expected from Reef Plan and the resources invested in the research, development and extension of B and A-class practices over a five year timeframe. Ideally, the outcome is to have more agronomy, economic, social and environmental information becoming available on A and B-class practices and feeding back into the ABCD frameworks. Downward reclassification may be due to increased efficiencies over time and scale, technological developments or increased access to capital (e.g. lower interest rates or government grants) required to facilitate adoption.

Many new A and B-class practices were introduced in the MW (18 A-class and 17 B-class), Burdekin (four A-class and six B-class) and Wet Tropics (seven A-class and four B-class) regions in the most recent frameworks. These were practices that were different enough to past practices not to be categorised as a reclassification (see Table 7 below for the new practices). These 'new' practices were distinguished from old practices that had been finessed or updated a little bit but essentially still described the same practices/equipment from the 2009 version (described as 'adjusted' in Table 6).

These regional differences were one of the drivers for the development of the P2R water quality risk framework in 2013-14. The P2R framework describes only the practices with highest relevance to water quality risk, and provides a consistent basis for describing the impacts of interventions aiming to improve farm management as it relates to off-farm quality.

Table 6: Practice classification changes between 2009 and 2014

Region	Practices that have moved up a class[a]	Practices that have moved down a class[a]
Mackay Whitsunday	Automated base cutter height on harvesters (B to A). Yield monitors fitted to harvesters (B to A). Strategic or zonal tillage of fallow crops and plant cane (B to A – adjusted).	Adjust herbicide strategy during crop cycle if required (A to B). Limited water quality testing conducted on some irrigation water sources (B to C – adjusted). Site specific application of ameliorants applied based on soil mapping (A to B – adjusted).
Burdekin		Soil test taken prior to planting. Not all blocks tested. Planning based on 6ES. (B to C – adjusted). Fertiliser calibration (A to B and B to C – adjusted). Primary reliance on knockdown over residuals (A to B). Pesticide calibration (C to D). Minimum tillage (B to C). Variable rate ameliorants applied based on soil tests and prescription mapping (A to B). Irrigation to match crop requirements and minimise loss to deep drainage (A to B – adjusted). Metering and pump audits (A to B – adjusted). Soil moisture monitoring tools across irrigation management zones to determine irrigation timing (A to B – adjusted). Appropriate furrow shape and length for soil type and slope (A to B). Recycle pits on suitable soil types capturing first flush (B to C – adjusted). Recycle pits on suitable soil types capable of capturing all irrigation runoff and sufficient pumping capacity to reuse (A to B – adjusted). Herbicides delayed based on label recommendations (B to C – adjusted).
Wet Tropics	[Herbicide] Calibrated for each situation (product and water rate) with appropriate nozzles (C to B – adjusted). [Herbicide] calibrated electronic rate-controlled equipment used with latest application technology such as air inducted nozzles (B to A – adjusted).	Sub-surface applied within the stool by stool splitter or similar modified equipment (A to B – adjusted). Paper based records of block activities along with mill supplied production records (B to C – adjusted). Computer based records covering all block activities and production, trends in soil nutrient content, weed survey data and water quality testing results (A to B – adjusted).

Note: a - the term adjusted is used to highlight that practices that have moved up or down a class between 2009 and 2014 have had some minor adjustments in the wording but are essentially the same practice, hence can be attributed to moving up or down a class over time rather than be considered as a new practice.

Table 7: New practices introduced between 2009 and 2014

Region	New Best practice	New Aspirational practices
Mackay Whitsunday	Application of mill mud/ash should not exceed crop cycle nutrient requirements and be directed to the planting zone. Identify soil types/productivity zones for each block. Geo-referenced soil sampling in key soil types in blocks prior to planting each year which may include more comprehensive sampling. Legume crops incorporated as close to planting as possible to maximise nutrient availability. Risk assessment conducted prior to fertilizing (48 hour rainfall prediction, weekly forecast, seasonal predictions). Incorporation of surface applied fertiliser as soon as practicable (e.g. within seven days) using overhead irrigation that does not result in runoff. Calibration of fertiliser applicator with some changes of product and monitored during operations. Ability to adjust rate for granular or liquid applicators. Directed applicators must have capacity for sub-surface application. [Pesticide] risk assessment conducted prior to spraying (48 hours rainfall prediction, wind speed and direction, weekly forecast, seasonal predictions). Calibration of spray equipment conducted before every change of product or nozzle type. Maintain some knowledge of latest chemical management issues and recommendations. Initial row establishment formed with GPS guidance as minimum. Rotational crops grown on all fallow where practicable and managed to retain some ground	Using individual block yield potential and taking mill by products, compost other organic nutrient sources into account. Application of mill mud/ash should not exceed crop cycle nutrient requirements and be banded on planting zone. Geo-referenced soil sampling in identified specific zones in blocks each year which include more comprehensive sampling. Legume crops left as stubble or incorporated just prior to planting as possible to maximise nutrient availability. Use of new fertiliser products such as slow release or polymer coated urea in higher risk areas or during identified higher risk times. Detailed risk assessment conducted prior to fertilizing (SafeGauge for Nutrients, 48 hour rainfall prediction, weekly forecast seasonal predictions). Incorporation of surface applied fertiliser within seven days using overhead irrigation that does not result in runoff. Calibration of fertiliser applicator with every change of product or application rate. Banded on-row applicator for mill by-products or other organic ameliorants. Knockdown herbicides replace residual herbicides in the inter-row and also where practical (residual herbicides only used where weed species and pressure demands it) within blocks. [Pesticide] detailed risk assessment conducted prior to spraying (48 hours rainfall prediction, wind speed and direction, weekly forecast, seasonal predictions, SafeGauge for Nutrients). A focus on good weed control in fallow and plant cane to ensure minimal herbicide in ratoon stages. Automated boom height control. Weed scanner/sensing equipment. Rotational crops grown on all fallow where practicable and managed to maintain good ground cover until planting. Utilization of harvesting technology to reduce impact on crop and soil condition. Irrigation strategy includes the incorporation of the majority of nutrient and chemical applications where possible. Storm water storages/sediment traps part of the drainage system.

	cover. Application amount matched to soil plant available water capacity (PAWC), infiltration rate and crop stage. Irrigation systems match soil and topography. Meet legislative requirements and minimum accreditation and competency standards for chemical storage, application and disposal.	
Burdekin	6ES based on individual block yield potential. Prior to mid- October in moist soil. Continual calibration if using flow rate controllers. Green cane trash blanket on suitable soils. Delaying irrigation application after fertiliser as long as possible. Irrigation application efficiencies – new category - >60 - 75% for Delta and >70 - 85% for BRIA.	Split applications in ratoons. Banded mill mud. Continual measurement of application volumes fed into automated control system. Irrigation application efficiencies – new category - >75% for Delta and >85% for BRIA.
Wet Tropics	Timing of herbicide applications as in C below *with short-term weather forecasting (7+ days) to avoid application close to heavy rainfall events.* Uses row spacing between 1.65 and 1.75 with GPS. Native riparian vegetation at <20m wide along 100% of the length of natural waterways managed by you ***old version used 'at a width and density which limits erosion*** Headlands are >5m wide ***old version used 'at a levels where they filter runoff but not an impediment***	Calibrated electronic rate controller used and outputs monitored. Leaves legume stubble standing and direct drills plant cane. Timing of herbicide application as in C below in conjunction with best available long-term weather forecasting to avoid or minimise use of residual herbicides within 30 days of the onset of the wet season. Native riparian vegetation at 20m wide for creeks and 50m wide for major waterways along 100% of the length of all sides of natural waterways managed by you *** old version had 'at a width and density which limits erosion'*** All farm drains engineered and maintained to minimise erosion including large and common drains (grassed or armoured). All farm drains engineered and maintained to minimise erosion using vegetation or rock. As in B below but including automated field data collection from tractor mounted computers/controllers with associated recording and reporting functions.

The Burdekin region framework had one completely new category in 2014 (irrigation efficiencies in the BRIA and Delta) compared with 15 from the Wet Tropics region.[11] However, it must be noted that many of the new categories in the 2014 Wet Tropics region frameworks contain practices that were in the 2009 framework under broader category headings that have now been replaced by these more specific ones – eight category headings from the Wet Tropics 2009 framework no longer exist[12] so there has been a net increase of seven new categories in the Wet Tropics region.

There were a number of new B-class practices introduced in the latest ABCD Frameworks put out by the regional NRM bodies. For a practice to be listed as B-class they are considered 'currently industry promoted practices that achieve current and future industry expectations and community standards' (see Table). There is an underlying assumption that for industry to promote a practice it should not negatively impact upon enterprise profitability. Many of the newly listed B practices are just a greater understanding or more detailed description of practices that were included in the past such as specifying the risk assessment required prior to fertilising and pesticide application in MW region and what is an appropriate density for riparian management in Wet Tropics region.

6ES based on block yield potential has been included as a B practice in the Burdekin region (listed as an A-class practice in MW region) and as best practice in the Paddock to Reef Sugarcane Water Quality Framework.[13] However, there has been limited economic analysis on this practice. *A Review of Nitrogen Use Efficiency in Sugarcane* (2014) by SRA reviewed existing knowledge around nitrogen use in sugarcane growing, however, the SRA (2014) report did not cite any studies that have used block yield potential within 6ES that included an economic analysis. In undertaking this review we found no studies that included an economic analysis of using 6ES based on block yield potential, however, there were two studies that undertook an economic analysis of variable rate nutrients within blocks based on management zones (See section 4.1 for a summary of Coventry and Hughes (2011) and Collier (2015)).

[11] New categories in the Terrain ABCD framework 2014 compared to 2009: application of mill mud/ash; residual herbicide use in plant cane; residual herbicide use in ratoons; knockdown herbicide used in plant cane; knockdown use in ratoons; spraying equipment; weed control in the fallow – flooding likely; weed control in the fallow – flooding unlikely; planting method; legume establishment practices; non-legume fallow practices; sediment risk management tools – silt traps; headland management; shallow drains; and deep drains.

[12] Categories from the 2009 Terrain ABCD framework that are not categories in the 2014 framework: leaf testing; herbicide strategies; weed management planning; herbicide rates; general herbicide issues; tillage in ratoons; fallow practices; and sediment risk management tools.

[13] The Terrain framework has nutrient applications rates at B-class as 'variable rate between blocks based on all components of 6ES' (Terrain 2014). Block yield potential is not explicitly specified here as in the NQ Dry Tropics framework. .

4. A review of economic studies on management practices for improved water quality outcomes

This section of the report reviews published studies on sugarcane growing BMPs for water quality outcomes that included an economic analysis. An economic analysis can take a number of forms and the three main types that were included in the publications reviewed in this section are defined below.

A partial net return or partial net benefit only considers the gross revenue received for sugar from the mill less the variable costs that are impacted by a particular practice change (e.g. levies, harvesting and fertiliser costs for reduced nitrogen rate practices). This is then compared to the partial net benefit of the current approach in isolation of the rest of the farming system. This approach gives an estimate of the relative benefit of alternative practice to the current application. Fixed costs are assumed to be constant when using this method and it does not consider other aspects of the farming system or capital requirements. This method is useful when comparing the relative difference of a simple management practice change that only involves revenue or variable cost attributes. Limitations are that this method assumes that the variable costs associated with all other management practices not being trialled remain constant which may not be true at all. For example, if growers are using a higher fertiliser rate then they may get more weeds and need to do more weed control, increasing this particular variable cost.

A gross margin approach (gross revenue less all variable growing costs) is similar to a partial net benefit approach but it also subtracts the variable costs of other practices involved in sugarcane growing, not just the practice that is being considered. For example, if reduced nitrogen rates are being analysed a gross margins approach would also include the variable costs associated with weed, pest & disease control, cultivation, planting and irrigation expenses as well as fertiliser application for each crop class

A whole-of-farm (WOF) approach to economic analysis looks at the impact of a change in farming practice across the whole business, rather than focusing on one particular component. Instead of looking at a single practice change it is possible to look at a suite of changes at the same time. FEAT is a computer spreadsheet based programme for sugarcane growers that allows them to undertake a whole of farm economic analysis or to compare the economics of various components of a new farming system. FEAT considers total farm gross margin plus other farm income less fixed costs to estimate the farm operating return.

Which economic analysis method is undertaken will depend on the data collected in a study, which is determined by the objective of the research and the subsequent design of the study.

4.1 Nutrient management practices

Key Points

- Eleven studies were reviewed which included some form of economic analysis of a single improved practice targeting nutrient management over the last seven years. While there has been an increased number of studies over the last five years some significant gaps are still evident.
- There is a substantial dearth of economic studies looking at nutrient management practices in the Burdekin and Mackay Whitsunday regions across all categories of nutrient management.
- The review indicated that economic studies including the nutrient management sub-categories of planning, timing and placement were not evident. Only one published study with an economic analysis that included the placement of phosphorus was found.
- The focus of economic analyses of nutrient management practices in recent years has been on comparing nitrogen application rates of 6ES (using district yield potential) with traditional rates and the N-Replacement approach in the Wet Tropics region.
- From the studies reviewed in this section N-Replacement delivered relatively better water quality outcomes in terms of reduced surplus of N, however, it was also the least profitable option trialled for growers. In specific circumstances, 6ES was the most profitable. This demonstrates that N requirements will vary according to site specifics and achievable yield, and growers may need continued assistance in understanding the agronomic processes and benefits associated with nutrient BMPs for both private and environmental benefits to be realised.
- Extended fallow was not profitable relative to traditional fallow periods in the sole study reviewed here and placement of nitrogen was found to be non-influential in the study that examined it.
- The recent review into nitrogen use efficiency (NUE) by SRA also identifies future work in the areas of understanding the economics of enhanced efficiency fertilisers and other various NUE strategies on farm/enterprise profitability as important. Only two studies were found on variable rate application that included an economic analysis, and these studies both focused on varying rates at the management zone level. No studies were found that included an economic analysis of adjusting N rates at the block level.
- Much of information in the publications reviewed for this section are in the form of research papers. Most of the studies are based on field trial results and used a partial net benefits approach to measure the economic benefits of nutrient management practices. Cost-effectiveness was unable to be determined due to lack of associated reduction in DIN from practices reviewed in the studies.

Eleven studies were reviewed which included some form of economic analysis of a single improved practice targeting nutrient management over the last seven years. All but two of these studies were undertaken in the Wet Tropics region, seven used a partial net benefit economic analysis, three a whole of farm analysis and one a gross margin analysis. A summary of the key points of each study reviewed in this section is provided in Table 8 below and Table 9 below provide an overview of the quality of information used in each publication specifically comparing N application rates.

Table 8 below shows that most of the papers exclusively focused on nitrogen application rates, in particular the comparison of at least two of the following rate classifications: traditional, grower developed (GD), Six Easy Steps (6ES) and N-replacement. Of these studies, four found GD N rates produced the higher economic returns for growers than 6ES between $25 and $267 per hectare and 6ES produced higher economic returns to growers than N-Replacement between $117 and $293 per hectare. One study had mixed results but averaged over multiple trial sites 6ES gave higher grower returns than the GD N application rate by $49 and $80 per hectare for 2007 and 2008 respectively.

Table 8: Summary of studies reviewed for nutrient management practices

Year	Author	Region	Publication type	Practice	Economic method	Biophysical method	Statistical analysis
2008	Schroeder et al.	Wet Tropics	Conference Proceedings	N application rates	WOF	Field trial, P - R4, 4 treatments replicated, cumulative response curves	Not specified
2009a	Schroeder et al.	Wet Tropics	Conference Proceedings	N application rates	PNR	Field trial, 2 sites, P – R4 and P1 – R3, 4 treatments replicated, cumulative response curves	Statistical significance (production data)
2009b	Schroeder et al.	Wet Tropics	Conference Proceedings	N application rates	PNR	Field trial, R1-R2, 9 sites, 2 treatments, replicated (except 1 site)	Not specified
2010a	Schroeder et al.	Wet Tropics	Conference Proceedings	N application rates	PNR	Four strip trials, R1, 3 treatments,	Statistical significance (production data)
2011	Coventry and Hughes	Mackay Whitsunday	Report	Variable N application rates in paddocks	PNR	Five study sites across Mackay Whitsunday, Wet Tropics and Burdekin had soil, ECa, elevation and yield mapping undertaken to develop spatial profiles of blocks. Only Mackay Whitsunday had an economic case study undertaken.	Statistical significance on Biophysical data only
2012	Skocaj et al.	Wet Tropics	Conference Proceedings	N application rates	PNR	replicated strip trials, R1 – R3, four sites, 3 treatments, 2 replicates on 2 sites and three replicates on 2 sites	ANOVA
2013	Edwards et al	Mackay Whitsunday	Contributed conference paper	Extended fallow	WOF and risk analysis	Field trial, P-R1, 2 treatments	No – risk analysis on gross margins
2013a	Skocaj et al.	Wet Tropics	Conference Proceedings	P application rate and placement	PNR	Experiment station trial, P-R1, 6 treatments, 5 replicates of each treatment	Statistical significance (production and economic data)
2013b	Skocaj et al.	Wet Tropics	Conference Proceedings	N application rate	PNR	APSIM calibration	Not specified
2013a	DAFF	Wet Tropics	DAFF publication – case study information sheet	N application rate	GMA	Replicated field trail, 2 treatments, R1,	no
2015	Collier	Wet Tropics	DAF publication – case study	Variable N application rates	WOF	Field trial – four treatments and three replicates each of variable rate nutrient application within	Statistical significance

			information sheet	in paddocks		blocks (2 zones) using 6ES	(production data and revenue)

Notes: N – Nitrogen; P – Phosphorus; 6ES – six easy steps; TRAD – traditional rate; GD – grower developed rate. Crop cycle terminology has P = plant; R1 = first ratoon; R2 = second ratoon; R3 = third ratoon; R4 = fourth ratoon.

Table 9: Summary of methodology used in studies reviewed for nutrient management practices

Type of trial	Region	I.D.	Reps (#)	Crop classes	Difference in average grower partial net return (using 6ES as base) *Grower rate*	*Traditional*	*6ES*	*N-replacement*	Comments	References
Small plots	WT (Macknade)	Herbert 1	Y (?)	P to 4R	-$28	-$5	$0	-$57	Results transformed to grower measure.	Schroeder et al. (2008, 2009b, 2010b) Wood et al. (2008)
	WT (Tully)	Tully 1		P to 3R	-$41	-$3	$0	-$131	Results transformed to grower measure.	Schroeder et al. (2009b, 2010a, 2010b)
	Central	Mackay 1	?	?	?	?	✓	?	Summary only. Not quantitative.	Wood et al. (2008)
Strip trials	WT (Johnstone)	Brosnan	Y (?)	2 ratoons	$188	-	$0	-	Examines all nutrients (NPKS).	Schroeder et al. (2009a)
		Bulgun			-$287	-	$0	-		
		Eubenangee	N		-$154	-	$0	-		
		Innisfail	Y (?)		-$222	-	$0	-		
		Maria	Y (?)		-$273	-	$0	-		
		Mundoo			$93	-	$0	-		
		Pin Gin		1 ratoon	-$31	-	$0	-		
		Thorpe		2 ratoons	-$286	-	$0	-		
		Tully		2 ratoons	-$110	-	$0	-		
	WT (Tully)	Murray	2	1R, 2R & 3R	$85	-	$0	-$99	Uses high sugar price ($450/t).	Schroeder et al. (2010a), Skocaj et al. (2012)
		Euramo			$132	-	$0	-$78		

		Riversdale	3	1R & 2R	$19	-	$0	-$245		
		Lower Tully		1R, 2R & 3R	-$20	-	$0	-$156		
	Central	Mirani 1	Y (?)	3 crops	-$50	-	$0	-	Summary only. Examines all nutrients (NPKS).	Schroeder et al. (2010b)
	Central Burdekin	Pioneer	Y (?) N	1 crop	-$274	-	$0	-	Summary only. Examines all nutrients (NPKS). Summary only.	Schroeder et al. (2010b) Schroeder et al. (2010b)
		Tannalo		2 crops	-$48	-	$0	-		
		Kutlabul		3 crops	-$115	-	$0	-		
		Marian/Cal		3 crops Plant cane	-$40	-	$0	-		
		Victoria Plai			-$51	-	$0	-		
		Mirani 2			-$10	-	$0	-		
		Cracking clay	Y (?)		-$498	-	$0	-$43		
	Burdekin Bundaberg	Sandy clay loam	Y (?) 3	Plant cane 1R & 2R	-$308	-	$0	-$3	Summary only. Summary only.	Schroeder et al. (2010b) Schroeder et al. (2010b)
		Alluvial			-$170	-	$0	-		

Notes: yellow highlighted cells indicate where 6ES had the highest grower returns.

Table 9 above presents a summary of nutrient rate trials that have examined the relative economic performance of several management strategies. While many trials were situated in the Wet Tropics, overall a variety of regions have been studied. It is quite clear from the table that for a large majority of trials, the 6ES nutrient management strategy was the most profitable (indicated by the highlighted cells). It is well known that the marginal benefit of N decreases with higher application rates and the results depicted show little evidence of a positive relationship between profitability and the amount of N applied above the 6ES guidelines.

There have been a number of studies undertaken that compare the DIN run off from various nutrient management practices (e.g.; Webster et al. 2012; Thorburn et al 2011a; Thorburn et al. 2011b) that are not included here as they focus on the biophysical component only and did not involve an economic analysis of the practices modelled. However, the aforementioned studies do provide insights to potential economic implications by reporting on yield differences between management practices. As yield is only one of many factors influencing profits it can be misleading to assume an increase in yields from one practice will result in an increase in overall grower profitability.

Thorburn et al. (2011a) used field data on three sites over three years to parameterise the Agricultural Production Systems Simulator (APSIM) Sugarcane cropping systems model in the Burdekin region to simulate long-term yields (cane and sugar) and N losses under a range of N fertiliser and irrigation management practices. Their long–term simulations found 'only the lowest N application (approximately75 kg ha^{-1} of N fertiliser) gave any marked reduction in yield' and 'yields were predicted to be unaffected by reduced N fertiliser until the estimated N surplus was less than ~50 kg ha^{-1}' (Thorburn et al. 2011a: 8).

