Economic assessment of best management practices for banana growing

Report to the Department of Environment and Science through funding from the Reef Water Quality Science Program

RP140B Final Synthesis Report 2018

Source: Kukulies, T, 'Banana farm grassed inter-rows', 2015.

Queensland Government

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Executive summary

This is the final report for the RP140B Economics of banana best management practices (BMP) project and it collates information from the initial synthesis report and findings from the grower case studies, representative modelling and grower survey on adoption of BMP with water quality outcomes. These outputs have made a significant contribution to the economic information available for industry, government and community. The project aim was to provide banana growers in the Tully and Innisfail regions of the Wet Tropics and industry stakeholders with greater confidence as to the likely profitability and water quality benefits of Banana Best Management Practices (BMP) adoption.

The main pollutants of concern with respect to the banana industry in the Wet Tropics region are nutrients in the form of dissolved inorganic nitrogen (DIN), particulate nitrogen (PN) and total suspended sediments (TSS). The extensive adoption of BMPs that improve water quality is considered a vital mechanism in improving the overall health and resilience of the Great Barrier Reef (GBR) ecosystem. A number of management practice responses to water quality issues currently exist, including targeted nutrient management, fertigation and enhanced efficiency fertilisers (EEF). Pesticides BMP in the banana industry has not been a priority for reef water quality programs due to the specific application techniques commonly used for pest and disease management in the banana industry limiting run-off from farms.

Despite the focus on improving water quality from agricultural land in the GBR catchments over the past ten years, banana growing has a noticeable lack of published reports on the economic implications of shifting to improved management practices. In the initial synthesis report just four studies were found that included an economic analysis of moving to particular management practices or a farming system that incorporates a number of management practices for improved water quality off farm.

Pannell *et al*. (2006) identified that practices are more likely to be adopted if they are perceived to have a relative advantage, are readily trialable as well as being consistent with farmers personal goals (economic, social and environmental). Adoption can be supported by a decision support tool (DST), which is a computer program or application that analyses data and presents it so that users can make decisions more easily. DSTs can be utilised over a wide range of economic and environmental areas.

Case studies were conducted on three growers who had made BMP changes in the Innisfail and Tully regions. A DAF economist visited the farms of the growers and with their assistance developed a detailed whole-farm economic analysis of their banana growing enterprise. The analyses indicated that after BMP changes were made, the case study growers experienced economic benefits, through cost savings on farm, and water quality benefits.

The *technical report* presents the methodology and findings of the representative economic study modelling the economic and water quality implications of Banana BMP adoption. The findings indicate that, in general, BMP adoption led to reductions in dissolved inorganic nitrogen (DIN) and total suspended sediment (TSS) leaving banana farms, while at the same time improving the profitability of farming businesses.

The adoption innovation profile report reports on identified key characteristics of best management practices as perceived by north Queensland banana producers. The data analysed is drawn from surveys completed by forty-six banana growers from the two major banana growing areas in north Queensland between May and July 2017. Overall, best practices were perceived to have neutral to positive impacts on economic outcomes (production costs, production, profitability and variability of production). For the perceived characteristics of practice adoption (high capital investment needed, contractors needed to implement change, does not fit my farming system, not easy to trial, requires new skills and information and too much time required to look into), there were only three negative results identified as constraining adoption and five neutral results.

Whilst average response rates to the *adoption innovation profile report* survey are reported, for each practice there are growers who (because of valid, underlying circumstances that are not explored in detail in this report), perceived the impacts of adopting particular practices to be unfavourable for their farming system. The variance in responses between growers (and case study results) and the additional reasons influencing growers' adoption decisions highlight the uniqueness and complexity of farming systems. This suggests that "one-size-fits-all" policy or extension approaches that fail to regard differences between farms and grower circumstances will be of limited effectiveness.

Sharing the findings from this project through extension and education programs is important and there are several avenues that will be used. The Queensland Government publications portal holds the project outputs and is found here. DAF economics staff will extend the findings from the project through written communication in several email updates, magazines and the 2018 National Banana Roadshow. The importance of ongoing communication and working with growers to share this vital information cannot be overstated.

There are several priority areas that would benefit from further assessment to provide greater confidence in the adoption of best management practices. Filling these identified gaps in knowledge would further support adoption of BMP.