Using data collected from 11 large plot field experiments over seven different regions (only four experiments had randomised block design and replications) for three nitrogen application rates (N low, N-replacement and N conventional farmer rates), Thorburn et al (2011b: 51) found that 'cane and sugar yields in the N-replacement treatment were similar to those achieved with farmers' conventional management, with a trend over successive crops for yields to increase relative to conventional management.' Of note, there was no statistically significant difference between cane yields for these two treatments where the experiments had replicates.

Webster et al. (2012: 131) conducted a field experiment comparing N-Replacement with N conventional nitrogen management strategies in the Mossman region over three years with three replicates for each treatment and similarly found 'sugarcane yield did not differ significantly between the … treatments in any of the crops'. These studies explicitly estimate the N losses or N surplus differences between conventional and N-Replacement nitrogen fertiliser applications and find N-Replacement to have large reductions in both of these measures compared to conventional applications without compromising on yields in the longer term.

Of all of the publications reviewed which found traditional and GD rates resulting in higher returns, the difference was greatest between 6ES and N-Replacement, with 6ES often only marginally behind traditional or GD. Results from the Schroeder et al. (2008) study saw gross margins for Traditional application rates $25/ha higher than 6ES and NR $222/ha lower than 6ES. Grower returns from the strip trials of Schroeder et al. (2010a) were more evenly spread with 6ES $84/ha lower than GD and N-Replacement $117/ha lower than 6ES per year.

Skocaj et al. (2013b) calculated the optimal N rate from individual response curves generated from both observed mean and simulated cane yields (using APSIM). They found overall the observed optimal N rates were fairly similar to the 6ES recommended N rates and the economic analysis indicated that the observed optimal N rate did not greatly increase grower marginal economic returns ($2185/ha averaged over crop cycle) compared to the 6ES rate ($2176/ha averaged over crop cycle). Skocaj et al (2012) compared 6ES, GD and N-Replacement on 4 strip trials, two on well-drained soil and two on poorly drained soil in Tully. They found that over two ratoon cycles GD N application rates produced higher returns than 6ES by $98/ha and 6ES grower returns were $293/ha higher than N-Replacement. The difference between GD and 6ES increased on poorly drained soils to $267/ha while the gap between 6ES and N-Replacement decreased marginally to $257/ha. Due to the limited number of treatments and replicates, a statistical significance analysis of these results was not undertaken.

The studies with mixed results had trial sites across a number of different soil types. Schroeder et al. (2009a) estimated partial net returns for industry (grower returns were not presented) and found grower developed application rates gave returns that were within $1 per hectare per year to 6ES at the Macknade trial site. In contrast, 6ES had higher industry returns than GD ($84 per hectare per year less than 6ES) and N-Replacement ($171 per hectare per year less than 6ES) respectively at the Tully trial site.[14]

Expanding on the influence of soil type, Schroeder et al. (2009b) estimated grower partial net returns for 6ES and GD application rates of NPKS + across the major soil types in the Johnstone catchment over 2 years. They found that 6ES outperformed GD in eight out of ten soil types in 2007 by an average of $49 per hectare and eight out of nine soil types by an average of $80 per hectare in 2008 in terms of grower return ($/ha).

A Queensland Department of Agriculture, Fisheries and Forestry (QDAFF 2013a) trial compared 6ES to a GD N application rate on a property near Cairns in a cost benefit analysis only considering variable costs. Established in a first ratoon there were no significant yield differences in the first year and through cost savings on urea, 6ES increased profit by $191/ha in this particular trial.

Two studies reported that the differences between N application rate practices were not uniform over the crop cycle. Schroeder et al. (2008) found differences in returns were most evident in ratoons with 6ES returns highest in ratoon 4, N-Replacement returns highest in ratoon three and Traditional and 6ES returns highest in ratoon one and ratoon two. Schroeder et al. (2009a) also reported differences in returns from alternative application rates were also most evident in the ratoon cycles.

The only study to also assess the effect of nutrient placement was Skocaj et al. (2013a) which assessed three Phosphorus (P) application rates (for plant and ratoon cycle) and two placement strategies on soils with both a very high phosphate buffer index (PBI) (>420) and BSES-P (>50 mg/kg) values.[15] They found application of 30 kg P per hectare in plant cane and 20 kg P per hectare to the first ratoon sub-surface increased grower returns by $251 and $299 per hectare respectively when compared with the equivalent application rates on the surface. This experiment found no significant response to P application rates in the first ratoon.

Edwards et al. (2013) undertook a whole of farm economic analysis of an extended fallow in the Mackay Whitsunday region. This paper is included here as ‘it is hypothesised that extended fallows with legume crops may further cumulate soil and yield benefits and further reduce the amount of nitrogen fertiliser required in the subsequent sugarcane crop’ despite gaps in knowledge around water quality impacts of an extended fallow system (Edwards et al. 2013: 3). They compared two sequences of extended fallow with a conventional single legume fallow. Their results found the extended fallows trialled improve gross margins by between $4 and $253 per hectare, and over a ten year period the net present value is between $20 and $1 141 per hectare, marginally better than breakeven over the same period. In both sequences the yield increase in plant cane from the extended fallow was insufficient to compensate for the loss of revenue from the reduction in area of cane production.

The communication of results from these trials has undoubtedly helped to validate 6ES and influence adoption. In response to continued concern about the effectiveness of the 6ES strategy, further research to validate the regulated N rate is underway in the Burdekin (RP20c project) and the Wet Tropics where QDAF

[14] Industry returns, however, cannot be accurately compared between N rate treatments because it only takes into account the revenue received by the mill and does not take into account the relative costs of milling each N rate treatment. For instance, if the higher N rate treatment yields relatively more cane yield but lower CCS then the milling costs should be relatively higher (for the higher N rate treatment) because the sugar mill has to mill more cane (energy, labour, R & M, etc.).

[15] BSES-P is used to describe a soil test developed by the Bureau of Sugar Experimental Stations to estimate plant available P in acidic sugarcane growing soils which uses a 0.005M H_2SO_4 extraction procedure and the PBI is a measure of the ability of soils to absorb P (Skocaj et al. 2013a: 2). Both these measures have different categories: PBI has three (low <140; moderate 140 – 280; high >280) and BSES-P has eight (<5 to >60 mg/kg).

has been delivering a large number of one-on-one participative trials with growers. There is also interest in shifting from district yield potential to block yield potential where the opportunity exists for a number of growers to target yield potential within the block. However, little economic research has been done in these areas. This review was unable to find any studies on adjusting N rates at the block level that included an economic analysis and only two studies on adjusting N rates at a management zone level, Coventry and Hughes (2011) and Collier (2016), which had an economic component included.

In a partial net benefit analysis, Coventry and Hughes (2011) estimated that by applying nitrogen rates determined by zone yield potential in a 9.3 ha block with three distinct zones for a second ratoon crop in the Mackay region, $60/ha would be saved for this block and an average of 29 kg/ha less of nitrogen applied compared to if the district yield potential application rate was applied across the entire block. This reduction in nitrogen used and the associated cost saving is only applicable for when reducing the nitrogen rate is the most economically efficient management practice to address below average yields. This would be determined on an enterprise by enterprise basis. As a partial net benefit analysis, the cost of compiling the data sets, any capital equipment investment required to estimate block and zone yield potential and any learning costs were not included in this economic analysis.

A Project Catalyst trial in the Herbert sugarcane district identified two yield potential zones within the trial area using mapping, soil sampling, satellite imagery and growers knowledge and a nutrient plan was developed using 6ES adjusting for yield potential in each zone (Collier 2015). The trial had three replicated strips of four different fertiliser treatments: treatment 1 was 6ES uniformly applied and treatments 2, 3 and 4 varied fertiliser application in the high EC zone. Results of the trial found no significant difference between the treatments in cane tonnes/ha, ccs, tonnes of sugar/ha or revenue ($/ha). Gross margin analysis found that average gross margin, inclusive of fallow and plant cane, for treatment 3 was the highest and the average gross margin for all variable rate treatments were higher than the average gross margin for the uniform treatment. An investment analysis of the variable rate nutrient application within blocks over a ten year period across the entire farm was undertaken and found that the annualised benefit was negative for treatments 2 and 4 and $1/ha for treatment 3. Profitability was found to be highly sensitive to a change in yield and also impacted by the size of the initial capital investment (purchase of a stool splitter and the variable rate application technology). Soil testing, EC mapping and yield mapping is undertaken on fallow each year until entire farm is mapped at a cost of $10/ha.

The studies reviewed here indicate that, depending on soil type, 6ES can be more profitable than traditional and grower developed rates, and when it is not it is only by a small margin. However, recent figures released in the reef report cards suggest that adoption of current nutrient BMP amongst growers is lower than other management practices despite nutrient BMP having few barriers to adoption for growers (e.g. lower production costs, possibly comparable production, no necessary capital investment required, easy to trial, and environmental/social benefits). Low adoption may be explained by accessibility to soil specialists (regular soil tests) and understanding the agronomic processes and benefits associated with nutrient BMPs. Continued assistance on the last point from Government through extension may be required over a long period for private and environmental benefits to be realised.

4.2 Pesticide management practices

Key Points

- Seven papers were reviewed for improved practices targeting pesticide management which included some form of economic analysis, all but one from the last five years. Most of the pesticide studies with an economic component focus on the Mackay Whitsunday region (five studies), one study on application method in the Wet Tropics, and one study that looks at a range of practices in all of the priority catchments.
- The studies reviewed cover a range of management practices for pesticide management such as types of products, rates of application, timing and method/management approach (such as use of green cane trash blanket (GCTB) or equipment). Only one study looked at a single management practice in isolation.
- ABCD frameworks advocate for a move away from residual chemicals, however, less is known about the water quality impacts of the replacements available. As such, more studies need to be undertaken on the alternatives offered – do they stack up on weed control and are they less damaging from a water quality perspective.
- Pesticide management is dependent on other farm management practices and needs to be considered as an integrated programme. Factors such as tillage practices and GCTB are shown to greatly influence the use of pesticides and economic return for a grower.
- Critical for water quality is the reduction in application rates and the use of known residual pesticides. This practice has potential to be cost-effective from the studies reviewed here under certain conditions such as when GCTB is greater than 6 t/ha and in conjunction with management that is responsive to weed type and considers climatic conditions. Precision spraying with some technologies is only cost effective under very specific conditions.
- Shifting to A level pesticide management practices, may not result in net benefits to the grower and is largely dependent on the size of the farming enterprise, existing management practices and the ability to successfully implement on a commercial scale.

Seven papers were reviewed for improved practices targeting pesticide management which included some form of economic analysis, all but one from the last five years. Five studies were undertaken in the MW region, one across the Wet Tropics, Burdekin and MW regions and one in the Wet Tropics region. Table 10 below provides a summary of key attributes of the publications reviewed in this section.

Table 10: Summary of studies reviewed for pesticide management practices

Year	Author	Region	Publication type	Practice	Economic method	Biophysical method	Statistical Analysis
2010	Fillols and Callow	Mackay Whitsunday	Conference Proceedings	GCTB, timing and product type	PNR	4 treatments with 4 replicate split plot design.	Statistical significance (production and economic data)
2011	Fillols and Callow	Mackay Whitsunday	Conference Proceedings	GCTB, timing and product type	PNR	2 treatments with 4 replications split plot design	Statistical significance (production and economic data)
2012	Fillols	Mackay Whitsunday	Conference Proceedings	GCTB, timing	GMA	5 trials, 4 sites, 3 treatments for GCTB and 7 treatments for herbicide, randomised complete block design at each trial site, 4 replicates of each treatment with a bare soil plot for each	Statistical significance (production and economic data)
2013	Fillols et al	Mackay Whitsunday	Conference Proceedings	Application method	PNR	5 treatments in Mackay. Split plot design with four replications for each treatment with adjacent untreated controls.	Statistical significance (production data)
2013	Baillie et al	Mackay Whitsunday	SRDC Report	Application method and product type	PNR	5 treatments in Mackay in 2011 and 2012. Split plot design with four replications for each treatment with adjacent untreated controls.	Statistical significance (production data)
2013	Thompson	Wet Tropics	DAFF publication	application method	WOF	Case study of DHS compared to standard Irvin Boom sprayer across 40 hectare first ratoon crop	No – risk analysis of discounted payment period and sensitivity analysis of GM and NPV to reduction in yields
2014	Poggio et al.	Wet Tropics, Burdekin, Mackay Whitsunday	DAFF RP62c Technical report to QDEHP	Profit and investment analysis moving from C to B, C to A and B to A herbicide management practices	WOF	APSIM and HowLeaky modelling for enterprises 50, 150 and 250 hectares	No – sensitivity analysis of economic results to changes in yields

Notes: : PNR – partial net return economic analysis; WOF – whole of farm economic analysis; PEH – pre-emergent herbicide; DHS – dual herbicide sprayer; GCTB – green cane trash blanket.

Fillols and Callow (2010) found the thickness of the green cane trash blanket (GCTB) layer was positively linked to weed control, with more than six tonnes per hectare proving sufficient (six t/ha gave mixed results). Net returns were greater for GCTB compared to bare soil with and without all herbicide applications on a seven t/ha layer of trash. On the nine t/ha trash blanket trial, GCTB had higher net returns than bare soil for all plots, treated and untreated with the exception of bare soil treated with Flame. In all plots with GCTB, applying herbicides reduced the net return, least by Balance at three per cent and most with knockdown mix at 23 per cent. Conversely, applying herbicides to bare soil increased net returns for all plots from eight per cent with Balance to 695 per cent with knockdown mix. Also the nine t/ha inhibited vines in the trial conducted in Mackay region. While GCTB has been accepted industry practice for some time, this study provides evidence, that if thick enough, growers can increase returns with a GCTB by reducing their herbicide use for a number of weeds. This is in comparison to bare soil where economic returns are highest with herbicide applications, which can have negative implications for water quality depending on a number of factors.

Fillols and Callow (2011) conducted two trials in the Mackay region, to test for the efficacy of pre-emergent herbicides on GCTB and bare soil with varying thickness of GCTB. In trial one it was found that the herbicides tested were equally efficient on bare soil and GCTB and that there was no statistical difference between the treated and untreated GCTB plots in terms of weed control. Trial two differed to trial one by two tonnes per hectare trash less, earlier application of pre-emergents (late June compared with August) and use of knockdowns in early December. The results were similar for bare soil but the opposite for GCTB with herbicide applications increasing net returns for all but Flame herbicide applications. The result from this study that a block with a thicker GCTB may achieve higher gross margins untreated with herbicides than if treated or a bare soil block treated or untreated with herbicides is consistent with findings from earlier work by Fillols and Callow (2010).

Fillols (2012) conducted five trials where trash levels and herbicide applications varied in Mackay region. Partial economic returns were presented for trials four and five which compared seven different herbicide application strategies. Trial four found no statistically significant difference between herbicide strategies for cane or sugar yield and net returns which were positive from all herbicide applications relative to an adjacent untreated control ($80/ha to $782/ha) except for P5 (mix of Balance, Soccer, Nuquat and Sprayseed) which had a -$730/ha impact. When treatments in trial four are grouped as early and late pre-emergent, results came close to significance indicating that the use of an early pre-emergence strategy tends to be more profitable than a late one. Trial five found no statistically significant difference between herbicide strategies for cane or sugar yield and net returns which ranged from $1178 /ha to $2188 /ha relative to the adjacent control.

Fillols et al. (2013) conducted five trials in the Mackay region comparing herbicide application methods: pre-emergents at leaf stage (broadcast and banded spray); knockdown at stooling stage (direct spray with droppers, shield blanket spray, precision spray (Weedseeker™ Shield Sprayer)) and knockdown at out of hand stage (shield blanket, precision spray (Weedseeker™ Shield Sprayer)). Results found no difference in yield between the herbicide treatments tested, although trial three and trial four did have slightly higher yields. Partial net benefit economic analysis found trial one to be the most costly (marginal return just below $3000/ha), trials two and three were cost equivalent (marginal return approx. $3200/ha and $3275/ha) and trial four and trial five were the cheapest (marginal return $3225/ha and $3200/ha) as they did not use pre-emergents and the precision sprayer used less herbicide. However, there was no statistical difference in marginal return between herbicide treatments and control treatments (marginal return of control treatment just below $3000/ha) – as yield gains offset herbicide costs. Further, results found that the precision sprayer

(Weedseeker™ Shield Sprayer) would only make a grower better off if the area to be sprayed was 31 per cent or less than total area covered by the sprayer.

Baillie et al (2013), also conducted five trials in the Mackay region on herbicide application methods featuring precision spraying equipment. Costs of the treatments were presented for trials done in 2011 and 2012. In 2011 and 2012 the most cost effective trial was no pre-emergence then Weedseeker™ Shield Sprayer with glyphosate + selective knockdown over the row when needed. The most expensive trial in 2011 was the broadcast application of a pre-emergent herbicide just after harvest followed by directed knockdown if needed and in 2012 the most expensive was the banded (idem 2) pre-emergence, Weedseeker™ Shield Sprayer. There was no difference in yield between the herbicide treatments and treated plots yielded 11.8 t/ha more than untreated plots. The study found that precision spraying (Weedseeker™ Shield Sprayer) would only be relatively cheaper if used on bare soil or trash blanket with isolated clumps of weeds – no analysis on revenue was undertaken. This study also included a water quality analysis, where run-off concentrations for all herbicides were directly proportional to the percentage of spray coverage and total load of herbicide on the soil and trash. Knockdowns ran off less than or equal to residuals and new residuals running off less than older ones.

Thompson (2013) completed a whole of farm economic analysis of the Dual Herbicide Sprayer relative to a standard Irvin Boom drawing on the farm operational data of a 120 hectare farm located in the Herbert region. The discounted payback period of the investment was found to be dependent on the size of farm and the cost to modify the Dual Herbicide Sprayer. For example, if a grower used the Dual Herbicide Sprayer over 200 ha per annum and it cost $1000 to modify the Irvin boom, then the grower could recoup their investment within 0.4 years. A break-even analysis found that the Dual Herbicide Sprayer needs to be utilised over at least 28 ha per year for the investment to payoff within 10 years. Moreover any property utilizing the Dual Herbicide Sprayer across 40 ha or more will have less than a five year payback period if their investment in the Dual Herbicide Sprayer is $2000 or less. The analysis found that the investment was highly sensitive to yield changes, with the investment becoming economically unviable if ratoon yields decline more than 10 per cent.

Poggio et al. (2014) undertook a comprehensive analysis into the reduction of Photosystem II herbicide equivalent concentration (PSII HEq) losses from shifting between C to B, C to A and B to A pesticide practices[16] in the Burdekin Delta, BRIA, Tully and Mackay regions for sugarcane growers in small, medium and large enterprises[17] – estimating both the reduction in pesticide run off from implementing management practices and the economic impact of doing so. The economic and water quality results were found to be critically dependent on regional-specific variables including biophysical characteristics and enterprise structure.

The economic analysis indicated that progressing from C- to B-Class herbicide management practices is generally expected to be profitable and provide the highest return on investment (IRR) across the farm sizes and cane districts investigated. Each enterprise size modelled in the priority regions had the potential to profitably shift from C to B-class herbicide management practices with a payback period less than five years,

[16] The A category practices included: use of electronic rate controller; precision and directed applications with appropriate nozzles (e.g. hooded sprayer, two tanks, air inducted nozzles); and consideration of climate forecasting. The B category practices included: rate varies between blocks with consideration of weed type and pressure; knockdowns and residuals using alternatives (excluding Diuron, Atrazine, Hexazinone, Ametryn); consideration of crop stage, weed size and type, crop cycle, environmental conditions and irrigation.

[17] The modelling undertaken required a number of assumptions to be made to come up with a representative enterprise for each size in each region. As such, the results are also representative for growers with those particular characteristics and do not necessarily apply to all growers in those regions of those sizes.

while reducing PSII HEq losses by 59, 58, 32 and 52 per cent respectively for the Burdekin Delta, BRIA, Tully and Mackay regions.

A change from C to A-class herbicide management practices was estimated to be profitable for each enterprise size modelled in all regions with the exception of small enterprises in both Burdekin regions and in Mackay. Water quality from these shifts in practices would see reductions of PSII HEq losses of 97, 97, 82 and 85 per cent respectively for the Burdekin Delta, BRIA, Tully and Mackay regions.

A change from B to A-class herbicide management practices is expected to be profitable for 150ha and 250ha farms. A shift from B to A-class practices is similar to that of C to A, however, in this scenario small enterprises modelled in Tully and medium enterprises modelled in Mackay become unprofitable as well as small enterprises in both Burdekin regions and the Mackay region. Water quality benefits are slightly less (between four and 16 per cent less) than those generated when shifting from C to A practices. Risk analysis illustrates the importance of ensuring production is maintained in order to remain profitable. This is especially the case when progressing to A-class herbicide management, which is based on practices under research and not thoroughly tested on a commercial scale.

In summary, the reduction in application rates and the use of residual pesticides identified as detrimental to the GBR ecosystems in management practices is critical for achieving water quality outcomes. Identified best and innovative practices have the potential to be profitable from the studies reviewed here under certain conditions such as when GCTB is sufficient to suppress weed growth and in conjunction with management that is responsive to weed type and considers climatic conditions. Likewise, precision spraying with some technologies is only profitable under very specific conditions due to the high capital costs involved in purchasing the technology and equipment required. Poggio et al. (2014) highlighted that shifting to A-class pesticide management practices, may not result in net benefits to the grower depending on the size of the farming enterprise and the region it is located in despite having benefits for water quality. Tailoring extension programmes and communications with growers should account for heterogeneity where it exists.