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Acronyms

- ABARES – Australian Bureau of Agricultural and Resource Economics and Sciences
- ABS – Australian Bureau of Statistics
- ABCD – Aspirational Best Conventional Dated
- ABGC – Australian Banana Growers Council
- ADR – Areal Delivery Ratio
- AEB – Annualised Equivalent Benefit
- APSIM – Agricultural Production Systems Simulator
- ARM – Agricultural Risk Management
- BMP – Best Management Practice
- BOM – Bureau of Meteorology
- CPI – Consumer Price Index
- CSIRO – Commonwealth Scientific and Industrial Research Organisation
- DAF – Department of Agriculture and Fisheries
- DAFF – Department of Agriculture, Fisheries and Forestry.
- DCF – Discounted Cash Flow
- DIN – Dissolved Inorganic Nitrogen
- DSITI – Department of Science, Information Technology and Innovation
- DST – Decision Support Tool
- EEF – Enhanced Efficiency Fertilisers
- FSS – Fine Suspended Sediment
- GBR – Great Barrier Reef
- GM – Gross Margin
- GST – Good and Services Tax
- INFFER – Investment Framework for Environmental Resources
- IPM – Integrated Pest Management
- IPC – Improved Practices Catalogue
- IRR – Internal Rate of Return
- K – Potassium
- MCAS-S – Multi Criteria Analysis Shell for Spatial Decision Support
- N – Nitrogen
- NPV – Net Present Value
- NRM – National Resource Management
- NSW – New South Wales
- NT – Northern Territory
- P – Phosphorus
- PDS – Product Data Sheet
- PiRisk – Primary Industries Risk Analysis Tool
- PM – Profit Margin
- PN – Particulate Nitrogen
- QPC – Queensland Productivity Commission
- RIS – Regulatory Impact Statement
- ROA – Return on Assets
- ROE – Return on Equity
- RWQ – Reef Water Quality
- SCAMP – Soil Constraints and Management Package
- SOI – Southern Oscillation Index
- TN – Total Nitrogen
- TP – Total Phosphorus
- TR1 – Tropical Race One
- TR4 – Tropical Race Four
- TSS – Total Suspended Sediments
- UNESCO - United Nations Educational, Scientific and Cultural Organisation
- WA – Western Australia
- WOF – Whole of Farm

1 Introduction

The Wet Tropics region of far north Queensland is an area of significant environmental value[1]. It is also home to more than 90 per cent of Australia's banana production. The Scientific Consensus Statement (Brodie, J. *et al.* 2013) identified fertiliser nitrogen reduction as the highest management priority in the Wet Tropics region to reduce the relative risk of degraded water quality entering the Great Barrier Reef. This was further refined in the recent update of the Scientific Consensus Statement (Waterhouse *et al*. 2017) where the Tully and Johnstone catchments were among the highest priority areas for reducing dissolved inorganic nitrogen in the Wet Tropics region. The land use that contributes the highest anthropogenic dissolved inorganic nitrogen (tonnes per year) is sugarcane, with bananas the second highest contributor from the Johnstone catchment, in the Wet Tropics region (Queensland Government 2014: 83). The Reef Water Quality Protection Plan (2013) and the Reef 2050 Long-Term Sustainability Plan (2015) set out the commitment by government, industry and regional bodies to act to reduce the contribution of total contaminants entering waterways from agricultural land located in the Great Barrier Reef catchment area.

In addition to the ongoing commitment to improve environmental outcomes, in particular reducing the nutrients and sediments leaving farms, the banana industry is currently dealing with the detection of Panama disease tropical race 4 (TR4) in the Tully area. The main way in which this disease is spread is through infected planting material and in the movement of water and soil infected with the fungus. Adoption of practices that reduce movement of soil and water off-farm will therefore also provide biosecurity benefits as a means of containing the disease.

This *final synthesis report* combines an overview of the current business environment of the banana industry in the Wet Tropics and updates the available information on the economics of the various banana growing management practices first reviewed in the initial synthesis report. Findings from the research conducted as part of this study is also presented. Specifically findings from the three grower case studies (section 7.1), the representative modelling in the *technical report* (section 7.2) and the *adoption innovation report* (section 7.3) based on a grower survey in the Tully and Innisfail regions. Finally, the *final synthesis report* sets out where the gaps remain and priorities for future research (section 8).

[1] It is listed as an identified United Nations Educational, Scientific and Cultural Organisation (UNESCO) World Heritage Area and is adjacent to the Great Barrier Reef, another UNESCO listed World Heritage Area.