4.3 Multiple practices analysed in a systems management approach

Key Points

- Thirty studies were reviewed with a focus on systems approach to management practice change which included some form of economic analysis. The number of studies reviewed in this section (30) is greater than all the studies looking at improved practices in isolation combined (17).
- Most of the studies reviewed in a systems approach had analyses for the Wet Tropics (16) and Burdekin (12) regions with the MW region only accounting for six analyses.
- There have been changes to irrigation allowances and pricing since most of the irrigation focus studies were undertaken as well as technological developments influencing the cost of and efficiencies of irrigation systems. It would be informative to revisit the profitability and water quality impacts of these options to get a more up to date picture of their cost effectiveness in meeting water quality targets.
- Many of the improved practices analysed in a systems approach provided cost savings which resulted in higher gross margins if yields remained the same or only marginally decreased.
- The studies reviewed also highlighted that there will be variation in yields over the crop cycle, with ratoons often responding better to improved management practices than plant cane.
- More studies reviewed in this section also included an estimate on the benefits to water quality from moving to improved practices. Findings indicate that many of the practices with highest water quality benefits are unlikely be adopted in the near term due to the costs to growers (many A-class practices, particularly N-replacement and those which require large capital investment such as specialised pesticide spraying equipment).

Thirty studies were reviewed with a focus on systems approach to management practice change which included some form of economic analysis (see Table 11). These studies are broken down into irrigation management (five studies) and a combination of all other types of management practices (twenty five studies)

Irrigation focus

Five papers were reviewed for best management practice change which included some form of economic analysis for irrigation practices. Unsurprisingly, all studies were from the Burdekin region, three used a partial net benefit approach while the other two undertook a whole of farm economic analysis.

Qureshi et al. (2001) compared the profitability of furrow, centre pivot and trickle irrigation using a bio-economic simulation model on a typical farm in the Burdekin Delta over a twenty year period under three different pricing schemes: Northern Burdekin Water Board pricing, Southern Burdekin Water Board pricing and volumetric water charge pricing. They found furrow irrigation to be the most profitable followed by centre pivot and then trickle irrigation under current Burdekin water board pricing schemes – this outcome is not sensitive to reasonable changes in discount rate, sugar prices, capital investment costs, farm ownership arrangement or other variables. Capital costs for a centre pivot would need to reduce by 40 per cent for it to become more profitable than furrow irrigation. Three soil types were represented in the modelling low, medium and higher permeability soils in the Burdekin Delta. Changing the proportion of high permeability soil from 11 to 100 per cent of the property also changes the ranking so that centre pivot becomes more profitable than furrow irrigation. Under volumetric pricing, centre pivot becomes the most profitable option, followed by furrow irrigation then trickle irrigation. It would be interesting to see how different the results might be if the bio-economic simulation model were run using current prices.

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Table 11: Summary of studies reviewed which analysed practices in a systems management approach

Year	Author	Region	Publication type	Practices	Economic method	Biophysical method	Statistical analysis
Irrigation Focus							
2001	Quershi et al.	Burdekin	Book Chapter	Overhead low pressure (OHLP), Trickle, Furrow	WOF – CANEIRRI algebraic model for NPV developed	APSIM over 20 year period; crop cycle P1, 3R;	no
2010	Poggio et al.	Burdekin	Conference Proceedings	OHLP, GCTB, Furrow	WOF – Net present value (NPV) over 20 year planning horizon	Three treatments, no replicates; P1, R1;	no
2013	Attard and O'Donnell	Burdekin	Online case study – RWQ webpage	Drip irrigation, Furrow	PNR	Case study; paddock trial of drip irrigation; P1, 3R;	no
1997	Holden and Mallon	Burdekin	BSES report	Minipans, u-shaped and v-shaped furrows, low till and conventional till	GMA	Water monitoring, three on-farm trials of furrow shape and tillage	no
1997	Holden et al.	Burdekin	BSES report	Minipans	PNR	200 minipans calibrated, crop water use estimated for different varieties and soil types; 37 farms data analysed.	no
System Focus							
2010	Park et al.	Wet Tropics	Conference Proceedings	Controlled traffic; zero and zonal tillage, timing of tillage	GMA	Split plot with four tillage treatments as main plots and two cane varieties as sub-plots, three replications, samples at 6 and 16 months	yes
2009	Garside et al	Wet Tropics Mackay Whitsunday	Conference Proceedings	Controlled traffic; minimum tillage	GMA – with FEAT	Tilled and non-tilled plots, factorial design, four replications, two sites	yes
2004	Garside et al.	Wet Tropics	Conference Proceedings	Controlled traffic; minimum tillage; legume fallow	GMA	Two sites, three treatments at one site and four at the other, two replications of each treatment in a randomised block design	yes
2006	Morris and Poggio	Wet Tropics	DPIF publication	Controlled traffic; minimum tillage; legume crop rotation	partial analysis only as does not account for any increase in	Case study, comparing costs of two different planting systems	no

					productivity		
2007	Poggio and Hanks	Wet Tropics	DPIF publication – FutureCane fact sheet	Controlled traffic; minimum tillage; legume fallow	WOF	Scenario analysis – four different fallow management practices	no
2007	Poggio et al.	Wet Tropics	Conference Proceedings	Controlled traffic; minimum tillage; legume fallow	WOF	Cost comparison of three different farming systems on same property old (1997), new (2006) and new plus legume fallow	no
2012	East	Mackay Whitsunday	DAFF publication	Controlled traffic; GPS; legume fallow; GCTB	GMA; investment analysis + risk analysis with FEAT	Model farms used – designed to approximate a typical cane farming scenario at different scales	no
2013	Di Bella	Wet Tropics	HCPSL publication	Controlled traffic; minimum tillage; legume fallow; reduced nitrogen applications	GMA – with FEAT	Comparison of two classes of management systems (B and C class practices) on adjacent blocks over four years. Single replicates. Run off sampling	no
2004	Roebeling et al.	Wet Tropics	CSIRO report to Douglas Shire Council	Minimum tillage; legume fallow; reduced nitrogen applications	Cost benefit analysis	APSIM, SedNet,	no
2007	Young and Poggio	Burdekin	DPIF publication – FutureCane report	Minimum tillage; legume fallow; reduced nitrogen applications	WOF	Case study, comparing costs of two different farming systems on same property old (2002), new (2006)	no
2015	Van Grieken et al.	Wet Tropics Burdekin, Mackay Whitsunday	Reef Rescue Research and Development Technical Report RRRD039	Reduced nitrogen rates, legume fallow, minimum tillage, sub-surface and split nutrient application	WOF – with FEAT + investment analysis	APSIM modelling	no
2007	Roebeling et al.	Wet Tropics	CSIRO report to Cardwell Shire Council	Zero tillage, legume fallow, reduced nitrogen rates, split nutrient applications, reduced herbicide application rates, grassed headlands	Cost benefit analysis	APSIM, LUCTOR, PASTOR, SedNet/ANNEX	no
2008	Carr et al.	Wet Tropics	Conference Proceedings	Controlled traffic; reduced nitrogen & pesticide application rates	WOF	Case study, comparing costs of two different farming systems on same property old (1997), new (2007)	no

2011	Agnew et al.	Mackay Whitsunday	Conference Proceedings	Controlled traffic; reduced nitrogen & pesticide application rates; legume fallow	PNR	Water quality monitoring at multi-block and multi-farm scales Marian site 5 plots/treatments, Victoria Plains site 2 plots /treatments. No replications within trials. Row spacing, herbicides and nutrient rates duplicated across the two sites	no
2010	East	Mackay Whitsunday	DEEDI publication	D – C; C – B; B – A class Controlled traffic; minimum tillage; legume fallow; reduced nitrogen rates; nitrogen application methods; pesticide application methods	WOF + risk analysis + investment analysis	APSIM	no
2010c	Poggio et al	Wet Tropics	DEEDI publication	D – C; C – B; B – A class Controlled traffic; minimum tillage; legume fallow; reduced nitrogen rates; nitrogen application methods; pesticide application methods	WOF + risk analysis + investment analysis	APSIM	no
2010b	Poggio et al.	Burdekin	DEEDI publication	D – C; C – B; B – A class Controlled traffic; minimum tillage; legume fallow; reduced nitrogen rates; nitrogen application methods; pesticide application methods	WOF + risk analysis + investment analysis	APSIM	no
2015	Terrain	Wet Tropics	Wet Tropics 2015-2020 WQIP	D/C – A; B – A for DIN and PSII practices	Use of reference reports	Use of reference reports	no
2011	Van Grieken	Wet Tropics Mackay Whitsunday	Journal article	D - C; C - B; B - A	GMA + investment analysis	APSIM; SedNet/Ann0065	no
2013a	Collier	Burdekin	DAFF publication	Controlled traffic; variable rate controller; water recycling pits	WOF + investment analysis	Case study comparing costs of two different farming systems on same property old and new systems	no
2013b	Collier	Burdekin	DAFF publication	Controlled traffic; legume fallow; variable rate controller; water	WOF+ risk analysis + investment analysis	Case study comparing costs of two different farming systems on same property old and new	no

				recycling pits		systems	
2013c	Collier	Burdekin	DAFF publication	Controlled traffic; variable rate controller; GCTB; water recycling pits	WOF+ investment analysis	Case study comparing costs of two different farming systems on same property old and new systems	no
2015	Thompson and Larard *update of Di Bella 2013*	Wet Tropics	DAFF publication		GMA	Comparison of two classes of management systems (B and C class practices) on adjacent blocks over five years. Single replicates. Run off sampling	no
2014	Collier	Wet Tropics	DAFF Report – SRDC project	Mill Ash	GMA	Case study with five treatments of different land preparation practices over a fallow, P1 and R1	no

Poggio et al. (2010a) conducted an economic analysis of shifting from a farming system that furrow irrigates and burns their cane prior to harvest to a system that uses overhead low pressure irrigation (OHLP) and maintains a GCTB. Due to savings in weed management and irrigation expenses, the OHLP irrigation systems modelled have higher gross margins than the traditional furrow and burnt cane system. Investment analysis of irrigation options over a 20 year period have the net present value for both OHLP farming systems as negative due to high capital requirements of the system. However, when the water saved by using OHLP systems is given a value, the net present value then becomes positive. Sensitivity analysis shows that the price of water would need to be $35/ML and $45/ML for OHLP green and burn respectively for net present value to become positive or for capital investment in OHLP green to be less than $200 000 (OHLP burn would need to be less than $150 000).[18]

Attard and O'Donnell (2013) estimate the change to gross margin from converting to drip irrigation to reduce nitrogen run-off from furrow irrigation using a paddock case study analysis. The site of the trial was in the Ayr district on sandy soils where furrow irrigation was in place and the paddocks had been 'producing lower than expected yields due to poor irrigation uniformity and excessive deep drainage.' They found that on average drip irrigation produced an extra 4.2 tonnes of sugar per hectare at each harvest over four harvests between 2008 and 2012. The drip tube will pay for itself in three years with these gross returns and total water use was reduced by approximately 50 per cent. The trial did not include changes to ongoing production costs (labour, pumping etc.) as a result of the conversion. Another limitation worth noting is that the trial was not replicated so the results only apply to the specific blocks that were being compared.

Holden and Mallon (1997) and Holden et al. (1997) both compared the shape of furrow when furrow irrigating in combination with reduced tillage practices, with the latter study also incorporating the impact of scheduling from using evaporative minipans. Holden et al. (1997) found in their study that the practices adopted ('v'shaped furrows, reduced tillage and irrigation scheduling) resulted in an increase in sugar yield without using any extra water, worth $225 per ha over a 70 hectare property, although this did not consider any changes to the cost of labour, water or pumping costs.

Holden and Mallon (1997) found that 'V' shaped furrows and reduced cultivation increased irrigation efficiency and reduced costs. They also found that deep drainage losses on highly permeable soils were halved by the use of either v shaped furrows or reduced tillage. The combination of these practices in one trial reduced water usage by up to 60 per cent and saved around $140 per hectare compared with conventional 'U' shape furrows and tillage. This savings estimate only included the cost of water and did not include other irrigation costs that accrue to a farm system or labour, and changes to revenue from adopting these practices was also not estimated.

While the Burdekin is the largest irrigated sugarcane growing region in Queensland, the results may not be applicable to other irrigated farms within certain districts of the Wet Tropics and MW regions. All of the studies in the review focus on the type of irrigation system, comparing traditional furrow irrigation with centre pivot, trickle, drip, overhead low pressure and furrow shape; only one study included type of irrigation system and scheduling in their analysis. Two studies included irrigated equipment with reduced tillage and one with GCTB. The whole of farm economic analyses found that adopting irrigation technologies that reduce water use can increase farm gross margins (consistent with the other three studies), but the net benefit of the investment was unlikely to improve farm profitability because of the high cost of capital (equipment required). There have been changes to irrigation allowances, markets for trading water allocations and pricing in the Burdekin since most of these studies were undertaken as well as technological developments influencing the cost of and efficiencies of irrigation systems. As irrigation is a critical vector for the transportation of nutrients and chemicals it would be informative to examine the profitability and water quality impacts of these options

[18] BHWSS variable water costs: drawing water from a river - Part B only ($0.54/ML); drawing water from a channel - Part B + D ($0.54+$27.49 = $28.03/ML) plus $35.99//ML (Part A + C) for all allocated water. The BHWSS Burdekin zone C has 20 000 M/L available for temporary trading strategies in 2015-16 which may influence the actual price paid for water by growers if they engage in trading which was not common when the study was undertaken (Sunwater 2015). In contrast, temporary water allocations for zone 7 of the Murray River in Victoria were trading at $254/ML on 9 May 2016 (accessed at https://www.waterexchange.com.au/prelogin/ on 9 May 2016).

to get an understanding of their cost-effectiveness in meeting water quality targets. In particular, there are no studies that evaluate the changes to profitability, nor the reduction in runoff and deep drainage and the transmission of pollutants, of shifting from conventional furrow irrigation management to BMP furrow irrigation management. Consequently, growers are unable to access information relating to the profitability of shifting to furrow irrigation BMP and might assume that adoption will erode their profitability. Informing growers of these impacts is likely to enhance BMP adoption, particularly if the changes provide economic benefits. Generating case studies of farms with different soil types (i.e. cracking clay and non-sodic duplex), water sources (i.e. channel and bore) and farm designs (i.e. row lengths, gradients and recycle pits) would likely be most informative for growers given that these factors greatly affect the costs and benefits of irrigation practice change. Irrigators would then be able to draw information from case studies that have similar attributes to their farms and irrigation systems.

Systems focus

Of the systems focus (two or more BMPs analysed) studies, three were exclusively undertaken in the MW region, thirteen in the Wet Tropics region and eleven in the Burdekin region. Two studies examined in sites in both the Wet Tropics and MW regions and one study had sites in all three priority regions. The number of studies that included a particular practice is indicated by the number in brackets: controlled traffic (18), reduced tillage (16), legume fallow (18), Nitrogen application rates (13), fertiliser application methods (8), Pesticide application rates (3), types of Pesticides applied and application methods (5), drainage management (4), and green cane trash blanketing (2). One study (van Grieken et al. 2013) did not specify the actual practices but refer to changing from classes within the ABCD classification system for management practices used by NRM groups. A whole of farm analysis was used in 18 of the studies using FEAT, capturing changes to farm gross margins from the specified management practices. Another five studies either did a simple gross margin analysis or used FEAT but without considering fixed or capital costs and two studies used a cost benefit analysis to determine the overall profitability of meeting water quality targets.

Park et al. (2010) and Garside et al. (2009) both reported on trials that examined a combination of controlled traffic and tillage scenarios. Garside et al. (2009) found minimum tillage produced a significant increase in both cane and sugar yield in plant cane at both Ingham and Mackay sites but that there was no effect of row spacing in either plant or ratoon crops or tillage on ratoon crops at either site. In their whole of farm economic analysis, there was little difference in the gross margins between the tillage and the zero tillage option. Park et al. (2010) analysed four treatments of tillage under controlled traffic: zero till; zonal tillage after the wet season; zonal tillage before the wet season and zonal tillage before and after the wet season in the Herbert region. They found zero till had significantly higher yields than zonal tillage which was reflected in the gross margin analysis which had zero till at $2754/ha; zonal till before $2427/ha; zonal till after $2470/ha and zonal till before and after wet season $2094/ha.

The combination of controlled traffic, minimum tillage and legume fallow were looked at in Garside et al. (2004), Morris and Poggio (2006), Poggio and Hanks (2007) and Poggio et al. (2007). Garside et al. (2004) found that while there was no significant difference in cane yields between the treatments in the experiment (conventional 1.5m, 1.5m raised beds with a single row, 1.8m raised beds with dual rows, 2.3m mounded beds with 3 rows for sites in Gordonvale and Ingham), a gross margin analysis found 1.5m raised beds ($262 per ha), 1.8m raised beds ($105 per ha) and soybean inter row planting ($94 per ha) performed better than 2.3m beds (-$486 per ha) and conventional 1.5m row spacing beds (-$5 per ha) in the experiment.

Morris and Poggio (2006) found similar results in the Herbert region using a whole of farm analysis with the combination of controlled traffic, minimum tillage and legume crop rotation producing savings in variable costs of $144/ha – in particular, costs of planting operations were reduced by up to 57 per cent. Poggio and Hanks (2007) also found new farming system practices in the Herbert region produced higher gross margins in their whole of farm economic analysis compared to conventional practices. Using the FEAT tool in their analysis, they compared a legume fallow with conventional practices, legume fallow with zonal tillage and a legume fallow with new system practices (minimal tillage, mounded beds, and controlled traffic) to a bare fallow conventional practices system. The legume fallow with conventional practices had a similar gross margin to the bare fallow system at $830/ha due to savings in fertiliser being cancelled out by increased tillage and legume planting costs, however, the legume fallow with zonal tillage had gross margins of $851/ha and the legume fallow with new system had gross margin returns of $856/ha. Poggio et al. (2007) found similar results modelling a farm in Ingham with FEAT that had introduced new farming system practices, with the old system gross margins at $1071.64/ha, new system at $1104.21/ha and new system plus legumes at $1176.52/ha.

East (2012) calculated the gross margins before and after the changes to controlled traffic using FEAT for 50 hectare; 150 hectare and 300 hectare representative model farms for the MW region. These model farm scenarios were based on a cane production system incorporating a legume fallow and green cane trash blanket harvesting. East found that implementing controlled traffic with and without GPS resulted in increased gross margins and positive net present values (over 10 years at seven per cent) for all enterprise sizes, with the exception of the 50 ha enterprise which had a negative net present value for controlled traffic with GPS even though gross margins increased. This indicates that capital costs are important considerations when investing in this particular improved practice, particularly for smaller enterprises. A risk analysis showed that by adopting controlled traffic, higher gross margins will be achieved than without controlled traffic regardless of the price of cane.

Di Bella (2013) analysed controlled traffic, minimum tillage, legume fallow as well as sub-surface application and minimal use of herbicides using the FEAT tool in a whole of farm approach in the Herbert district. The study found that the improved practice scenario generated higher yields in two ratoon crop stages, an average of 1.51 tonnes of sugar/ha and 1.52 tonnes of sugar/ha respectively. There was no impact on the yield in the plant cane stage. The incorporation of a legume fallow into the farm gross margin estimates saw the improved farming system with a gross margin seven per cent higher than conventional farming system at $1099/ha.

Roebeling et al. (2004) and Young and Poggio (2007) analysed the impact of minimum tillage, legume fallow and reduced nitrogen applications. Using results from production and hydrological simulation models for the Douglas Shire, Roebeling et al. (2004: 25) found in a cost benefit analysis that while BMPs such as reduced tillage, legume fallow and reduced nitrogen rates were all economically viable at the farm level 'improvements in water quality resulting from adoption of these management practices are likely to be relatively small'. They projected that larger water quality impacts would come from economically unviable practices such as drainage infrastructure. This conclusion is interesting given their modelling found adopting BMPs would result in a specialised cane grower using 7.8 tonnes of nitrogen less a year compared to the actual management scenario (approximately 50 per cent less) with only a 10 per cent reduction in production and a 35 per cent increase in gross income. Young and Poggio (2007) undertook a FEAT analysis of a farming system in the Burdekin, and assuming that the soybean crop increases cane yield, found that a new system incorporating minimum tillage, reduced nitrogen and a soybean crop in fallow that is harvested for seed produces higher gross margins compared to the old system ($1891/ha to $1730/ha). Savings in the new system are from reduced tractor hours and fertiliser needs.

Van Grieken et al. (2015) modelled several practice changes including: shifting from old industry nitrogen rates to 6ES to N-Replacement, bare fallow to legume fallow, high tillage to low tillage, surface to sub-surface application of nutrients and single to split application of nutrients to plant cane across three enterprise sizes and for the three priority regions. Some of the findings from this comprehensive study include:

- That the 6ES rate generates the highest farm gross margins across all comparative scenarios.
- Changing from 6ES to N-Replacement provides substantial water quality benefits in the Wet Tropics and MW but limited in the Burdekin, and generally at a cost to the farmer through reduced yields.
- Changing from old industry rates to N-replacement only provides financial benefits in a legume fallow system.

- Changing from a bare fallow to a legume fallow system will come at a cost to the farmer in the absence of yield improvement and will only reduce DIN losses in limited cases (depending on nutrient and tillage management).
- Moving from high to low tillage will generally provide financial benefits but water quality benefits will be variable and regionally specific.

Specifically, van Grieken et al (2015) found the water quality benefits from shifting to A and B class practices to be noticeably lower for the BRIA compared to the other three regions. Also the class of practices with the highest economic returns for the Burdekin Delta region had similar water quality outcomes as the class of practices that delivered the highest water quality outcomes.[19] In comparison, the practices with the highest economic benefits deliver almost no water quality benefits in the Wet Tropics (see Table 12 below).

Table 12: Economic benefits and water quality benefits of practices across priority regions (150 ha)

	Mackay Whitsunday	Burdekin River Irrigation Area	Burdekin Delta	Wet Tropics
Management practices with highest water quality	Moving from C to A-class application rate with legume, low till, sub-surface	Moving from C to A-class application rate with legume, low till, sub-surface	Moving from C to A-class application rate with legume, high till, sub-surface	Moving from C to A-class application rate with legume, low till, sub-surface
Change in DIN (kg/ha/year)	29.08	8.04	39.35	24.39
Annualised Economic Benefit ($/ha/year)	63.00	51.57	54.56	8.89
Management practices with highest economic benefits	Moving from C to B-Class application rate with legume, high till, sub-surface	Moving from C to B-Class application rate with legume, high till, sub-surface	Moving from C to B-class application rate with legume, high till, sub-surface	Moving from C to B-class tillage with bare fallow
Change in DIN (kg/ha/year)	18.75	6.31	35.20	0.6
Annualised Economic Benefit ($/ha/year)	81.67	96.62	86.63	48.23
Management practices with highest cost-effectiveness	Moving from C to B-class tillage with bare fallow	As above	Moving from C to B-class tillage with cover legume	As above
Change in DIN (kg/ha/year)	1.24		0.77	
Annualised Economic Benefit ($/ha/year)	28.00		56.25	

Source: van Grieken et al. (2015)

The economic and water quality figures are all presented in Table 12. Economic benefits provide insight into why some practices may not be being adopted in some regions and water quality figures give insights as to where the largest reductions can be made if certain practices are adopted.

They also found that variation within gross margins in regions to be modest but there was large variation between the regions with the management practices with the highest economic benefits in BRIA being double than those in the Wet Tropics region. The variation between regions is mostly due to the different farming systems used accounting for soil type and rainfall drivers of production.

Roebeling et al. (2007) also modelled the economic benefits and water quality outcomes of implementing improved practices for water quality, including shifting from high tillage to zero tillage, bare to legume fallow,

[19] As such practices that are not considered A-class may, in combination with other practices, result in higher water quality outcomes in particular regions than all A-class practices. For example, modelling results have high tillage (B-class) in the Burdekin Delta in combination with moving from C to A-class application rates with legumes and sub-surface application as having the highest water quality outcomes compared to if low tillage were used (A-class).

various nitrogen application rates, split and single nitrogen applications, current and reduced herbicide application rates and grassed headlands in the Wet Tropics region. The changes to water quality from moving to improved practices was modelled at the plot level with a production simulation model, hydrological model and combined into a benefit cost analysis. They found that most of the improved practices modelled offered financial benefits and led to improved water quality. A practice that did not have much impact on water quality in the modelling was split applications of nitrogen and while reduced pesticide applications led to considerable reduction in pesticide delivery, the cost of equipment meant that it was not cost-effective.[20]

Carr et al. (2008) and Agnew et al. (2011) analysed the impact of controlled traffic, reduced nitrogen and pesticide application methods in the Wet Tropics and MW regions respectively. Carr et al. (2008) also included minimum tillage and undertook their analysis using FEAT. They found that the farming system using improved management practices increased gross margins from $789/ha to $897/ha, reduced time spent operating tractors by 54 per cent across the farm and increased return on investment from 1.6 to 2.7 per cent over the ten years since first making the changes (Carr et al. 2008).

Agnew et al. (2011) also included a legume fallow in their trials which compared both productivity and profitability (partial net analysis of farm gross margins) in two locations (soil types) over three years. They also measured water quality impacts at multi-block and multi-farm scales of different combinations of C, B and A class practices for soil, nutrient and pesticide management. The treatments at both sites which used all C class practices across soil, nutrient and herbicide management had the lowest gross margin returns of all treatments with the exception of the legume treatment at Marian which was 37 per cent lower (legumes grown in skipped rows is an A class soil management practice). At the Marian site, the treatments with the highest gross margins of $2069/ha and $2051/ha both used 1.8m rows in controlled traffic, however, the higher of the two used C class nutrient and herbicide practices and the second highest used B class nutrient and herbicide practices. The treatment at the Victoria Plains site with the highest gross margin of $2439/ha had B class practices in soil and nutrient management and A-class practices in herbicide management. Cost estimates excluded land preparation, irrigation, fertiliser (except for nitrogen) and fixed costs other than harvesting – there was also no value estimated for the benefits of nitrogen fixing from legume crops or soil health benefits from skip rows.

The water quality monitoring results at the paddock scale did not differentiate between treatments for the Marian site. For the Victorian Plains site they measured 20 per cent more runoff from 1.5m compared to 1.8m row spacing, nitrogen concentrations were approximately three times higher for the high N treatment than for the lower N treatment in the first two runoff events, and pesticide runoff was relatively high in the first runoff event but tapered off quickly, with greater run off of applied hexazinone compared to diuron from treatment one.

In 2010 the then Queensland Department of Employment, Economic Development and Innovation (DEEDI) modelled the impact on gross margins at the farm level from changing to improved management practices such as controlled traffic, minimum tillage, a legume fallow, reduced nitrogen rates, nitrogen application methods, pesticide application methods in the MW (East 2010) and Tully (Poggio et al. 2010d) regions; and those practices as well as a GCTB in the Burdekin Delta (Poggio et al. 2010b) and BRIA (Poggio et al. 2010c). In particular, the changes from D to C, C to B and B to A class management practices were modelled using APSIM and FEAT and a risk analysis performed using PiRisk.

The economic analyses found that only grower's investments in the BRIA would attain positive NPVs with progressive management practice changes over both 5 and 10 year investment periods. Grower's investments in the Burdekin Delta would attain similar NPV results to those in the BRIA with the exception of moving from B to A practices over a 5 year horizon which would not achieve a positive NPV from the

[20] In the reduced herbicide application option (H2), persistent herbicides like Diuron are only applied on the plant row and non-persistent herbicides like Round-up in the interrow using a hooded sprayer (common in the Douglas Shire area). Alternatively, a knock-down herbicide is used on the plant row and Diuron is used on the interrow using a hooded sprayer (more common in the Cardwell Shire). In both cases, persistent herbicide use is halved using a hooded sprayer, while assuming no yield impacts (Roebeling et al. 2007: 3).

investment. NPVs in the MW had farmers better off moving from D to C, B to A and D to A over 5 and 10 year periods but not from C to B over either time horizon. Tully growers on the other hand could attain positive NPVs on their investments when shifting from D to C and C to B practices over 5 and 10 year timeframes but not from B to A practices in either investment period. The risk analyses showed that all growers could expect higher gross margins with any adoption of improved practices for MW and BRIA scenarios. Growers using A and B practices would have higher farm gross margins than those with D and C practices, all else being equal, in Tully and Burdekin Delta scenarios.

In the MW and Tully analyses bare and legume fallow management have negative gross margins, with legume losses being greater than bare fallow losses, for all classes of management practices in MW and particularly when used with B-class practices in Tully. In the BRIA managing a bare fallow delivered negative gross margins with D, C and B-class practices but was positive when combined with A-class practices. Planting soybean during the fallow in the Burdekin Delta generates a positive gross margin when harvested using A-class practices. The analysis did not include estimates of the economic benefits of nitrogen fixing properties of legume fallow. For the scenarios modelled in the BRIA and Tully it was found that higher gross margins corresponded with improvements in management practices with the exception of plant cane crops in the BRIA.

Van Grieken et al. (2013) modelled the transition of all D and C practicing growers to B-class (their proxy for a regulation scenario) and A-class (aspirational) over a five and ten year period for the Tully-Murray and Pioneer regions. Benefits were estimated in terms of the net present value of making the shift to B and A-class practices and the associated water quality improvement to DIN reduction.[21] Results of the modelling for the Tully-Murray region found that the net present value of shifting from current practices to regulation practices (B-class) was positive for both five and ten year time periods ($5.8 and $18.4 million respectively) but negative for shifting from regulation to aspirational practices over both time periods (-$18.3 and -$14.3 million respectively). Pioneer had a positive net present value for transitioning from current practices to regulation practices over a ten year period ($12.8 million) and from regulation to aspirational over a ten year period ($6.3 million). Reductions in DIN corresponded to management practice adoption, with the highest levels of DIN reduction occurring with aspirational practices. The highest net present value per tonne of DIN reduction at the end of catchment was estimated in the Pioneer region for the shift from current practices to regulation over ten years at $22 066. This was followed by the same shift over ten years in the Tully Murray region with an expected net present value of $20 880.

QDAF undertook a detailed economic analysis to estimate the costs of management practice change for the Wet Tropics WQIP. The costs were estimated using farm economic data collected through the Paddock to Reef Programme and Reef Rescue Research and Development Projects by van Grieken et al. (2015). The costs of management practice change were estimated using APSIM for sugarcane yields and FEAT for farm gross margins including capital expenditures for equipment and machinery but not transaction costs.

The following assumptions were made in relation to the profitability or costs associated with practice shifts (Terrain 2015: 65):

- A discount rate of 6 per cent with an investment period of ten years was used
- Costs of shifting to A-class practices were estimated by weighting by current proportion of farming area within each class and current proportion of farming area grouped into representative farm sizes
- Practice change transitions are required for DIN: D/C to A-class– 96 480 ha and B to A-class – 26 800 ha and for PSII: D/C to A-class – 100 500 ha and B to A-class – 26 800
- The investment analysis is based on three average farm sizes 50ha, 150 ha and 250 ha

Management practice categories modelled included:

[21] At the time this article was published regulation was B class management practices in the previous ABCD framework (2009) and that some of these practices are now C or minimum standard in the updated Paddock to Reef WQ risk framework and NRM ABCD frameworks.

- Rate of fertiliser use
- Placement of fertiliser
- Residual herbicide use in plant crops
- Residual herbicide use in ratoon crops
- Cultivation prior to planting.

Results of the modelling estimate that a total weighted cost of approximately $3.665 million per year is required to shift all growers to A-class practice for DIN and PSII herbicides in the Wet Tropics region over ten years and almost neutral cost to shift to all B-class practices (Terrain 2015: 65).

4.4 Economic projects currently evaluating management practices

Key Points

- A number of economic studies focusing on nutrient and pesticide management are currently being undertaken in the Wet Tropics, Burdekin and Mackay regions.
- The SRA and Queensland DAF research project 'The Impact of Smartcane BMPs on Profit and the Environment' will provide a comprehensive understanding of the economic and environmental implications for a number of BMPs (as defined by Smartcane BMP) in the Wet Tropics.
- As part of the Catalyst and Game Changer programs economic analyses will be undertaken in all of the priority catchments. The assessment of management practice will be undertaken by incorporating data collected from replicated field trials and incorporating statistical analysis where applicable. The broad management practice themes being investigated are alternatives to PSII herbicides, fallow crops for weed cover, nutrient management and soil health, nitrogen use efficiency, controlled release and enhanced efficiency fertilisers, mill mud, irrigation efficiencies, variable rate applications of N and pesticides and lower N rates on lower yielding blocks and late harvest ratoons. The main methodologies are field trials, case studies and whole of farm economic analysis using FEAT where QDAF is a partner.

This sub-section looks at economic studies that are in progress or not yet finalised, on management practices with a focus on water quality outcomes. Taken together with the gaps in research from completed economic research, these ongoing studies will give a better idea of where future work needs to be directed. Table 13 lists projects currently being undertaken on best management practices with water quality outcomes across a number of organisations and priority regions.

A review of information from studies that are currently being undertaken found that some of the imbalance of the stand-alone studies from sections 4.1 and 4.2 will be addressed with a nitrogen use study being undertaken by the QDEHP Science Programme in the Burdekin (although still a focus on rates, rather than products, placement of liquid fertilisers or timing) and a pesticide (product type) study by SRA in the Wet Tropics. The Wet Tropics will also have studies on controlled released fertilisers (CSIRO and SRA) and a project looking at the profitability of Smartcane BMPs and life cycle assessment done for sugarcane in the next few years (SRA, LCS and QDAF). It is worth pointing out that studies that analyse management practices in isolation of the entire farming system may not capture the interactions between different components of the farming system which are inextricably connected to each other. For example, interactions between a legume fallow crop and nutrient management across the crop cycle.

In addition, QDAF is collaborating with NRM groups as part of the Catalyst and Game Changer programmes as listed in Table 13. Two of the three studies listed for the Burdekin will explicitly focus on nutrient management (mill mud and controlled release fertilisers). The irrigation trials may reduce the quantity of run off from farms which could decrease the quantity of fertilisers and pesticides leaving the farm. There are four Project Catalyst trials (as shown below in Table 13) and sixteen Game Changer trials not listed in Table 13 (eleven trials comparing Urea, ENTEC™ and controlled release fertiliser; three banded mill mud trials; one irrigation telemetry and automation trial and an irrigation efficiency trial) in the Burdekin (pers. comm. Matthew Thompson 19 August 2015).

The studies being undertaken in the MW region are focused on nutrient management (legume fallow, controlled release fertilisers and variable rate applicator) and pesticide efficiency and application (comparison of knockdown and residual herbicides, shielded sprayer vs conventional boom, variable rate application) while the studies being undertaken in the Wet Tropics cover nutrient management (controlled released and enhanced efficiency fertilisers, mill mud applications, variable rate applications, legume fallow), pesticide management (fallow cover crops, post-emergent alternatives and pre-emergent herbicides) and minimal tillage options. Many of the studies listed in Table 13 will be based on field trials and written up as case studies and the economic analysis undertaken using the whole of farm FEAT program (where QDAF is a partner). In addition to these studies the NRM bodies are also in the process of updating their WQIPs. One of the main objectives of a WQIP is to 'identify the most cost-effective and timely projects for investment by all parties' and seek 'to deliver significant reductions in the discharge of pollutants to agreed hotspots'.[22]

Table 13: Current projects with economic analysis of sugarcane growing management practices

Project Name and timeframe	Management Practices with economic analysis	Region	Project Partners
Project No 2014/050 Three year project from October 2014	Investigate alternatives to the use of diuron based herbicides: - Pre-emergent herbicides - Post emergent alternatives - Fallow cover crops for weed control *project description did not include whether or not a cost component will be incorporated*	Wet Tropics	SRA/TropWater
Reef Plan Action 5 (Deliverable 3 & 4 Sugarcane Economics	Undertake a targeted analysis on specific case studies to validate economic findings in a commercial setting	Wet Tropics Burdekin Mackay Whitsunday	QDAF/QDEHP
Profitability and environmental implications of transitioning to Smartcane BMP July 2015 – Dec 2017	Develop case studies to evaluate the changes to profitability and the environment from BMP adoption.	Wet Tropics	SRA Life Cycle Strategies (LCS) DAF
Nitrogen Use Efficiency Trials – RP20/14c May 2015 – April 2017	Conduct an economic assessment using project data to evaluate the profitability of various nitrogen application rates mid-term and over the full crop cycle period. Four nitrogen treatments tested: Low rate; 6ES; Grower rate; and Above grower rate	Burdekin	QDEHP Science programme with SRA and DAF
Controlled Release (CR) Fertiliser project 2015 - 2018	Controlled release fertilisers	Wet Tropics	SRA CSIRO
Increasing farm business intelligence project July 2014 – June 2018	To provide industry baseline data on farm business profitability; assess the relative impacts of farm capitalisation, gate prices, rising input costs and market price trends on business viability All practices	Wet Tropics Burdekin Mackay Whitsunday	SRA - AgProfit
NQ Dry Tropics Project Catalyst and Gamechanger Programme	Advance the work of NQ Dry Tropics programme by providing an economic dimension to innovative grower based projects leading to water quality improvement. Projects validating the four themes: - banded mill mud - enhanced efficiency fertiliser trials - drip irrigation - irrigation telemetry and automation	Burdekin	NQ Dry Tropics Farmacist QDAF
Terrain Wet Tropics	Advance the work of Terrain's programme by providing		Terrain

[22] http://www.environment.gov.au/water/quality/improvement

Project Catalyst, Gamechanger and Reef Water Quality Programme July 2014 – Dec 2016	an economic dimension to innovative grower based projects leading to water quality improvement. Up-skill extension providers knowledge on economics and demonstrate the profitability of improved land management practices through the Wet Tropics Reef Water Quality Programme (Training and Extension). This includes validating the following project themes: - Minimal tillage - Variable rate application - Enhanced efficiency fertiliser - Fallow length and rotational crops - Mill mud applications on fallow	Wet Tropics	QDAF
Reef Catchments Project Catalyst and Gamechanger July 2014 – Dec 2016	Advance the work of Reef Catchments programme by providing an economic dimension to innovative grower based projects leading to water quality improvement. Projects validating the following themes: - two year fallow system - enhanced efficiency fertilisers - variable rate nutrient application (VRA) - VRA of N based on zone yield potential - Lower N rates on blocks with low yield potential and late harvest ratoons - Rate of ameliorant application - Efficiency of mill mud applications - Efficiency of knockdown and residual herbicides on in crop weeds - VRA of herbicides - Efficiency of pesticide methods of application	Mackay Whitsunday	Reef Catchments DAF

4.5 Extension and adoption of management practices

Key Points

- Factors perceived as constraining the adoption of BMPs in sugarcane growing have been identified as high capital investment, new skills required to implement the practice and a negative impact on farm profitability. Perceptions of the practice as being compatible with existing farming system, easy to trial, and required limited new skills and capital investment were identified with higher adoption rates.
- A defining characteristic of the sugarcane industry is its ageing demographic, with farmers reporting to be under 45 years of age declining from 35 per cent of those surveyed in 1999 to just over 20 per cent in 2010.
- There are two levels that information can be provided at: 1) Directly targeting individuals and tailoring information to their specific needs; and 2) More general information available through the usual sources (e.g. the internet, field days, and grower groups).
- In the context of agriculture a decision support system can be a way of converting knowledge gained from research into a form that can assist growers and extension officers in making decisions about farm management. A number of decision support systems have already been developed for the Queensland sugarcane industry.
- The Improved Practice Catalogue (IPC) on the DAF website is an example of general targeting and is a valuable source of information on BMPs. However, it is not regularly updated and it is not known which part of the industry users come from and how they use the IPC. This information would be invaluable in understanding how it is used and what improvements might increase its use.

Adoption of improved management practices, new technologies and innovations is a complex process that can take many years. Providing funding to support the process is no guarantee that it will occur, especially if the targeted management practices do not align with grower values or are not perceived as providing a relative advantage over their current farming system. In his work investigating the diffusion of innovations, Rogers (2003) specifies that relative advantage, complexity, observability, trialability and compatibility are perceived characteristics of an innovation that, after extensive investigation, have been found to explain about fifty percent of the variance in the rate of innovation adoption. Relative advantage is the perceived net benefit to be gained by adopting an innovation relative to the practice it supersedes. Building on Rogers' (2003) work, Pannell et al. (2006) brought together the extensive collection of research through a cross disciplinary approach and identified that conservation practices are more likely to be adopted by rural landholders if they are perceived to have a relative advantage (particularly economic), are readily trialable as well as being consistent with their personal goals (economic, social and environmental).

Pannell et al. (2006: 1408) also highlight that adoption is a learning process which can be divided into 'collection, integration and evaluation of new information to allow better decisions about the innovation' stage and a learning by doing stage where 'improvement in the landholder's skills in applying the innovation to their own situation.' In this section studies on specific characteristics of both sugarcane growers and the management practices targeted for adoption are reviewed as well as a brief look at how information on management practices is provided to growers to assess whether or not it is something worth trialling on their farm.

While the Smartcane BMP programme is not a complete measure of adoption of BMP practices, progress reports on this programme suggest that the benefits of many BMPs do not apply to or are not apparent to many sugarcane growers. In June 2015 the Queensland Audit Office (QAO) report Managing water quality in Great Barrier Reef catchments found that the industry-led Smartcane BMP programme has fallen well short of its targets since its introduction in 2013 (QAO 2015).[23]

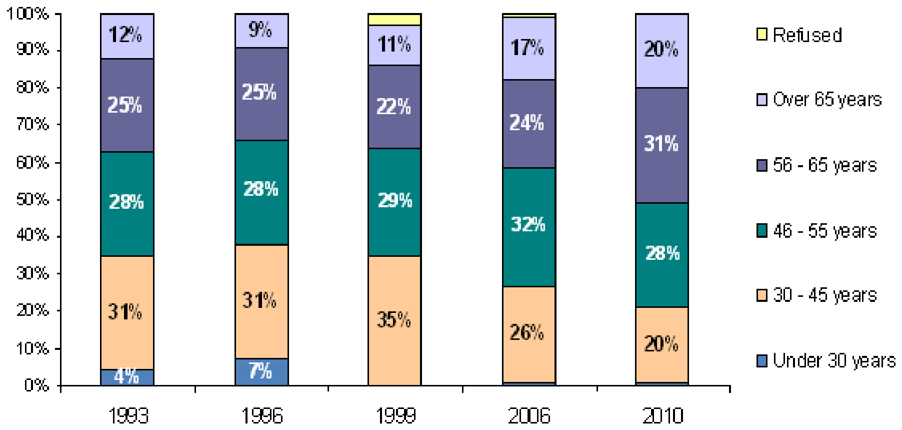
The sugarcane industry has attributed the low adoption rate to delays resulting from the time consuming nature of the programme, combined with the fact that it can only be undertaken in the off-season. The report also cited a perception on the part of growers that there is a lack of value in participating in the programme and becoming certified. While some growers are likely to be adopting BMPs outside of the Smartcane programme, they should be accounted for in the Paddock to Reef monitoring programme. In December 2014 the Queensland Government allocated an additional $5.855 million in funding to extend the Smartcane programme for a further three years (QAO 2015).

A recent study by Thompson et al. (2014) into factors influencing adoption of BMPs in sugarcane growing found for the BMPs with the lowest adoption rates that high capital investment, new skills required to implement the practice and a negative impact on farm profitability were perceived by growers as constraining factors. Conversely, for the BMPs with the highest adoption rates, the majority of growers perceived the practice as being compatible with existing farming system, easy to trial, and required limited new skills and capital investment. Unsurprisingly, on average, adopters believed more positively in the economic benefits of adoption compared to non-adoption (Thompson et al. 2014). Perceptions between adopters and non-adopters were significantly different for the impact on enterprise profitability for four of the six practices analysed (legume fallow, low tillage, precision and directed herbicide application and nutrient and weed management plans); for compatibility of all the practices analysed with their existing farming system; and for high capital investment for precision and directed herbicide applications. Farmers managing properties greater than 200 ha were also significantly more likely to have adopted precision and directed herbicide application practices.

Even though most of the socio-economic factors and farm characteristics were found to be relatively insignificant in influencing adoption in the Thompson et al. (2014) study, younger farmers aged 45 or less were significantly more likely to have adopted precision and directed herbicide application practices and electronic records (which facilitate the use of many new technologies). Smith et al. (2014) note a defining characteristic of the sugarcane industry is its ageing demographic, with farmers reporting to be under 45 years of age declining from 35 per cent of those surveyed in 1999 to just over 20 per cent in 2010 (see figure 10). This is an important consideration for policy approaches as the study by Thompson et al. (2014) indicates that age may be a factor in adopting particular new technologies.