2 Queensland banana growing industry

2.1 Farm business environment

The primary variety of bananas grown in Australia is Cavendish, followed by Lady Finger and other cultivars with niche markets. The Australian banana industry is almost entirely made up of the domestic market with zero current imports and minor exports. There are no imports mainly due to overseas countries being unable to economically meet Australia's stringent phytosanitary conditions under which bananas are permitted into the country. These conditions were set to quarantine the country and provide safeguards from a foreign disease incursion (Australian Government, 2009). Exports are minor predominantly due to the cost of production being higher in Australia, compared to many other banana producing countries. The minor exports are mostly from organic markets, for example, Pacific Coast Eco Bananas distribute their wax-tip fruit through a direct airline service to Hong Kong from Cairns (Queensland Government, 2015d).

In 2015-16, the Wet Tropics NRM region produced approximately 97 per cent of the nation’s bananas, with a gross value[2] of $397 million (Australian Bureau of Statistics [ABS], 2017a,b) making a substantial contribution to the local economy in north Queensland (QLD). Other regions of banana production in Queensland, in order from largest to smallest, include Cape York, Northern Gulf, Burnett Mary, South East Queensland, Burdekin and Mackay Whitsunday[3].

Figure 1 illustrates the Wet Tropics and Australia’s total banana production over eight years. The level of banana production has trended upwards from 2007-2016 and the lower years of production can be explained by tropical cyclones (Larry in 2006, Yasi in 2011 and Ita in 2014) and seasonal conditions. Recent forecasts (Department of Agriculture and Fisheries, Agtrends, 2017) show favourable growing conditions and good yields have resulted in greater banana production than expected; however, wholesale market prices are lower than the October 2016 forecast, resulting in a slightly lower banana gross value production forecast for 2016–17.

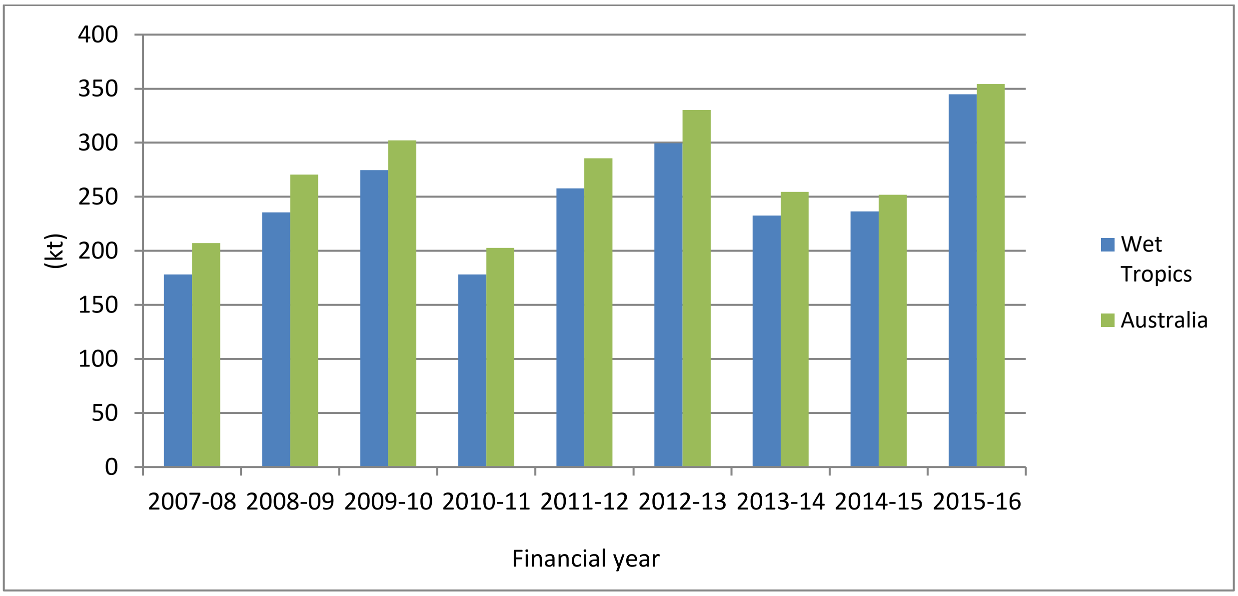

Figure 1: Australian Banana Production
Source: Australian Bureau of Statistics, (2017a).

[2] Gross value is the value placed on recorded production at wholesale price(s) realised in the market place.

[3] (Australian Bureau of Statistics, 2016a,b)

Bananas are a perennial crop, with an all-year-round supply, which helps them compete with other fresh fruit that are seasonal. This supply is mainly transported via full road vehicle loads and minor rail transport (Queensland Transport and Logistics Council, 2015). The supply chain is usually followed by Wet Tropics growers is shown below in Figure 2.