[23] Targets for the first 12 months of the program were to facilitate growers with accredited environmental risk management plans (approximately 560) to complete the Smartcane BMP self-assessment. After the first 12 months 1520 growers (75 per cent from Mackay Whitsunday, Burdekin and Wet Tropics catchments) would be required to complete Smartcane BMP self-assessment and of those 1520 growers, 380 were to be accredited in the key modules of drainage and irrigation; pest, disease and weed management, and soil health and plant nutrition management (Smartcane BMP newsletter issue 2 September 2013).

Figure 10: Age of main decision makers for sugarcane farms



Source: Canegrowers Members research Report 2010 – Demographics (2010) cited in Smith et al. 2014 –

In their study drawn from 116 sugarcane farmers in the Mackay and Bundaberg regions, Akbar et al. (2014) found that a mix of economic and socio-economic factors influence the adoption of BMPs with water quality benefits. Influencing factors included: access to and availability of cash; working full time on the farm; self-desire to protect natural resources; self-awareness and openness to current and scientific knowledge; focus on controlling own practice; maintaining a quarterly budget; having a cost control and risk management plan; capacity to maximise profit and minimise labour and overhead costs and maintaining a long-term steady profit and long-term involvement in farming.

Institutional contexts also play a part in sugarcane growers participating in programmes which encouraged adoption of BMPs. With specific reference to the Reef Rescue programme, Taylor and van Grieken (2015) found some of the main risks of participation included: possible disruption to local economic cooperation amongst farmers that relied on continuation of shared farming practices; inequitable financial burdens of participation; lost farm productivity and interference of central governments in their farm business (Taylor and van Grieken 2015: 10). All of these factors illustrate the complexity of adoption beyond an assessment of profitability in an economic model.

The Bureau of Sugar Experimental Stations (BSES) project 'accelerating the adoption of best practice nutrient management in the Australian sugar industry' specified what they believed to be the best steps to achieve adoption (Schroeder et al. 2010b: i):

1. Improve knowledge of the constraints to the adoption … using grower surveys
2. Developing a [package] for improving on farm management decision making
3. Facilitating the use of nutrient management plans at block and farm scales and the implementation of soil/site specific fertiliser applications using a participative approach
4. Assessing the risk of on and off-site impacts of land management practices using vulnerability maps at catchment scales
5. Demonstrating the benefits of best nutrient management practices with on-farm strip trials
6. Reviewing the NUE factors associated with relevant trials
7. Developing a computer based decision support system for the 6ES nutrient management package.

This is consistent with the learning process described by Pannell et al. (2006) of collecting and evaluating new information and learning by doing. Of note is step two; getting the information to growers that they need to decide whether or not to trial a particular management practice on their farm. People learn in different ways, have different preferences for interacting with information providers and have specific requirements in terms of the characteristics of their property, their farming enterprise and their personal values. The ‘package’ refers to this complexity and may include such things as websites, fact sheets, field days, farm visits with a grower group, one on one with an agronomist or NRM officer or using a decision support tool to work through stylised scenarios representative of their situation.

For any communication delivery to be effective in engaging growers it needs to provide the latest research results, come from a respected and trusted source of information (i.e. proven record of being reliable and useful) and be presented in a format that is easy to use or navigate. There are two levels that information can be provided at:

1) Directly targeting individuals and tailoring information to their specific needs. For example through one on one extension or guidance to work through FEAT to analyse the impact on the farming enterprise of making a change or a decision support system that provides information given a defined set of parameters specific to a given farming enterprise; and

2) More general information available through the usual sources (e.g. the internet, field days, grower groups) where growers can access and assess by themselves how particular techniques might be applicable to their farming enterprise. This level of information is often the first port of call in the adoption process before proceeding to the more tailored type.

A decision support system (DSS) is a computer-based information system that can support decision making processes for businesses and other organisations. In the context of agriculture DSSs can be a way of converting knowledge gained from research into a form that can assist growers and extension officers in making decisions about farm management. A number of DSSs have already been developed for the Queensland sugarcane industry and include:

1. FEAT is an Excel-based planning and decision-making tool that enables growers to model their current farming practices against alternative management scenarios and calculate the difference in their farm's financial performance, by estimating parameters such as gross margin, operating return and return on investment.
2. NutriCalc is a web-based nutrient management application and helps growers determine nutrient requirements for individual blocks based on soil test reports, as well as keeping records of on-farm nutrient management and benchmarking yields against district and industry averages.
3. SafeGuage for Nutrients is an application that allows users to enter fertiliser management details and obtain a risk assessment regarding the potential for nutrients to be lost through runoff, deep drainage and denitrification.
4. The Soil Constraints and Management Package (SCAMP) is an Access-based decision support system that can identify soil constraints to productivity and suggest appropriate management strategies.

An example of a more general form of information can be found in the Improved Practices Catalogue (IPC) hosted by the QDAF on its website (QDAFF 2014).[24] The IPC is described as:

> … an online resource for farmers in the Great Barrier Reef catchments. This tool highlights a number of key practices for the sugarcane, banana and grazing industries and aggregates the evidence both for the benefits to water quality with the economic costs and benefits.

Developed as part of Action 4 of Reef Plan in 2011-12, the aim of the IPC is to ‘support agricultural profitability while improving the quality of water in the Great Barrier Reef’. It does this by collating scientific research from a number of sources that support the improved management practices (see Table 18 in Appendix 4 for a listing of improved practice categories on the IPC). Practices included on the IPC were selected in consultation with industry groups and underwent a cost benefit/water quality benefit assessment.

[24] https://www.daff.qld.gov.au/environment/sustainable-agriculture/reef-water-quality-protection-plan/improved-practices-catalogue

The IPC is emphasised as an information source only and recommends working with industry BMP programmes such as Smartcane for sugarcane (see Appendix 3) which consider productivity, resilience and business performance. Designed as a central repository for all scientific studies on improved practices, all relevant published studies from various sources should be found here. The IPC provides links to relevant organisations and to all the studies cited for each category of practice management. However, possibly due to resourcing constraints, the IPC has not been regularly updated as new information becomes available with the most recent study referenced from 2012. However, at the time of writing this report the IPC was undergoing review and being updated.

Data collected internally on how often the IPC is accessed shows that in the 12 months preceding January 2016 there were 215 unique page views for the IPC webpage and 151 for the sugarcane page on the IPC. The most downloaded fact sheet was on 'nutrient application rates' at 70 downloads followed by 'spray out or slash legume crop' and 'pesticide use as part of an integrated pest management plan' at 20 downloads each. It is not known which part of the industry users come from: are they growers, extension officers, or researchers as this information is difficult to obtain. However, the feedback form at the bottom of the webpage could be expanded to try and capture this type of data as understanding who the main users of the IPC are could help further refine the tool to increase its use.

As identified in section 4.5, grower perceptions around relative advantage (particularly economic) and what factors are constraining or enhancing their decisions to adopt improved management practices are critical. Perceptions around improved management practices can be influenced through information provision either at a targeted individual level or a more general level. While there are a number of decision support systems available that provide information tailored to the specific needs of growers, there is little information on who is using these tools and how they are being used to facilitate the adoption of improved management practices in the sugarcane growing industry. Ensuring that the ever growing body of scientific research in the sugarcane industry continues to improve farm management practices remains an ongoing challenge. QDAF is currently exploring options for the development of additional DSSs that can fulfil this role, especially in relation to improved nutrient use efficiency.

5. Key findings and information gaps

Key Points

- There is a clear lack of field trials supporting the economic or water quality benefits of using block, farm or sub-district yield potential in the 6ES despite their inclusion in recent frameworks either as A or B-class practices for nutrient rate application
- There is limited information on nutrient management as a whole system, including irrigation as a critical vector for the transportation of nutrients and chemicals, how nutrients interact, timing of application and identifying production constraints and their implications for economics and water quality
- Research currently being undertaken that looks at the timing of fertiliser applications includes enhanced efficiency fertilisers and variable rate application, however, no planned economic studies explicitly into the timing of herbicide application with respect to climate were found
- There is a need for greater understanding of pesticide management practices as part of the broader farming system, in particular new innovative practices and products, and their potential implications on water quality and economic outcomes for industry
- A number of studies aggregated BMPs into classes when analysing their impact on water quality and economics. As many management practices are inextricably connected to each other, analyses which identify these interactions as well as the economic and agronomic performance of individual practices within a systems approach may help with convincing growers they are worth trialling
- The costs (monetary and non-monetary) involved in learning about new practices were not included in any of the studies. Explicitly recording this information where possible could provide insights as to the size of these transaction costs for different BMPs, in different regions and across different socio-economic factors. Having this information would assist in targeting extension and policy design in the future
- Very few of the studies reviewed for this report included a water quality outcomes component. Where the studies feature practices that are aspirational or novel, some measure of the water quality benefits would greatly enhance their value
- The results of the studies reviewed in this report must be considered in the context of the quality of the information and the limitations of the methodologies used. Many of the studies did not have enough data points to allow statistical significance of the results to be tested. This makes it difficult to apply the results outside of that particular trial site at that point in time
- Tools available to growers can be individually targeted or more generally targeted. There are a number of tools already available in both these groups such as the IPC (more general) and the FEAT provided by QDAF (individually). Further research into the use of existing tools may help with adoption of best management practices for water quality outcomes particularly in an age where more farmers are accessing smartphone technology.

5.1 Nutrient management

From the review of studies in this report, it is clear that 6ES using district yield potential (DYP) consistently outperformed N-replacement on grower profitability, and in one study it outperformed traditional rates over a number of sites. 6ES using district yield potential is considered industry best practice and is formally recognised as such under the Smartcane BMP programme launched in 2013.

However, 6ES using the district yield potential will potentially only deliver a reduction in DIN transported to the GBR of approximately 15 – 30 per cent (QDEHP 2014: 12; Thornburn and Wilkinson 2013; Waters et al. 2014). While the most recent ABCD frameworks released by the NRM bodies and Smartcane include using block, farm or sub-district yield potential in the 6ES, either as A or B-class practices for nutrient rate application, there are limited studies supporting the economic or water quality benefits of this approach.

Studies with an economic component on nutrient management have almost exclusively focused on nitrogen application rates and legume fallows and predominantly in the Wet Tropics region in the past five to ten years. There is little information on the use of site specific nutrient management as a whole system, including how the interaction with other nutrients and identifying production constraints, along with interactions with nitrogen to meet sugarcane needs and their implications for economics and water quality.

The SRA report into NUE identified that refining '6ES to more accurately account for the contribution of indigenous sources of N and yield potential at appropriate spatial scales' is a research priority, and that 'any changes to the district yield potential used with the 6ES program … should be well-researched' and 'not adversely impact productivity' (SRA 2014: p.7,p.14, p.311). An economic component should be incorporated into the research agenda into alternatives to district yield potential within 6ES so that grower profitability of this management practice can also be determined and subsequently be a measure of cost-effectiveness. This research would benefit from using the most informative economic methodologies that can be tested for statistical significance.

There were a few studies that included timing and placement of nutrients, however, it was not clear from the results how important these are to economic performance and water quality outcomes – more studies on these other aspects of nutrient management would help with this.

More recent studies have shifted focus to enhanced efficiency fertilisers, variable rate applications and longer fallows where the fallow crops are harvested. As well as the Burdekin, many of these studies are being undertaken in the MW region where few studies on nutrient management with an economic component had been previously published (see Section 4.4 for current studies). Research priorities for nutrient management from SRA (2014), Thornburn et al (2013) and Terrain (2015) are shown in Table 14.

Table 14: Research priorities identified for nutrient management in the literature

Source	Priorities
SRA (2014)	• Seasonal block/management zone yield potential and application of N fertiliser at optimal rates. • 6ES guidelines accounting for spatial variability and address the temporal needs of the crop. • Development of N-efficient varieties. • Better accounting of all sources of N and appropriate use of enhanced efficiency nitrogen fertiliser. • Technologies and tools to determine most effective application strategies and mitigate risks. • Understanding of economic implications of various NUE strategies, including use of enhanced efficiency nitrogen fertilisers, on farm profitability.
Thorburn et al. (2013)	• Defining the minimum N surplus needed to maintain yields of crops growing in the GBR catchments. • Determining if this minimum surplus can be reduced if coupled with management practices that aim to increase N use efficiency of crops. • Exploring whether N losses can be reduced if N fertiliser management varies in response to seasonal climate forecasts.
Terrain (2015)	• Target the amount used [nitrogen] and timing, and to a lesser extent its placement. • Variable rate application (VRA) through identification of georeferenced zones to reflect block yields and soil characteristics. • Research and development into slow release fertilisers, innovative fertiliser reduction schemes also known as enhanced efficiency nitrogen (EEF) fertilisers.

Some of these are being addressed in QDAF current work (see Table 13) such as EEF and VRA across all priority regions and SRA and CSIRO are also undertaking research on EEF.

5.2 Pesticide management

Studies reviewed in this report found that targeted application of pesticides through specialised spraying equipment and use of GCTB above a certain thickness (greater than 6 tonnes/ha) can increase pesticide efficiency, however, the cost of equipment may prevent this being a cost effective option. In particular, precision spraying pesticide technology (e.g. Weedseeker™) is only profitable in very specific circumstances of weed type and coverage.

In their review '*The economics of pesticide management practices on sugarcane farms*', Smith et al. (2014) identified a number of key findings and information gaps with regards to the understanding of the economics of pesticides in sugarcane farming. These include:

- Not enough emphasis on heterogeneity of farm enterprises across individual landholders and regions – this distinction helps farmers identify which practices are best for them on an economic level
- Lack of knowledge about the water quality and economic implications of irrigation recycling pits
- Testing is required to enhance water quality modelling work on herbicides – e.g. confirming that combined effect of herbicides in a mixture is concentration additive
- More research to investigate mixture toxicity of herbicides on locally important species relevant to the GBR – particularly with respect to relatively new alternative chemicals

Thornburn et al. (2013) also identified that a wide range of new and emerging herbicides are being used in cropping systems; much less is known about their behaviour and fate than older herbicides. In their latest WQIP plan, Terrain (2015) identify targeting timing of herbicide application (using forecasting to respond to the wet season) as a priority for research, however, no planned economic studies explicitly into the timing of herbicide application with respect to climate were found in current or planned research (see Table 13). There is a need for greater understanding of pesticide management practices as part of the broader farming system, in particular new innovative practices, and their potential implications on water quality and economic outcomes for industry.

5.3 Other gaps

While a number of studies reviewed provided economic information on outcomes of moving from a suite of lower class practices to a suite of higher class practices, the performance of individual practices was sometimes lost in the aggregation – this is particularly important for practices that have limited stand-alone studies. As many management practices are inextricably connected to each other such as pesticide management and tillage practices, analyses which identify these interactions as well as the economic and agronomic performance of individual practices may help with convincing growers they are worth trialling.

The complexity of implementing particular improved practices is often called a transaction cost and covers the costs (monetary and non-monetary) involved in learning about new practices, deciding whether to trial them, and gaining the skills required to trial and assess them. These costs were not included in any of the studies and only acknowledged as a cost that would not be estimated in a few studies. The adoption literature has shown that perceptions of these costs can be important factors in deciding whether or not to trial a new innovation in agricultural production systems. Extension staff, facilitators for the Smartcane BMP programme and NRM officers all play a vital role in working with growers to adopt BMPs and witness first hand some of these transaction costs. Formally recording this information could provide insights as to the size of these transaction costs for different BMPs, in different regions and across different socio-economic factors such that they could be explicitly incorporated into economic analyses of BMPs going forward.

Very few of the studies reviewed for this report included a water quality outcomes component. Out of the 46 studies reviewed, only six explicitly included an analysis of water quality impacts from moving to improved management practices. While the focus of the studies reviewed is the economics of management practices that have already been classified as best practice with respect to water quality outcomes, where the studies feature practices that are aspirational or novel, some measure of the water quality benefits would greatly enhance their value.

A few studies identified water quality benefits from improved practices that require large upfront capital investments such as precision spraying equipment (Roebeling et al. 2007) or irrigation infrastructure (Poggio et al. 2010; Qureshi et al. 2001) that can make them economically unviable. It would be informative to understand the role that recent policy approaches in supporting the adoption of such practices (e.g. Water Quality Improvement Grants under Reef Rescue) have had in overcoming these barriers and including a break-even analysis in future economic analyses of BMPs which require large upfront capital investments.

The results of the studies reviewed in this report must be considered in the context of the quality of the information and the limitations of the methodologies used. In terms of methodologies used, the economic evaluation at a gross margin level is preferred to a partial net benefits approach as it allows for a more comprehensive assessment by including other aspects of the farming system. Although many of the nutritional studies are focused on incremental changes in nitrogen alone, other aspects of the farming system will inherently impact on the production outcomes and therefore should be considered in the capture of data and assessment. A partial economic analysis may be suitable in certain circumstances and where sufficient trial data is not available to capture other parts of the system, however, results from its use should be treated with caution.

With respect to the quality of the information, if the purpose of the study is to validate a practice it is important that the right data is collected and consideration is given to the trial design to allow a robust analysis of the data, for example, a statistical analysis to test if the results of the trials being compared are actually different to each other. While resource constraints can often mean not enough data is collected to facilitate statistical significance testing, sensitivity analyses and risk analyses also provide additional insights into results from trial data. Another important aspect to consider is many studies only collected data for one or two crop stages. As sugarcane has a crop cycle up to five ratoons, depending on location, it is critical to assess the improved management practices over the full crop cycle to fully understand the economic impacts.

Finally, it is worth noting the importance of tools available to growers to use the information generated from the economic and agronomic studies that have been done on management practices for water quality outcomes and apply it to their own circumstances. This review categorised them into two types: 1) Individually targeted; and 2) more generally targeted. There are a number of tools already available in both these groups such as the IPC (more general) and the FEAT provided by QDAF (individually targeted). Further research into the use of the Improved Practices Catalogue and further development and promotion of both to increase their use may help with adoption of best management practices for water quality outcomes.[25] Additionally, the development of a decision support tool focusing on improved NUE has the potential to enhance adoption in an age where more farmers are accessing smartphone technology.

[25] FEAT currently has 255 registered users that represent a diverse range of groups engaged with the sugarcane industry such as growers, QDAF staff, NRM extension officers, research institutions and industry bodies. This number may include duplicates where users have registered multiple times though.

6. Priorities for work in Reef Plan Action 4 2016 – 2017

The priorities for QDAF in meeting the objectives for Reef Plan Action 4 project over the next year can be grouped into two areas: 1) economic analyses of management practices with water quality outcomes and 2) how the information from these economic analyses is distributed to industry.

High priority work

- Continued collaboration with project partners to provide economic expertise in research trials in order to validate the profitability, risk and cost-effectiveness of the adoption of new management practices. In particular research trials that:
    - Use site specific (block, farm or sub-district) yield in 6ES for nutrient management.
    - Use relatively new and emerging alternative herbicides.
    - EEF or alternative forms of nutrient management (other than 6ES).
    - Investigate fallow crops in rotation with cane and fallow length.
    - Effective use of mill mud.
    - Investigate the influence of different irrigation systems in transporting excess nutrients and chemicals into water pathways to the GBR.
    - Evaluate the profitability of shifting from conventional furrow irrigation management to BMP furrow irrigation management with different soil types (i.e. cracking clay and non-sodic duplex), water sources (i.e. channel and bore) and farm designs (i.e. row lengths, gradients and recycle pits).

- Evaluation of improved management practices as part of a whole-of-farm system to provide a greater understanding of their interactions and combined impact on social, economic and environmental outcomes. Use specific case studies to better understand the economic implications in a commercial setting for management practices identified as having water quality outcomes.

- The continued provision and enhancement of decision support tools to enable growers to develop individual advice on the adoption of improved management practices. This includes the update regional FEAT files for the Burdekin Delta, BRIA, Mackay and Tully areas to support industry BMP and continued development of FEAT files for other regions (e.g. Herbert) to facilitate understanding of the cost-effectiveness of management practices classified as innovative that have water quality outcomes.

- Update the Improved Practices Catalogue and measure how often it is accessed. Review how it is used by industry and how it can be improved to increase use.

- Review the potential for a Decision Support System for NUE – a tool which would provide an economic analysis of specific NUE practices under a set of specified farm enterprise characteristics. Any work on a Decision Support System for NUE will need to be collaboratively undertaken between government, industry and NRM bodies to ensure that if such a tool is developed it is relevant and the final product is able to be regularly updated and maintained so that it remains relevant.

Medium priority work

Update the Paddock to Reef Monitoring & Evaluation studies undertaken in 2009. These studies undertook economic analysis of moving between categories of ABCD cane management practices for the cane growing regions in the GBR catchments. Since then all NRM regions have updated their ABCD cane management practices for water quality outcomes (see tables in Appendix 2).

Appendix 1 Paddock to Reef water quality risk framework

Table 15: Paddock to Reef water quality risk framework

Priority	Management tactic	Weighting (water quality assessment)	Indicative practice levels 2013			
			High risk	**Moderate risk**	**Moderate – low risk**	**Lowest WQ risk, commercial feasibility may be unproven**
			Superceded	**minimum**	**Best practice**	**innovative**
Soil management						
1	Crop residue cover	25%	No Green Cane Trash Blanket	Often burn fallow blocks, maintain trash on ratoons.	Green Cane Trash Blankets maintained in all blocks.	
2	Controlled Traffic 25	25	Old industry standard row spacing. Farm equipment not on matching wheel centres.	Matching wheel centres on equipment used for all land prep and pre-harvest operations. Harvester and haul-out wheel spacing not matched to other farm equipment	Permanent wheel tracks. Row spacing at 1.8m or more. ALL equipment including harvesters and haul-outs utilising same wheel spacing. DGPS guidance for bed forming/planting operations as a minimum.	Permanent wheel tracks. Row spacing at 1.8m or more. ALL equipment including harvesters and haul-outs utilising same wheel spacing. DGPS guidance for all operations.
3	Land management during cane fallow	20	Plough Out, Replant (PORP) OR No rotational crop. Bare or "weedy" fallow maintained with cultivation and/or herbicides.	Legume rotational crop grown during cane fallow period. Conventional cultivation to prepare for legume planting. Legume mechanically incorporated. OR Well managed fallow with trash blanket, sprayed out with no tillage.	Legume rotational crop grown during cane fallow period. Min/zonal tillage prior to planting legume. Legume crop harvested for grain. OR Killed with herbicide and residues left intact until necessary pre-plant operations for cane.	Legume rotational crop grown during cane fallow period, with legume direct drilled into previous sprayed out cane. Legume crop residues left intact above ground until necessary pre-plant operations (minimum or zero till) for cane.
4	Tillage in plant cane	20	Full cultivation (number and nature of cultivations region-specific)	Reduced tillage (number and nature of cultivations region-specific).	Bed renovation and/or zonal tillage, minimum required to be suitable for planting.	Zero tillage plant cane
5	Tillage in ratoon cane	10	Full cultivation (number and nature of cultivations region-specific)	Minimum tillage (region-specific). Ripping of wheel tracks as necessary	No tillage except as a component of Integrated Weed Management planning for avoiding herbicide resistance	
Nutrients						
1	Matching N supply to crop N requirements	60	District rules of thumb determine applied N rate	Nitrogen budget developed (e.g. 6ES) with estimated N demand based on a yield expectation of Estimated Highest Average Annual Yield + 20% (district yield potential) for plant or ratoon stage. Final application rates are as per calculated amount.	Nitrogen budget (e.g. 6ES) developed with estimated N demand based on growers own yield expectations for specific blocks and ratoon numbers and considers seasonal climate predictions. Final application rates are as per calculated amount.	As for Best Practice, but with planning and application targeting yield zones within blocks.
2	Timing of fertiliser application	30	Weather only impacts upon ability to complete application at that time	Application occurs with consideration given to short term (<4 days) rainfall forecast.	Application occurs prior to expected wet season commencement and with adequate risk assessment, including weekly rainfall forecast.	As for Best Practice, plus utilising seasonal climate forecasts.

3	Application method	10		Surface applied, not incorporated.	Subsurface (including surface applied and watered in)		
Herbicides							
1	Timing application of residual herbicides	40		Residual herbicides applied when it is most convenient and/or in salvage situations. Due consideration to current weather conditions including BoM radar and 48hr rainfall forecast.	Residual herbicides applied as soon as practical after harvest, with due consideration to current weather conditions and 4 day rainfall forecast.	As for Min Standard, plus: Plan to ensure residuals have been applied at least 3 weeks prior to anticipated wet season commencement	As for Best Practice, plus: Use of SafeGauge for Pesticides to further inform risk of off-site movement of herbicides.
2	Targeting application to reduce the volume of herbicide applied	40		100% coverage through conventional boomspray for all applications. Generally use a set residual + knockdown tank mix	100% coverage through conventional boomspray for most applications. Tank mix tailored to weed situation in each block, with residuals not used if not required	Area treated with residual herbicides is reduced through use of band spraying, except for specific problem situations requiring more complete coverage. Inter-rows managed with knockdown products through directed or shielded spraying.	As for Best Practice, plus use of weed detecting equipment to further reduce total herbicide applied.
3	Residual herbicide use in ratoons	20		Residual herbicides used whenever likely to be effective, in both plant and ratoon cane.	Residual herbicides used once only on ratoon crops.	Overall weed management strategy is based upon use of knockdown products in ratoons. Residual use in ratoons occurs only in strategic response to problem situations.	
Water							
1	Calculating the amount of water to apply	Irrigation	No irrigation	Amount of water applied to each block exceeds the soil water deficit by more than 50%.	Amount of water applied to each block exceeds the soil water deficit by less than 50%.	Amount of irrigation water applied to each block is less than or matches the soil water deficit.	
		70	0				
2	Managing surface runoff	20	100	Headlands and drains are not specifically designed to prevent erosion and are sprayed out and/or cultivated. No on-farm water capture.	Crop row orientation and surface topography ensures runoff is directed from most blocks without causing soil loss or waterlogging. The majority of drainage lines are designed to minimise erosion and are maintained with grass cover. Recycle pits have insufficient capacity to capture all irrigation induced runoff.	Crop row orientation and surface topography ensures runoff is directed from all blocks without causing soil loss or waterlogging. All drainage lines are designed to minimise erosion, are maintained with grass cover, and filter sediment before entering trap or pit. Recycle pits have sufficient capacity to capture all irrigation-induced runoff. Recycle pits have sufficient pumping capacity to re-use stored water.	All drainage lines are designed to minimise erosion, are maintained with grass cover, and filter sediment before entering trap or pit. Farm layout directs all runoff safely to these structures. Runoff from the first 15 mm of rainfall is captured and retained on farm. All irrigation runoff is able to be captured and stored on-farm. Recycle pits have sufficient pumping capacity to re-use stored water.
3	Optimising the irrigation system	10	0	Irrigation system performance assessments have not occurred.	Irrigation system performance assessments occur on an irregular basis.	Irrigation system performance assessments occur on a regular basis.	

Source: personal communication Kevin McCosker QDAF

Appendix 2 Water Quality Improvement BMPs

In this appendix the ABCD frameworks for management practices for sugarcane (for water quality outcomes) as compiled by the NRM bodies for the priority catchments are presented. They have been formatted so that they are all presented in a similar way to allow for easier comparison. Each practice category contains the most recent practices listed under the ABCD categories and where these practices differ from those that were listed in the 2009 ABCD frameworks, the 2009 practices are described in red.

Below in Table 16 is the ABCD Framework of Management Practices for Sugarcane Growers in the Burdekin Region.

Table 16: ABCD Framework of management practices for sugarcane growers in the Burdekin region

Management Practices	D Degrading	C Code of Practice	B Best Practice	A Aspirational
Nutrient management				
1.1 Nutrient rates	Above industry recommended rates.	At industry recommended rates (6ES based on district wide yield potential for whole farm) Flat rate for whole farm at industry recommended rates	At industry recommended rates (6ES based on individual block yield potential). Variable rate between blocks using current industry recommend	Variable rates within blocks based on field variability using 6ES. Use of emerging nutrient technologies. Variable rates within blocks using current industry recommend
1.2 Planning	Future rates based on past application rates.	Soil test taken prior to planting. Not all blocks tested. Planning based on 6ES. Future rates adjusted for plant and ratoons	Soil test taken per plant block prior to planting. Planning based on 6ES. Nutrient management plan based on 6ES or N-replacement	Soil tests taken within management zones prior to planting. Planning based on 6ES. Same as B plus soil and yield mapping
1.3 Timing		Before first irrigation into dry soil. none	Prior to mid-October in moist soil. Same plus 3-5 days after first irrigation	Split applications in ratoons. As B practice
1.4 Placement	Granular fertiliser surface application. Any form of nutrient including mill mud applied in the furrow. All on surface	Sub-surface	Sub-surface application of granular or solid fertiliser. Surface applied liquid nutrients on the hill. Sub-surface and rate controlled accurately with fertiliser box shut off at end of paddock (no fertiliser in tail drain) and liquid products applied above surface 3 days before first irrigation	Sub-surface application of liquid fertiliser. Banded mill mud. Same as c but no surface application
1.5 Calibration	Fertiliser box rarely calibrated.	Fertiliser box calibrated for each block. Fertiliser box calibrated annually	Rate controlled fertiliser box calibrated daily and between product changes. Fertiliser box calibrated weekly and between product changes	With each paddock and between product changes
Pesticide management				

2.1 Use of Residuals	Heavy reliance on residual products with no attempt made to minimise runoff losses.	Use of both residual and knockdown products. Minimised use and reuse of tail water. Same but without minimise use …	Primary reliance on knockdown herbicides over residuals in ratoons. Knockdown replace residuals where practical. Variable weed strategies b/w blocks. Sprays off as machine turns around	Knockdown herbicides replace residuals. Primary reliance on knockdown over residuals. Same as rest of B
2.2 Chemical rates/application	Maximum label rates regardless of weed pressure.	Chemicals applied at lowest rate for effective weed control. Chemicals applied using standard spray rig and applied at lowest effective rate	Chemicals applied at lowest rate for effective weed control. Flow rate monitor, GPS guidance and dual/banded application systems utilised. Same up to GPS … use shielded sprayers where appropriate	Implementation of new technology for improved placement and application efficiency (e.g. weed seekers). Same plus (shielded sprayers, weed seekers) using GPS guidance and computerised control monitors
2.3 Timing	Ad hoc.	Spray as per label recommendations.	Spray as per label recommendations with all weeds controlled before four leaf stage. Multiple weed control events during fallow.	Use of safe gauge tool. Same as B
2.4 Calibration	Once a year. never	Once a year	Continual calibration if using flow rate controllers. Once per month	Once per month
2.5 Planning	Reactive. One strategy for whole farm	More than one weed management strategy for entire farm.	Weed management plan and variable weed strategies between plant blocks.	Weed management plan and variable weed strategies within management zones. GPS based Herbicide management plan implemented
Soil Health				
3.1 row Spacing & Guidance Farming system	Conventional row spacing, no guidance. none	Conventional row spacing, some machinery matched, not all. none	Row spacing and all machinery wheel spacings are matched and are operated on GPS guidance for bed-forming, planting, and harvesting and haul out operations. All operations based on controlled traffic beds with GPS guidance for bedforming, planting and harvesting operations	All operations based on controlled traffic permanent beds with GPS guidance for all in crop operations (including harvesting)
3.2 Plant Cane Establishment	Cultivated conventional.	Minimum tillage.	Zonal tillage during establishment of plant crop.	Zero till planting. Same as B
3.3 Ratoons	Cultivated conventional.	Minimum tillage.	Zero tillage. Minimum tillage with GPS guidance	Same as B
3.4 Fallow	Cultivated bare fallow.	Minimum tillage bare fallow with chemical weed control.	Well managed fallow crop.	

3.5 Ameliorants	No ameliorants.	Ameliorants applied based on soil test. Ameliorants applied where necessary	Variable rate ameliorants applied based on soil tests and prescription mapping. Same up to prescription mapping	Same as 2013 B
3.6 Trash Utilisation	Burnt crop and residual trash burnt.	Burnt.	Green cane trash blanket on suitable soils.	
3.7 Headlands	Bare. none	none	Ground cover maintained on headlands and drains.	
Water and Irrigation Management				
4.1 Matching water use to crop requirement Method metering	Irrigation applied with no evaluation of quantity. Furrow No metering	Limited measurement of irrigation application. Furrow No metering	Regular measurement / monitoring of volume supply with water meter and application rates matched. Pump audits conducted and outcomes incorporated into management plan. Irrigation matched with crop requirement, runoff and deep drainage are minimised. Furrow with optimised volumes which minimise excess run off & deep drainage metering	Continual measurement of application volumes fed into automated control system. Drip, overhead or optimised furrow irrigation to match crop requirements and minimise loss to deep drainage Metering and pump audits
4.2 Scheduling	Scheduling by guesswork or set cycle.	Simple/ limited soil moisture monitoring. Some scheduling efforts (minpans)	Soil moisture monitoring tools across irrigation management zones to determine irrigation timing. Quantitative scheduling and soil moisture monitoring	Quantitative scheduling and soil moisture monitoring and precision water application across soil type or management zones using software
4.3 Furrow shape & length	Inappropriate furrow shape and length for soil type. No adjustment of furrow shape and length to soil type	Appropriate furrow shape for soil type	Appropriate furrow shape and length for soil type and slope.	Same as B
4.4 Runoff management Drainage	No laser levelling. none	Laser levelling. Recycle pit on suitable soil types unable to capture all irrigation runoff. Laser leveling only	Recycle pits on suitable soil types capable of capturing all irrigation runoff and sufficient pumping capacity to reuse. Meets approved design guidelines for recycle pits. Recycle pits on suitable soil types capturing first flush	Same as B plus pit bypass overflow
4.5 timing After fertilising	No consideration of timing of fertiliser and herbicide application relative to irrigation. none	Herbicides delayed based on label recommendations. none	Delaying irrigation application after fertiliser as long as possible. Delayed 2-5 days depending on soil type post fertilizing	Same as B

4.6 Irrigation Application Efficiencies (%) * New category in 2013	<40 Delta	40-60 Delta	60-75 Delta	>75 Delta
	<50 BRIA	50-70 BRIA	70-85 BRIA	>85 BRIA
Record Keeping				
5.1 All Farm Records	No written/documented records.	Basic record keeping using a farm diary and spray log book.	BSES paddock journal or better and spray log book. Simple water quality monitoring of water leaving the farm. ABCD Management Practices Same up to simple …	Farm management software incorporating spray logbook. More detailed water quality monitoring of water leaving the farm. Same up to more …

* Numbers are based on 20 years of accumulative project data including SIMROD runs and local knowledge. Irrigation efficiencies are a guide and may differ between blocks or between irrigations within blocks.

Source: NQ Dry Tropics (2013)

Terrain NRM is currently updating Water Quality Improvement Plan for the Wet Tropics region with an expected release for 2015. The management practices classified using the ABCD framework was updated for phase 2 of the Reef Rescue/ Reef Water Quality grants programme in 2014 and are shown below in Table 17 in black text. The red text indicates the practices as they were described in 2009 and differ from the current description.

Table 17: ABCD framework of management practices for sugarcane growers in the Wet Tropics region

Management Practice	D	C	B	Uncertain/Aspirational
Nutrient management				
CN1.0 Soil Testing MA: Extension	Not done	Once per crop cycle per soil type	At least once per crop cycle for every plant cane block irrespective of soil type	in specific areas within blocks at least once per crop cycle in relation to soil and yield mapping. Frequent soil sampling in specific areas within blocks at least once per crop cycle
CN 2.0 Nutrient rate assessment MA: extension	Application rates not in line with 6ES Application rates based on old industry recommendations	Use latest industry recommendations (6ES) based on advice (No Nutrient Management Plan (NMP))	Completed 6ES and developed and implemented a NMP and associated recommendations 2009 did not include 'and associated recommendations'	Develop GIS based NMP using yield potential, soil mapping and specialist interpretation of latest industry recommendations including the use of slow release fertilisers. 2009 did not include 'including the use of slow release fertilisers
CN3.0 Rate of fertiliser use MA: Extension & investment	One fixed rate for plant and one for ratoons based on historic application rates or rule of thumb	One rate for plant and another for ratoons based on 6ES 2009 had 'on soil tests/soil type' instead of 6ES	Variable rate between blocks based on all 6 components of 6ES Variable rate between blocks based on soil test, varieties, plant/ratoon including: • 6ES principles • And specialist interpretation of results or from training	Variable rate within blocks based on all 6 components of 6ES and where the basis of variability in the block is accurately identified. Variable rate within blocks where the basis of variability is identified.
CN4.0 Timing of fertiliser application MA:extension	Weather only impacts on ability to do application at the time.	Follows weather (i.e. 4-5 days ahead) but does not consider crop stage or time of year. 2009 did not have 'time of year'	Timing of nutrient applications with respect to proximity to the start of the wet season, crop stage, irrigation and weather conditions. 'proximity to the start of the wet season' not in 2009	Climate forecasting (i.e. 2-3 months ahead) used in determining the timing and amount of fertiliser applied. 2009 included 'along with crop stage, irrigation and weather conditions'
CN5.0 placement of fertiliser MA: extension & investment	Surface applied using broadcasting methods	Surface applied, on the row only Surface applied including liquids using banding methods	Sub-surface applied beside the stool (or surface applied on the row, only where rocks or other block characteristics prevents sub-surface application). Sub-surface applied within the stool	Applies fertiliser sub surface within the stool using a stool splitter where topography and soil type allow, taking into account the types and form of fertiliser

			by stool splitter or similar modified equipment Applies fertiliser subsurface beside the stool (or banded where soil type (stony) and slope prevent subsurface application).	
CN29.0 Placement of fertiliser (overhead irrigation only) MA: investment	Broadcast a single application of N fertiliser	Band a single application of N fertiliser over the stool	Apply a single application of N fertiliser sub-surface either within the stool or beside the stool	Apply N fertiliser via the irrigation water (fertigation) using split applications.
CN6.0 Calibration of fertiliser applicator MA: extension& investment	No calibration of equipment done	Calibrates once per season for each fertiliser product	Calibrates for each product and batch and monitors application Calibrates own fertiliser box each product and batch	Calibrated electronic rate controller used and outputs monitored. No A practice in 2009
CN31.0 application of mill mud/ash Not included in 2009 MA: investment	Application without rate control and at rates over 100t per ha N/A Does not apply mill mud on farm	Application with or without rate control at rates lower than 100t per ha	Variable rate mill mud application at less than 100t per ha. Applied to stool only when used n ratoons or plant.	Variable rate mill mud application at less than 100t per ha using GPS and site specific applications. Applied to stool only, when used in ratoons or plant.
CN23.0 Leaf Testing not included in 2015 but in 2009	Not considered worthwhile	Leaf test sampling frequency once per crop cycle per soil type	Leaf test sampling frequency at least once per crop cycle per block	Leaf sampling in specific areas within the block
CN 7.0 General Nutrient Management		Application rates taking nutrient contributions from mill by products and legumes into account	Site specific and tailored application of ameliorants such as lime and mill products are based on soil test Banded surface application only if stony soil or is the second part of a late split application	Electro-magnetic mapping used to determine best use of soil ameliorants Infield monitoring of yield Controlled release of nitrogen products used
CN8.0 Managing Legume Nitrogen contribution MA: extension& investment	Legumes disced in weeks before planting N/A fallows but does not use legumes N/A Does not usually have a fallow area	Mulching or discing-in of legume crop just prior to planting No D or C practices in 2009	Spray out/slash legume crop and residue left on the surface until preparing for planting. May include mulching depending on degree of. First sentence above + use adequate nutrition for legume crops based on soil test, and applied before planting.	Leaves legume stubble standing and direct drills plant cane. No A practices in 2009
Weed Management				
CP10 Herbicide strategies This was included in 2009 – not in 2015	One herbicide recipe used for the whole farm based on historic application rates or rule of thumb	Flexible herbicide recipe but applied across whole farm	Different herbicides between blocks appropriate to weed species in those particular blocks	Different herbicides for different weeds within blocks
CP11 Weed Management planning This was included in 2009 – not in 2015	Spray in response to weeds	Basic weed management plan developed and implemented at the time of application	Integrated weed management plan developed and implemented taking the crop cycle, weed type, pressure and timing into account	Identify weeds using a survey of types/pressure and soil types within blocks for GIS based weed management plan.

CP10 Residual Herbicide use in plant cane MA: extension Not included in 2009	Residual herbicide applied at full label rates and whenever convenient rather than in response to weed size & type or timing of the wet season.	Residual herbicide applied at rates appropriate to weed size and type but applied right up to the commencement of the wet season	Residual herbicides are applied with extra caution after October to avoid use close to heavy rainfall events. Herbicides (& their break down products), with proven lower toxicity and shorter half-lives, are used instead wherever possible.	Residual herbicides used sparingly and in conjunction with sophisticated weather forecasting to avoid use close to heavy rainfall events. Herbicides (& their break down products), with proven lower toxicity and shorter half-lives, are used instead wherever possible.
CP33 **Residual Herbicide use in ratoons** MA: extension Not included in 2009	Residual herbicide being applied whenever seen as likely to be effective.	Residual herbicide applied only once on each ratoon crop with knockdowns used at other times	Residual herbicide only used in ratoons on problem blocks & on less than 10% of total ratoons area.	Residual herbicide not applied to ratoon crops at all
CP34 **Knockdown Herbicide used in plant cane** MA: extension& investment Not included in 2009		Whole area of plant cane sprayed with broad-spectrum brew covering broadleaf's and grasses	Broadleaf weeds & grasses targeted separately by sprayer with two tanks & directed sprays.	Weed recognition on all spray equipment allowing targeting of particular weeds with relevant chemicals.
CP35 Knockdown use in ratoons MA: extension& investment Not included in 2009		Whole area of ratoon cane sprayed with broad-spectrum brew covering broadleaf and grasses	Broadleaf weeds & grasses targeted separately by sprayer with two tanks & directed sprays.	Weed recognition on all spray equipment allowing targeting of particular weeds where relevant
CP12.0 Herbicide Application Timing MA: extension	Applies at a time when it has become a salvage operation No D practice in 2009	Timing of herbicide applications with regard to e.g.: • crop stage • weed size, • soil-moisture • trash & canopy cover • temperature • irrigation but only taking weather conditions at the time into account uses correct application timing only taking into account weather conditions	Timing of herbicide applications as in 'C' below, in conjunction with short-term Weather forecasting (7+ days) to avoid application close to heavy rainfall events. Timing of pesticide applications with regard to crop stage, weed size, irrigation, rainfall and effectiveness.	Timing of herbicide application as in 'C' below, in conjunction with best available long-term weather forecasting to avoid or minimise use of residual herbicides within 30 days of the onset of the wet-season. No A practice in 2009
CP 13.0 Herbicide rates Not in 2015	Often uses at maximum label rates residual and knockdown products irrespective of weed type and pressure	Uses residual and/or knockdowns at rates appropriate to weed type according to label specifications but on all crop classes	Use residuals at correct timing and label rates in plant cane and fallow crops but not on trash blanket (knock downs replace residuals in ratoons)	No practice A
CP14.0 Calibration MA: extension& investment	Occasional calibration and maintenance of equipment Limited instead of occasional in 2009	Regular calibration and maintenance of equipment Calibrated for each situation (product and water rate) with appropriate nozzles	Manually calibrated for each situation (product and water rate) with appropriate nozzles and technology.	Calibrated electronic rate-controlled equipment used with latest application technology such as air inducted nozzles.

			Implements proven up to date application technology for efficient placement and timing e.g. air inducted nozzles, rate control)	Mixes chemicals on the machine at time of application using appropriate equipment.
CP36 Spraying equipment MA: extension& investment Not in 2009	Uses boom spray for all spraying operations with only one tank and applies mixes to whole farm.	Uses boom spray for all spraying operations with residual/knockdown mix but targets weeds by block	Uses directed sprays or hoods and two tanks with separate application capacity to control weeds.	Precision spot-spraying using image analysis for weed recognition. Likely includes use of GPS guidance.
CP37 Weed control in the fallow – flooding likely MA: extension Not in 2009	Mechanical plough-out and maintain bare fallow. N/A No fallow	Mechanical plough-out followed by grassy fallow.	Spray out cane & retain trash blanket. Continued weed control (spray) when necessary.	
CP38 Weed control in the fallow – flooding unlikely MA: extension Not in 2009	Bare or Grassy Fallow N/A No fallow used	Cultivate block then plant legumes.	Zonal-till old stool prior to zonal planting of legumes. Continued weed control within legume crop	Spray out cane and direct drill with legumes. Continued weed control within legume crop.
CP 15.0 General Herbicide Issues Not in 2015	No practice D listed	Chemcert qualified and up to date	Keeps records of wind speed, direction, time & date of spraying, herbicide rate & weed pressure Knockdown herbicides used with shielded sprayer where effective to replace residuals in ratoons	Spot spraying using weed recognition by image analysis
Soil Management				
CS16.0 Row Spacing (compaction) MA: investment	Uses row spacing below 1.65m No D practice in 2009	Uses row spacing between 1.65 m and 1.75m without GPS Conventional (less than 1.8m) row spacing	Uses row-spacing between 1.65 and 1.75 with GPS Controlled traffic with no GPS (at > 1.8m)	Controlled traffic > 1.75m with GPS guidance on all equipment used in the paddock (including harvester and haul outs) Controlled traffic with row widths determined by harvester wheel measurements with GPS guidance
CS39.0 Planting Method MA: extension & investment Not included in 2009	Cane planted after full cultivation across whole paddock (>5 passes), regardless of planter type.	Cane planted after minimum till across whole paddock (<5 passes) regardless of planter type,	Cane Planted into zonal-tilled row regardless of planter type (conventional, mound, DOP), with or without GPS.	Cane Planted using GPS guided, zero till, disc-opener cane planting (DOP). No subsequent cultivation.
CS17.0 Cultivation prior to planting MA: investment	Fully cultivated before planting (> 5 times)	Reduced tillage before planting (< 5 times) 2009 uses minimum instead of reduced	Zonal tillage before planting Renovates permanent beds followed by zonal tillage before planting 2009 does not include 2nd sentence	Zero till plant cane + using double disc opener for planting
CS 18.0 Tillage in ratoons **Not in 2015**	Cultivated ratoons	Zero till ratoons (excludes occasional strategic ripping of wheel tracks for drainage and compaction following late wet	No practice B	No practice A

		weather harvesting)		
CSL19.0 Legume Establishment Practices MA: investment	Fully cultivated, broad-spread legume fallow - not in 2009 N/A Do not use legumes Grassy fallow	Fully cultivated legume fallow on beds. 2009 did not have 'on beds'	Zonal-till legume fallow Zonal tillage legume cover crop	Zero till legume fallow (using direct-drill legume planter)
CSNL19.0 Non legume fallow practices MA: extension 2009 did not distinguish between non-legume and legume fallow – CS19.0 Fallow practices	Cultivated bare fallow N/A Uses legume fallow - not in 2009 N/A No fallow N/A Rotate with other crops on the farm – not in 2009	Stools sprayed out, grassy fallow on country that does not flood Spray out fallow (without legumes)	Stools sprayed-out, grassy fallow, on country that floods Not in 2009	
Q 24 CS20.0 Plough out replant policy MA: extension	Continual plough out replant used as a routine practice on most of farm	Occasionally use plough out replant as a practice	Plough out replant not used	
CS21.0 Riparian management MA: extension & investment	Riparian vegetation along natural waterways is sparse or non-existent Riparian vegetation generally removed N/A No natural waterways on farm Not in 2009	Riparian vegetation on >50%, but <100% of the length of natural waterways, managed by you. Riparian vegetation along natural waterways kept to a minimum	Native Riparian vegetation at <20m wide along 100% of the length of natural waterways managed by you Native riparian vegetation at a width and density which limits erosion and allows filtering of farm runoff along **sections** of the natural waterways on the farm	Native Riparian vegetation at 20m wide for creeks and 50m for major waterways along 100% of the length of all sides of all natural waterways managed by you. Native riparian vegetation at a width and density which limits erosion and allows filtering of farm runoff along **both sides** of all natural waterways on the farm
CSST22.0 Sediment risk management tools – silt traps Silt traps not specified in 2009 – all practices combined under Sediment risk management tools and all practices categorised as B MA: investment	N/A Not relevant on my farm Not in 2009	Silt traps are used to capture some sediment. Some sediment loss in heavy rainfall events still occurs. Not in 2009	Silt traps designed and used in appropriate locations on farm, based on professional advice. 'based on …' not in 2009 Farm layout optimised to minimise soil loss impacts using e.g. laser grading Erosion sites managed using methods derived from professional advice Permanent beds maintained with zonal tillage between crop cycles in a controlled traffic system	
CS40.0 Headland Management Included in CS 22.0 in 2009	Headlands are eroding and /or have poor groundcover.	Headlands grassed and maintained to minimise erosion.	All headlands are >5m wide, grassed, shaped and maintained to	

MA: extension	Not in 2009	Not in 2009	control water shedding, erosion and nutrient transport. Headlands at a level where they filter runoff but are not an impediment; grassed drains and waterways managed as grassed filter strips	
CSSD22.0 Shallow drains Included in CS 22.0 in 2009 MA: investment	N/A not relevant on my farm Not in 2009	Some shallow box drains on the farm needing battering or changing to a spoon drain Not in 2009	All shallow drains are spoon type where topography allows, are grassed and maintained. 'and maintained' not in 2009	All farm drains engineered and maintained to minimise erosion including large and common drains. (grassed or armoured) Not in 2009
CSDP22.0 Deep drains Included in CS 22.0 in 2009 MA: investment	N/A not relevant on my farm Not in 2009	Some deeper box drains on the property needing attention Not in 2009	All deep drains on farm are battered and stable through the use of rock armouring or vegetation. Deep drains stable and battered and vegetated	All farm drains engineered and maintained to minimise erosion using vegetation or rock. Not in 2009
CN 25.0 Irrigation scheduling MA: investment	Irrigation scheduled depending on water availability or set time cycle (e.g. time taken for irrigator to complete full cycle around farm)	Use subjective tools such as visual inspection of crop &/or soil to determine a need for irrigation	Use objective tools such as capacitance probes, tensiometers, gypsum blocks &/or evaporation pans to directly or indirectly measure changes in soil moisture to determine the weekly irrigation requirement for individual or multiple blocks (e.g. whole farm)	Use a tool such as "WaterSense" to integrate factors such as climatic conditions, soil PAWC & crop development to estimate daily crop water use and determine the weekly irrigation requirement for each individual block
CN26.0 Furrow design (applicable to furrow irrigation only) MA: investment	No land forming carried out and furrow shape and length not altered for different soil types	Slopes modified by land forming (not laser guided). Furrow shape and length not altered for different soil types	Laser guided land forming used to modify slope to industry recommendations based on soil type. Furrow shape & length modified to industry recommendations depending on soil type	Appropriate furrow shape, slope and length determined for each block using "SIRMOD". Land forming carried out with laser guided machinery
CN27.0 Irrigation distribution uniformity (re: overhead irrigation only) MA: investment	Distribution uniformity less than 60%	Distribution uniformity between 60% - 75%	Distribution uniformity between 75% - 90%	Distribution uniformity greater than 90%
CN28.0 Recycle strategy MA: investment		No recycling	All off farm water recycling strategy with a well-designed recycle pit on suitable soils (or suitable materials). 2009 also had 'that is empty at the end of an irrigation cycle' on the end of the above sentence	Recycle pit on suitable soils or materials, with first flush capture of water overflow

Record Keeping				
CR24.0 Record keeping	No record keeping	Detailed paper-based records of field activities & inputs (e.g. nutrient rates in kg/ha, types & rates of herbicides etc.) as well as mill-supplied production records Diary with basic records	Detailed computer-based records of field activities, farm inputs production results and monitoring data (e.g. soil analyses, weed-survey, water-quality) & any nutrient/weed management plans paper based records of block activities along with mill-supplied production records	As in B below, but including automated field data collection from tractor-mounted computers/controllers with associated recording and reporting functions. Computer based records covering all block activities and production, trends in soil nutrient content, weed survey data and water quality testing results.

Source: Terrain (2014) Wet Tropics Water Quality Improvement Plan November 2014

Note: 1. Each practice also has a corresponding category label C [letter representing category] [number identifying specific practice within a category]. This labelling was specific to Terrain NRM. 2. MA stands for method of application.

The Mackay Whitsunday Isaac (MWI) NRM plan for 2014 – 2024 specifies two key outcomes focused on the adoption of best management practices. The first is that ‘Landholders have capacity and knowledge to move towards implementation of evolving best management practice activities’ with the following management actions (MWI 2014: 73):

1. Improve land manager understanding of the key natural resource management issues impacting land and water resource health, and in moving from dated and conventional, to best management and innovative practices
2. Promote best management practice and the positive impact of this on water quality, soil health, ecosystem health and profitability
3. Create easy to access decision support tools at an appropriate scale
4. Identify impact of improved management practice on freshwater, estuarine and marine ecosystem health and undertake key indicator species monitoring to measure change.
5. Communicate impacts and uptake of best management practice throughout industry and the community.
6. Develop catchment based models of improved environmental outcomes resulting from implementation of best management practice, which can integrate farm and catchment scale monitoring.
7. Deliver activities that invest in and promote irrigation and water best management practice, increasing adoption of water management action plans.

Second, that ‘Continuous improvement of best management practice to reflect innovative science, knowledge and practice’ is achieved through the following management actions (MWI 2014: 73):

8. Support industry and landholders in identification of innovative practice via research and development to enable continual improvement of best management practice standards.
9. Promote new innovative solutions as they emerge via agricultural industry groups and networks.
10. Update ABCD frameworks and the definition of best and aspirational management practices according to prevailing technologies and achievements
11. Development of best management practice frameworks for a range of other activities, such as integrated pest management activities for the management of high priority pest plants and animals.
12. Support land managers to document, monitor, evaluate and thus constantly improve farm based practices to be in line with known best management practice.
13. Explore incentives such as environmental stewardship payments for those participating in increasingly innovative practice.

The most recent document for improved management practices for the MWI region was released by DAFF (2013) and is shown below in Table 18. The latest ABCD management practices are compared with 2009 ABCD management practices in red.

Table 18: ABCD framework of management practices for sugarcane growers in the Mackay region

Management Practices	D - Degrading	C - Code of Practice	B - Best Practice	A - Aspirational
Nutrient management				
1.1 Nutrient rates	No accounting for mill-by products or other organic sources of nutrients such as legumes. One rate for whole farm	Application rates based on soil test analysis and current industry recommendations. Mill-by products or other organic sources of nutrients such as legumes only accounted for as required. One or two rates for whole of farm Application based on old industry recommendations	Application rates based on latest industry recommendations taking mill by-products, compost, other organic nutrient sources and block history into account As above up to by-products then has – and fallow history into account Application of mill mud/ash should not exceed crop cycle nutrient requirements and be directed to the planting zone. Not in 2009 Apply different nutrient programme (fertiliser rates or products) between blocks where identified. Variable rate between blocks Change fertiliser rates between blocks	Application rates based on specialist interpretation of the latest industry recommendations using individual block yield potential and taking mill by-products, compost other organic nutrient sources into account. Same up to using Application of mill mud/ash should not exceed crop cycle nutrient requirements and be banded on planting zone. Apply variable nutrient application programme (fertiliser rates or products) between and within blocks where identified. Variable rate within blocks
1.2 Planning	No soil testing not in 2009 Application rates based on historic rates or rules of thumb	Sample representative soil types prior to planting. Some soil testing Conduct soil tests Develop basic nutrition management plan	Identify soil types/productivity zones for each block. Geo-referenced soil sampling in key soil types in blocks prior to planting each year, which may include more comprehensive sampling (e.g. A and B horizon at the same site) not in 2009 Develop Nutrient Management Plan using varieties, yield, soil mapping and latest industry recommendations. As above but minus varieties Soil test fallow blocks each year Knowledge of latest NM issues and recommendations Conduct soil tests (and leaf analysis if required) Adjust nutrient rates for next year if required	Geo-referenced soil sampling in identified, specific zones in blocks each year, which includes more comprehensive sampling (e.g. A and B horizon at the same site). Identify soil types/productivity zones within each block using GPS yield and soil mapping same in 2009 Develop spatial –based crop cycle Nutrient management Plan using varieties, yield, soil mapping and specialist interpretation of latest industry recommendations. As above but without crop cycle or varieties Knowledge of latest nutrient management issues and recommendations same Some basic/periodic water quality monitoring same Near infra-red (NIR) data or leaf analysis used to adjust nutrient rates same Soil sample specific areas within

				block
1.3 Timing	No risk assessment conducted prior to fertilizing – none in 2009	Some risk assessment conducted prior to fertilizing (48 hour rainfall prediction) None in 2009	Timing nutrient applications with respect to crop stage and rainfall probabilities As above in 2009 but includes irrigation Legume crops incorporated as close to planting as possible to maximise nutrient availability. Risk assessment conducted prior to fertilizing (48 hour rainfall prediction, weekly forecast, seasonal predictions).	Timing nutrient applications with respect to crop stage irrigation and rainfall probabilities. Same Legume crops left as stubble or incorporated just prior to planting as possible to maximise nutrient availability. Use of new fertiliser products such as slow release or polymer coated urea in higher risk areas or during identified higher risk times. Detailed risk assessment conducted prior to fertilizing (Safeguage for Nutrients, 48 hour rainfall prediction, weekly forecast, seasonal predictions etc.)
1.4 Placement		If surface applied, irrigated/cultivated into soil where possible surface applied and irrigated into soil	Incorporation of surface applied fertiliser as soon as practicable (e.g. within seven days) using overhead irrigation that does not result in run off. None in 2009	The majority of nutrients sub-surface applied where practical Incorporation of surface applied fertiliser within seven days using overhead irrigation that does not result in run off. None in 2009
1.5 Calibration	No calibration of equipment None 2009	Some calibration of equipment None in 2009	Calibration of fertiliser applicator with some changes of product and monitored during operations. None in 2009	Calibration of fertiliser applicator with every change of product or application rate. None in 2009
Machinery	Surface fertiliser box Surface or sub-surface fertiliser box	Surface or sub-surface fertiliser box (granular) As D plus or surface applied and irrigated into soil.	Ability to adjust rate for granular or liquid applicators. Directed applicator for mill by-products or other organic ameliorants. Granular applicators must have capacity for sub-surface application. Granular: sub surface fertiliser box with rate control	Variable rate applicator for granular sub-surface or liquid surface with remote/automatic rate controller and GPS guidance Banded on-row applicator for mill by-products or other organic ameliorants. Sub-surface variable rate fertiliser box with remote/automatic rate control and GPS guidance
Pesticide management				
2.1 Use of Residuals			Residual herbicides used where weed species and pressure demands it and incorporated as soon as practicable after application. Knockdown herbicides replace	Knockdown herbicides replace residual herbicides in the inter-row and also where practical (residual herbicides only used where weed species and pressure demands it) within blocks.

			residual herbicides where practical such as in the inter-row same as 2009 (except interow)	Same as B in 2009
2.2 Chemical rates/application	Often uses maximum label rate residual and knockdown products, irrespective of weed pressure. Same in 2009	Uses residual and/or knockdowns at rates appropriate to weed pressure. same as 2009	Change herbicide strategy between blocks where identified.same as 2009 (under planning) Efficient use of pre-emergents to reduce overall chemical application. Use only non-mobile per-emergents at correct timing and correct label rate. Efficient use of per-emergents will lower overall chemical application. Avoid resistance issues. Enable correct application timing in wet weather. Implementation of new application technology for improved placement (banded/directed spray) and timing (low drift nozzles, high rise equipment etc.) allowing a number of herbicide strategies across the farm. Same as 2009 except includes examples and instead of 'allowing …' has 'to improve application efficiency, accuracy and to extend the window of opportunity.'	Change herbicide strategies within blocks where identified (e.g. weed pressure on row ends; patches of weeds/vines; turning nozzles on/off). Same as 2009 Efficient use of pre-emergents to reduce overall chemical application. Same as B in 2009 Implementation of new application technology for improved placement (banded/directed spray) and timing (low drift nozzles, high rise equipment etc.) allowing a number of herbicide strategies across the farm.
2.3 Timing	No risk assessment conducted before spraying None in 2009	Some risk assessment conducted before spraying (48 hour rainfall prediction, wind speed and direction) None in 2009	Risk assessment conducted prior to spraying (48 hour rainfall prediction, wind speed and direction, weekly forecast, seasonal predictions). Timing chemical applications with respect to crop stage, irrigation and rainfall probabilities. same as 2009 Adjust herbicide strategy during crop cycle if required.	Detailed risk assessment conducted prior to spraying (48 hours rainfall prediction, wind speed and direction, weekly forecast, seasonal predictions, Safeguage for Pesticide). Same as B in 2009 Adjust herbicide strategy for whole of crop cycle
2.4 Calibration	No calibration of spraying equipment None in 2009	Calibration of spray equipment conducted regularly. None in 2009	Calibration of spray equipment conducted before every change of product or nozzle type. None in 2009	Calibration of spray equipment conducted before every change of product or nozzle type. None in 2009
2.5 Planning	One herbicide strategy for the whole farm based on historic application rates or rules of thumb. Same in 2009	One or two herbicide strategies for the whole farm same as 2009 Develop basic Herbicide Management Plan same as 2009	Identify – weed types/pressure, soil types and productivity zones for each block same as 2009 Develop herbicide management plan using weed pressure, soil types, crop stage, yield mapping and appropriate chemicals same as	A focus on good weed control in fallow and plant cane to ensure minimal herbicide in ratoon stages. Identify – weed types/pressure, soil types and productivity zones within each block using GPS yield and soil mapping. Weed survey of blocks

			2009 except for appropriate chemicals PLUS Formulate best practice pre-emergent management plan avoiding the use of mobile pre-emergents (e.g. Diuron & Atrazine) Maintain some knowledge of latest chemical management issues and recommendations Some monitoring of weed pressure same as 2009 except not some A focus on good weed control in fallow and plant cane to ensure minimal herbicide in ratoon stages. Same as 2009 PLUS Variable herbicide strategies between blocks Attend herbicide management course. Attend spray nozzle technology workshop Adjust herbicide strategy for next year if required Keep records in paddock journal (including yield), including wind speed, direction, time of spraying, herbicide and rate	Develop GPS herbicide management plan using weed pressure, soil types, crop stage, and yield mapping
Machinery	Standard spray rig, with conventional nozzles Standard spray rig both high and low clearance	Standard spray rigs, with a range of nozzles for various application tasks. Same as D class	Standard and/or modified spray rigs, with a suitable range of appropriate nozzles (low drift, air injected etc.) for various application tasks, an ability to do some banded or directed spraying and a manual rate controller Shielded sprayers and/or high clearance spray equipment for applying knockdown chemicals in the inter-row or at out of hand stage. Multiple tanks for spraying different chemicals simultaneously. Hooded sprayers, more accurate nozzles (matched to job) and high clearance tractors with manual rate of control	Modified spray rigs with a wide range of appropriate nozzles (low drift, air injected etc.) for various application tasks, an ability to do all banded or directed spraying and a remote/automatic variable rate controller with GPS guidance. Shielded sprayers and/or high clearance spray equipment for applying knockdown chemicals in the inter-row or at out of hand stage. Automated boom height control. Weed scanner/sensing equipment. Multiple tanks for spraying different chemicals or other operation such as chemical injection. Same as B but with remote/automatic rate control and GPS guidance
Soil Management				

3.1 row Spacing & Guidance	Machinery and equipment does not match crop row spacing	Harvester and haulout equipment does not match crop row spacing	Controlled traffic permanent wheel tracks matched to harvesting machinery wheel centres Controlled traffic permanent beds maintained by zonal tillage Permanent bed widths determined by harvester wheel centre measurements	Controlled traffic permanent wheel tracks matched to harvesting machinery wheel centres with GPS auto guidance systems used on bed formers, planting, zonal tillage, harvesting and haulout machinery. Controlled traffic permanent beds with GPS guidance of planting zonal tillage, harvesting and haulout machinery.
3.2 Plant Cane Establishment	Fully cultivated plant cane	Reduced cultivation of plant cane replaced by strategic chemical weed control	Initial row establishment formed with GPS guidance as minimum Strategic or zonal tillage of fallow crops and plant cane including bed renovation Strategic or zonal tillage of fallow crops and plant cane	Strategic or zonal tillage of fallow crops and plant cane including bed renovation as required Develop variable rate application programme
3.3 Ratoons	Cultivated ratoons.	Strategic ripping of wheel tracks in ratoons	Strategic ripping of wheel tracks in ratoons, only when necessary	
3.4 Fallow	Cultivated bare fallow. as above plus or 'plough out and replant'	Minimum tillage bare fallow with chemical weed control. Rotational crops may be grown not in 2009	Rotational crops grown on all fallow where practicable and managed to retain some ground covers Strategic or zonal tillage of fallow crops and plant cane including bed renovation Strategic or zonal tillage of fallow crops and plant cane	Rotational crops grown on all fallow where practicable and managed to maintain good ground cover until planting
3.5 Ameliorants	none	Broadcast application of ameliorants (ash, lime, gypsum, etc.) none	Site specific application of ameliorants applied based on soil mapping. none	Site specific banded application of ameliorants based on specialist recommendations from soil mapping and analysis. Site specific application of ameliorants and mill by products
3.6 Trash Utilisation and Harvesting				Utilisation of harvesting technology to reduce impact on crop and soil condition Not in 2009
3.7 Headlands			Headlands, drains and waterways managed as filter strips	Headlands, drains and waterways managed as filter strips
Machinery	Standard equipment	Standard equipment	Matched wheel spacing for planting equipment based on harvesting machinery wheel centre measurements GPS guidance on row	Minimum till rotational crop and cane planting equipment (e.g. Double Disc Opener Planters). Automated base cutter height fitted to harvester

			establishment equipment Zonal tillage equipment Rotational crop establishment equipment Standard wheel spacing based on harvester wheel centre measurements GPS Guidance on bed formers, planting equipment and cane harvester Automated base cutter height on harvesters Yield monitors fitted to harvesters	Yield monitors fitted to harvester Standard wheel spacing on all equipment GPS auto guidance systems on bed formers, planting equipment, and harvesting machinery inc haul outs
Water and Irrigation Management				
4.1 Matching water use to crop requirement	Irrigations based on gut feel same as 2009 Application amount unknown same as 2009 no consideration of matching nozzles to pump same as 2009	Irrigation strategy based on length of cycle to get around farm and/or prioritized on crop cycle (e.g. plant cane, 1st ratoon over 5th ratoon). How long it takes to get around Irrigation strategy sometimes matched to water availability. water availability Based on experience same as 2009 Amount often unknown, loosely determined by pump meter reading/time/ha same as 2009 No efficiency checks conducted on equipment same as 2009 May change nozzles to match pump size and pressure. Same as 2009 Limited water quality testing conducted on some irrigation water sources	Irrigation strategy based on crop growth requirements and matched to water availability Irrigation strategy includes the incorporation of the majority of nutrient and chemical applications where possible. System efficiency checks conducted annually same as 2009 Application amount matched to soil plant available water capacity (PAWC), infiltration rate and crop stage. Application amount determined through management plan – an informed decision Water quality testing conducted on some sources of irrigation water such as bores. Water testing incorporated, mainly for on-farm use Water tests conducted where an impact on application amount is applicable e.g. EC and infiltration/holding capacity	Irrigation strategy based on crop growth requirements and matched to water availability. Irrigation strategy includes the incorporation of the majority of nutrient and chemical applications where possible. Water quality testing conducted on all sources of irrigation water. Application amount matched to soil plant available water capacity (PAWC), infiltration rate and crop stage Application amounts matched to soils with a high degree of precision, possible using EM mapping or equivalent. Software such as TravGun, SIRMOD, IPART used System efficiency checks conducted annually same as 2009 Use of low pressure overhead and trickle irrigation systems. Possible fertigation technology through irrigation equipment. Water testing incorporated, mainly for on-farm use (same as in B 2009)
4.2 Scheduling	No scheduling tools utilized same as 2009	Scheduling based on visual checks visual checks – experience	Scheduling tools used manually on main soil type or limiting soil type same as 2009 up to 'on main …'	Software scheduling tools used Scheduling tools utilised with some level of automation. same as 2009

			Tools broadly used e.g. to main soil type or limiting soil type	Scheduling tools located based on block/management units or specific soil types same as 2009
4.4 Runoff management	Basic drainage considered in original farm layout same as 2009	Existing farm layout and infrastructure considers drainage – laser levelling. same as 2009	Existing farm layout and infrastructure considers drainage – laser levelling Storm water storages/sediment traps part of drainage system same as 2009	Comprehensive drainage plan considering all farm drainage points. Same as 2009 Storm water storages/sediment traps part of drainage system
Planning	No recording or planning for water management	General knowledge of local rainfall history Irrigation systems may not match soil and topography Some consideration due to soil type – mainly textural same as 2009 Consideration to land formation and slope same as 2009 Basic understanding of soil moisture characteristics – based on texture rather than scientifically determined PAWC Planning based on verification of meter readings, not measured system outputs Planning based on productivity potential, e.g. favour plant cane, disregard rubbish cane Planning based on amount of effort required, e.g. it may be more efficient to water over three nights but more labour intensive.	Weather forecasting models used climate forecasting models used Irrigation strategy developed for each crop year irrigation scheduling plan for each crop year Irrigation systems match soil and topography Block based water management plan encompassing: soils; scheduling; efficiency – system check; allocation; farm layout and infrastructure; economics. Water management plan encompassing: soils; scheduling; efficiency – system check; allocation; farm layout and infrastructure; economics	Weather forecasting models used Irrigation strategy developed for each crop year Soil type based water management system encompassing: soils; scheduling; efficiency – system check; allocation; farm layout and infrastructure; economics. Irrigation systems match soil and topography Comprehensive knowledge of soil and water interactions: certificate in irrigation management
Planning and Record Keeping				
5.1 All Farm Records	Records kept in head	Written records kept Meet legislative requirements and minimum accreditation and competency standards for chemical storage, application and disposal. Keep material safety data sheets (MSDS) Water meter readings recorded in pocket diary Records kept in head (water management)	Identify soil types and productivity zones using existing maps, digitised mill data and other technology EM technology GPS Technology for spatially identifying problem areas Develop computer skills enabling access to digital mill data and GIS software Develop basic 'soil management plan' utilising soil mapping (slope, soil type, flooding, specific soil problems)	Spatially identified soil types and management zones across blocks and farms utilizing remote sensing and Electro Magnetic (EM) soil mapping technology Integrate a spatial based Soil Management Plan, addressing Land and Water Management Plan (LWMP) or current environmental risk management criteria Same as above up to SMP Geo-referenced spatial data captured in GIS software systems

			As above but finish at mapping Records kept in paddock journal and/or electronic data capture records kept in paddock journal Meet legislative requirements and minimum accreditation and competency standards for chemical storage, application and disposal. not in 2009 For water management – comprehensive recording system: paddock journal; recording format is able to be collated and analysed Building knowledge of soil and water interactions: industry training; soil mapping	Records kept in electronic data capture Keep records in computer database /paddock journal Production of harvester yield maps not in 2009 Comprehensive records kept using spatial software

Source: adapted from DAFF (2013) to be consistent with headings used from other BMPs for water quality outcomes and does not include ABCD framework as applied to Harvesting, Workplace Health and Safety, Business and financial management practices.

Appendix 3 Smart Cane BMPs (three key reef water quality modules of seven BMP modules)

Table 19: Smartcane BMP management practices

Key areas	Below industry standard	Industry standard	Above industry standard
Soil Health and Nutrient Management			
Managing compaction	Row spacing is not matched to wheel spacing Machinery is operated in wet field conditions	Row spacing and most machinery wheel spacings are matched, initial row establishment formed GPS guidance. Where possible machinery operations are delayed to avoid operating in wet field conditions	Row spacing and all machinery wheel spacings are matched, GPS guidance is used for all field operation: bed forming, planting, spraying and harvesting. Machinery is not operated in wet field conditions
Trash management	Cane is burnt prior to harvest and trash is raked and burnt after harvest or Cane is burnt prior to harvest or Green cane trash blanket is burnt after harvest or Green cane trash blanket is incorporated after harvest or Green cane trash blanket is raked and baled after harvest	Green cane trash blanket is retained on suitable soils. In cold environments trash is raked from the stool and maintained in the interspace or cane is burnt prior to harvest. Where a water logging risk exist, cane is burnt prior to harvest	Green cane trash blanket is retained throughout the crop cycle and after the final ratoon as fallow cover
Fallow management	Fully cultivated bare fallow over the wet season where weed growth is controlled by a series of cultivations or No fallow period is used as plough-out replant is practiced	Soil cover is maintained throughout the wet season either through the use of a trash blanket and sprayed out cane or through the growth of a fallow crop like legumes No living cane is present during the fallow period to break pest and disease cycles	Well managed rotational crops are grown on all fallow land to break weed and pest cycles Residues from rotational crops are maintained on the soil surface and not incorporated between crop cycles (Cane is zero till planted into rotational crop stubble)
Preparing land for planting	Plant cane is established using excessive cultivation, soil is cultivated to a fine tilth through multiple machinery operations	Plant cane is established after a fallow using zonal or minimum tillage. Tillage methods minimise soil structural damage and compaction	Plant cane is established after a fallow using zero tillage
Tillage management in-crop	Multiple tillage events in both plant and/or ratoon crops are conducted. Soils in crop are tilled to a fine tilth which is prone to soil erosion and encourages soil structure decline. No ground cover present in crop	Tillage in plant cane is kept to the minimum necessary to establish row profiles and irrigation furrows and to apply fertiliser and pesticides For GCTB – no tillage in ratoons other than fertiliser and pesticide applications is used	Cultivation in plant and ratoon crops limited to coulter applied fertilisers and pesticides. Preformed beds used in plant cane
Managing salinity and sodicity	The presence / risk of salinity and sodicity is unknown Or No specific management of a known salinity and sodicity risk is practiced	The presence / risk of salinity and sodicity is determined and monitored through the use of soil tests and on-farm management practices including application of soil ameliorants. The quality of irrigation water and its effect on the presence / risk of salinity and sodicity is considered and managed	Where the presence / risk of salinity or sodicity has been identified, regular monitoring of root zone soil and water conditions is conducted. Current knowledge regarding local shallow groundwater conditions is used to manage salinity
Soil Sampling	No regular soil sampling programme prior to planting	Soil sampling that meet industry and legislative requirements are collected from blocks to be planted and sent for analysis. Records kept refining future nutritional programmes.	Soil types are mapped and management zones developed and soil samples are collected for each management zone. Location sample sites are recorded to identify trends in the fertility
Calculating optimum nutrient rate	General rule of thumb determines applied nutrient rate	Regulatory minimum (for growers in Wet Tropics, Burdekin, Mackay-Whitsundays): The regulated method is used to develop nutrient programme for	6ES Nutrient Management programme is used with nutrient rates based on farm or sub-district yield potential. And Mechanisms to more closely

		N & P. For N, district yield potential is used with adjustments made according to the N mineralisation index of soils which is based on OC%. Other sources of N including from irrigation water, mill mud and legumes are voluntary deductions. OR 6ES Nutrient Management programme is used	match nutrient rates to crop requirements (improved nutrient use efficiency) are explored.
Placement of fertiliser	Fertiliser is applied on the surface, and not incorporated. Mill mud is applied broadcast in ratoons	On steep slopes only (i.e. Innisfail on Red Ferrisol soils), fertiliser is applied banded on the surface. Apply when crop root system has developed. Mill by-products are applied on the row, not in the interspace. or Granular fertilisers are applied subsurface in the drill (i.e. stool split or side banded). Mill by-products are applied on the row, not in the interspace. or Surface-banded applied fertiliser products are incorporated by overhead irrigation as soon as possible or within 7 days. Mill by-products are applied on the row, not in the interspace. or Liquid fertiliser products are applied subsurface, or on the surface only under pressure. Mill by-products are applied on the row, not in the interspace.	
Timing of application	Fertiliser is applied soon after harvest before the new root system has developed. And / Or All fertiliser for the plant crop is applied in one application.	Apply fertiliser six to eight weeks after harvesting or when cane is approximately 600mm high on early- to mid-season cut cane where practical. And if late cut cane, apply when practical taking weather into consideration. Never apply fertiliser when runoff from storms is expected before the nutrient can penetrate to the root zone.	
Calibration of application equipment	Equipment is calibrated annually or less	Application equipment is calibrated prior to the season and at each product and batch change	Use of correctly calibrated automatic controllers and variable rate application equipment
Record keeping	No records kept of nutrient management	Records are kept of soil tests, application rates, products, placement, calibration of equipment and person applying. Records are used to review and modify future nutrient management	Records are kept in digital form linked by GPS for operations and used to monitor and modify future nutrient management.
Integrated Pest Management			
Cane grub Management	Insecticides are routinely applied to the whole farm regardless of grub pressure. OR • Cane grubs are NOT managed either through ignorance of their presence and economic impact or by deliberate action.	Cane grub control decisions are based on monitoring plant damage, and/or on risk assessment based on soil texture, proximity to known adult feeding sites and topography • Grub species has been identified	Grub management plan is developed based on monitoring grub levels and plant damage and applying an individual block risk assessment framework, including paddock history.

Rat Management	No control or monitoring of rats	Both in-crop and harbourage areas are managed to avoid build-up of rats.	Rat populations are monitored and managed through harbourage management and baiting as required.
Other Pests	Farm practices encourage other pests	Presence of or potential presence of other pests is known and management practices carried out as required.	Management programme based on risk assessment of specific pests
Weed Management	Weed management strategies are generally based on historic application rates or rules of thumb without consideration of weed species mix, or level of potential infestation or environmental considerations.	Weed management plan is developed and implemented in line with the SRA weed plan template and key considerations	Integrated weed management plan is developed and implemented Yield maps used to determine low production areas more susceptible to weed incursions. Herbicide selection influenced by soil texture data derived from ground-truthing of deep EC mapping patterns in conjunction with yield mapping layers.
Disease Management	Mechanisms of disease spread are not considered in farm planning and operations	Farm planning and operations take account of the mechanisms of disease spread and deliberate and considered strategies are implemented to avoid introduction of diseases and/or spread of diseases on farm. Known diseased blocks are actively managed to reduce or eliminate disease.	As above plus a disease survey is prepared for the farm and updated each season. Rotational crops are selected on their susceptibility (or ability to host) known pathogens such as lesion and root knot nematodes.
Product Selection	Products used are not approved (registered or permitted) for use in sugarcane in Queensland.	All products used are approved (registered or permitted) for intended purpose and timing of application Products are selected in accordance with integrated management plans (weeds/pests/diseases)	
Chemical Storage And Mixing And User accreditation	Chemicals are applied by people without appropriate competencies and training or not supervised by someone with these competencies (where applicable). Chemicals are not stored, mixed or disposed of in accordance with legislative requirements.	All people who apply chemicals have the appropriate competencies and training or are supervised by someone with the appropriate competencies and training. Chemicals are stored in appropriate storage premises that meet the requirements of workplace health and safety. Chemicals are mixed at locations on farm that meet label requirements and legal requirements under Reef protection legislation. Chemical drums are disposed of through drumMuster. Unwanted chemicals are disposed of through Chemclear or other approved disposal systems	All people who apply chemicals maintain competencies (AusChem / ChemCert™)
Chemical Application And Record Keeping	All products are not applied according to label or permit directions or legislative requirements under the Chemical Usage (Agricultural and Veterinary) Control Act 1999 Chemicals, particularly residual herbicides are applied when it is most convenient with no consideration of timing relating to weather or irrigation. Application equipment is calibrated annually or less	Products are applied according to the label or permit directions and legislative requirements under the Chemical Usage (Agricultural and Veterinary) Control Act 1999. and Records of chemical management inputs are kept for each field and Nozzles are selected based on label requirements for product and target.	Use of residual herbicides is reduced by banding residuals along the drill and using knockdowns in the inter-row Use of automatic flow rate controllers and precision application equipment Continuous monitoring and calibration

		Application equipment is calibrated at the start of each season and at change of product or change of water rate. Herbicides are applied at the ideal weed and crop growth stages and A chemical management plan that identifies sensitive areas, buffer zones, problem pest areas and is reviewed annually, is included as part of an IWM or IPM plan. and Timing of chemical applications minimises loss of chemicals in runoff and residual chemicals are applied prior to the commencement of the wet season.	
Irrigation and drainage management			
Calculating the amount of water to apply	The water holding capacity of farm soils is not known. The volume of water being applied is not matched to the water holding capacity	Water holding capacity of farm soils has been determined from soils maps or published data and irrigation application amounts are matched accordingly	Water holding capacity of farm soils has been measured and irrigation application amounts are matched accordingly
Calculating How Often To Apply Water	Water is applied on a set cycle without regard to the amount of water used by the crop.	Water is applied to match crop demand based on simple crop growth monitoring or district evaporation figures and crop factors Weather and climate forecasting is used when making irrigation decisions	Water is applied to match crop demand based on infield measurements with soil moisture monitoring equipment Weather and climate forecasting is used when making irrigation decisions
Seasonal Allocation Management	Irrigation water use is unplanned; allocation is kept 'just in case'	Historical rainfall data and climate forecasts are used to determine the best time to use irrigation water. The application time and the allocation is matched to cane growth stage	Crop water requirements are known and annual effective rainfall is understood so that a whole of season irrigation allocation is determined. If extra water is required leasing and temporary allocation transfers are investigated, though they may not be feasible to implement
Run-off And Deep Drainage Management	No management of irrigation run-off or deep drainage is practiced.	Irrigation is managed to minimise run-off and deep drainage by matching application volumes to soil water deficit	Irrigation is managed to minimise run-off and deep drainage; run-off is captured in tail water systems and recycled on farm
Recycle Pits	Pit capacity is too small and it cannot capture irrigation run-off; or Capacity is sufficient but the pumping capacity is too low; or Pit has been poorly sited and leaks or access the groundwater table	Pit has been designed to capture irrigation run-off and some rainfall run-off; and Pumping capacity is sufficient to re-use the water quickly; and The pit is well cited and does not leak or access the groundwater table	
Irrigation Water Quality Testing	Irrigation water quality has not been tested for suitability as an irrigation source	Irrigation water quality has been tested. The results have been used to make decisions on the best management of that water e.g. application of ameliorants, mixing water supplies	
Using Effluent Water For Irrigation	Recycled water is used, but there is no knowledge of the regulatory requirements regarding its use.	The recycled water has been tested for nutrient and salt levels. A management plan that takes into account nutrients supplied by the water and aims to minimise the risk of salinity occurring has been	The recycled water has been tested for nutrient and salt levels. A management plan that takes into account nutrients supplied by the water and aims to minimise the risk of salinity occurring has

		developed. Irrigation is managed so that run-off does not occur Recycled water is appropriately signed and measures have been taken to control access to the water source	been developed. An ongoing monitoring programme has been put in place Tail water recycling has been implemented
System Management - Furrow	Furrow • row length and profile are not matched to soil type • inflow rate is too low or high leading to deep drainage or run-off	Furrow • row length and profile are matched to soil type • inflow rate is managed to ensure soakage while minimising drainage and run-off losses	
System Management - Overhead high pressure	Overhead high pressure • tow path spacing is too wide or narrow leading to poor application patterns – dry areas or excessive overlap • application rate is not matched to soil infiltration rate • irrigators are operated regardless of wind conditions • no check is made of the nozzle or application pattern	Overhead high pressure • tow path spacing is matched to the machine and operating conditions • application rate is matched to soil type • irrigators are only operated in low wind conditions • nozzles are checked to ensure they aren't worn and are operating correctly	
System Management - Overhead low pressure	Overhead low pressure • end of pivot instantaneous application rate exceeds soil infiltration rate • application rate is not matched to soil infiltration rate • sprinklers are never checked	Overhead low pressure • end of pivot instantaneous application rate does not exceed soil infiltration rate • application rate is matched to soil infiltration rate • sprinklers are regularly checked to see if they are operating correctly	
System Management - Drip	Drip • emitter spacing and output are not matched to soil type or crop requirement • filtration system is inadequate and not maintained	Drip • emitter spacing and output are matched to soil type and crop requirement • filtration system is adequate and maintained	
Surface Drainage System Design	The farm has no surface drainage system and water pools on farm; or Water drains too quickly and causes erosion and downstream flooding	A whole of farm (or area) drainage plan has been developed – water is removed from the farm within 72 hours (or as quickly as possible given local conditions) while minimising erosion and downstream flooding.	As above with a sediment retention basin to filter sediment and chemicals
Subsurface Drainage System Design	No subsurface drainage has been installed even though high water tables or soakage areas are affecting yield	A drainage system that removes excess water from the root zone has been implemented. Acid sulphate soils should be considered Saline drainage water is disposed of appropriately	
Erosion management	Headlands and drains are sprayed out or cultivated No wet season fallow cover	Grass is maintained on headlands and drains Cover is maintained on fallow ground	Grass is maintained on headlands and drains Cover is maintained on fallow ground Sediment traps have been constructed and used

Source: Smartcane (2013)

Appendix 4 Improved Practice Catalogue: Sugarcane

Table 20: Improved Practice Catalogue for sugarcane in the Great Barrier Reef catchments

Management objective	Improved practices
Optimise nutrient rate and application as part of a nutrient management plan	
Crop nutrient application rates	Fertiliser application should be optimised through the implementation of a detailed nutrient management plan Account for physical and chemical properties of the soil, yield potential, block history and possible loss pathways Optimise the timing of application based on crop stage/plant requirements and seasonal conditions Keep records to track applications rates and inputs over the life of the crop to help with assessing enterprise profitability
Apply granular and liquid fertiliser subsurface	Proven application techniques for the placement of fertiliser is close to the roots of the plant include subsurface banding of fertiliser at planting; and stool-splitting in the ratoon crop fertigation as part of an integrated nutrient management plan. This can also minimise loss pathways (leaching, volatilization, denitrification and runoff)
Spray out or slash legume crop	incorporating a fallow legume can improve farm profitability through improvements in cane yield (through improved soil health, water infiltration, improved weed and disease control), reduced nitrogenous fertiliser inputs and/or the sale of the legume crop spray out or slash legume crop and leave residue on the surface until planting next crop
Optimise pesticide use as part of an integrated pest management plan	
	Use flexible management strategies based on block monitoring and taking into account: pest threshold numbers, populations of beneficial species and levels of crop damage block history, prevailing environmental conditions, chemical options, rate and timing applications and selection of equipment efficient use of residual and knockdown chemicals (e.g. regular calibration of equipment, nozzle selection, band application, product label recommendations)
Optimise soil retention and water infiltration	
Minimal tillage reduced soil compaction with enhanced water penetration and reduced irrigation applications reduced tractor hours and labour costs enhanced soil health with an improvement in productivity over time efficiency improvements in mechanical operations such as spraying and strategic zonal tillage	Minimise tillage using controlled traffic (at > 1.8m) giving uncompacted permanent beds. Best used with GPS technology. Full crop cycle green cane trash blanket (exception in the furrow irrigated areas of the Burdekin)
Manage headlands, vegetation buffers, drains and sediment traps to capture and or filter runoff from crop production areas	Vegetated filter strips and grass buffers have proved effective in the management and trapping of sediment and attached nutrients leaving paddocks. Riparian buffer strips can also help to reduce stream bank erosion, provide wildlife habitat and landscape connectivity.
Schedule irrigation based on soil properties, crop growth requirements, and monitoring of soil moisture and weather forecasts	Frequency and amount of water applied should be matched to plant requirements. Soil moisture monitoring equipment, including tensiometers can be used to inform decisions about how often to irrigate and how much water to apply. This minimises water logging and the amount of water lost through runoff and/or deep drainage Where overhead irrigation is suitable for your circumstances, benefits of use include saved labour, efficiency benefits from fertigation if possible, improved water efficiency, reduced deep drainage and run off, reduced loss of nutrient from deep drainage and denitrification and ability to adopt green cane trash for nutrient benefits

Source: adapted from DAFF (2014) (insert web page) last updated 26 March 2014

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