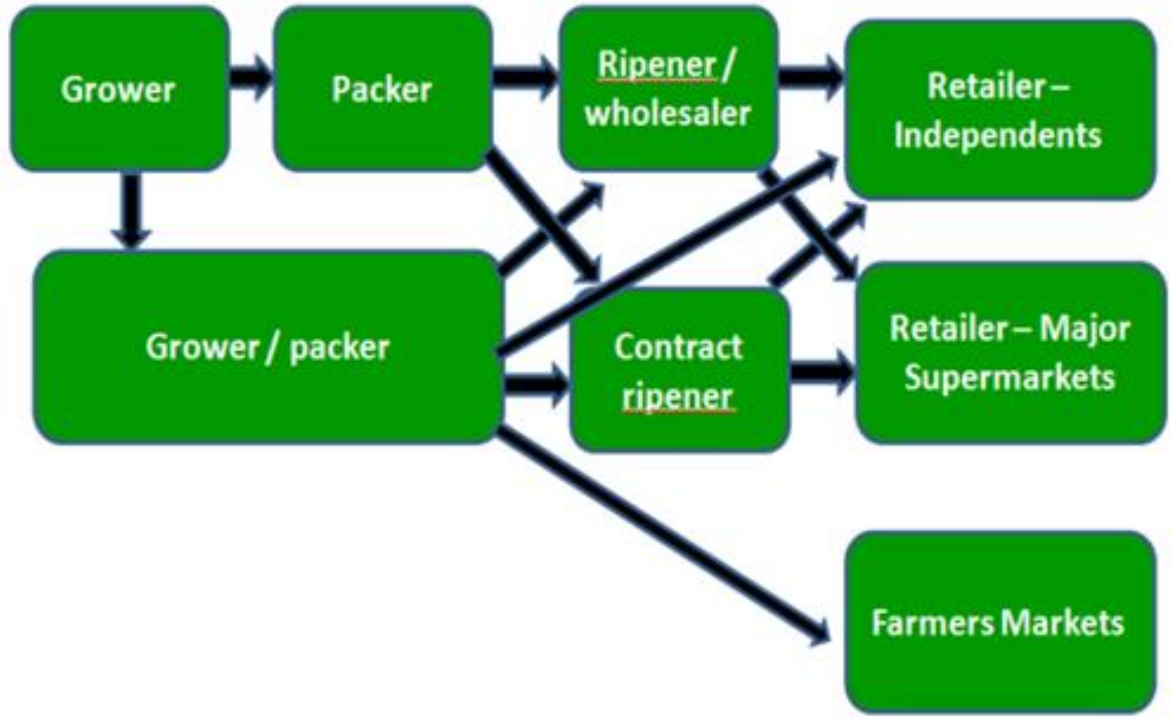

Figure 2: Wet Tropics Banana Supply Chain

Source: Horticulture Australia Limited, (2014).

There are approximately 25 wholesalers servicing Brisbane, Newcastle, Sydney, Melbourne, Adelaide and Perth, however, supply chain cost pressures and increased retail competition can push growers to directly supply to the supermarket. It is estimated that 60 per cent of all Australian bananas are sold into the supermarket channel (Horticulture Australia Limited, 2014).

Table 1 shows the local value, production and local price of Wet Tropics bananas from 2010 to 2015. It can be seen that price increased and production varied since 2011-12, after cyclone Yasi reduced supply from the Wet Tropics Region in 2010-11.

Table 1: Banana production, local value and local price, Wet Tropics, 2010-11 to 2014-15

Year	Local value[4] ($M)	Production (t)	Local price[5] ($/kg)
2010-11	211.0	178,105	1.18
2011-12	360.9	257,949	1.40
2012-13	396.1	299,602	1.32
2013-14	276.3	232,594	1.19
2014-15	380.7	236,638	1.61
		Average	***1.34***

Source: Australian Bureau of Statistics (2017a,b)

The Wet Tropics has two sub-regions that make up the majority of the banana plantations – Tully and Innisfail. Figure 3 indicates where the banana producing land is located in these two sub-regions, identified as irrigated perennial horticulture (dark purple with parallel diagonal black lines).

[4] Local value is the value placed on recorded production at the place of production, including indirect taxes. The local value of a commodity is calculated by subtracting total marketing costs from gross value. Marketing costs are the costs of moving the agricultural product from the place of production (i.e. farm) to the market place. These include freight, cost of containers, commission, insurance, storage, handling and other charges necessarily incurred by the producer in delivering commodities to the market place.

[5] Local price is derived by dividing local value by production.

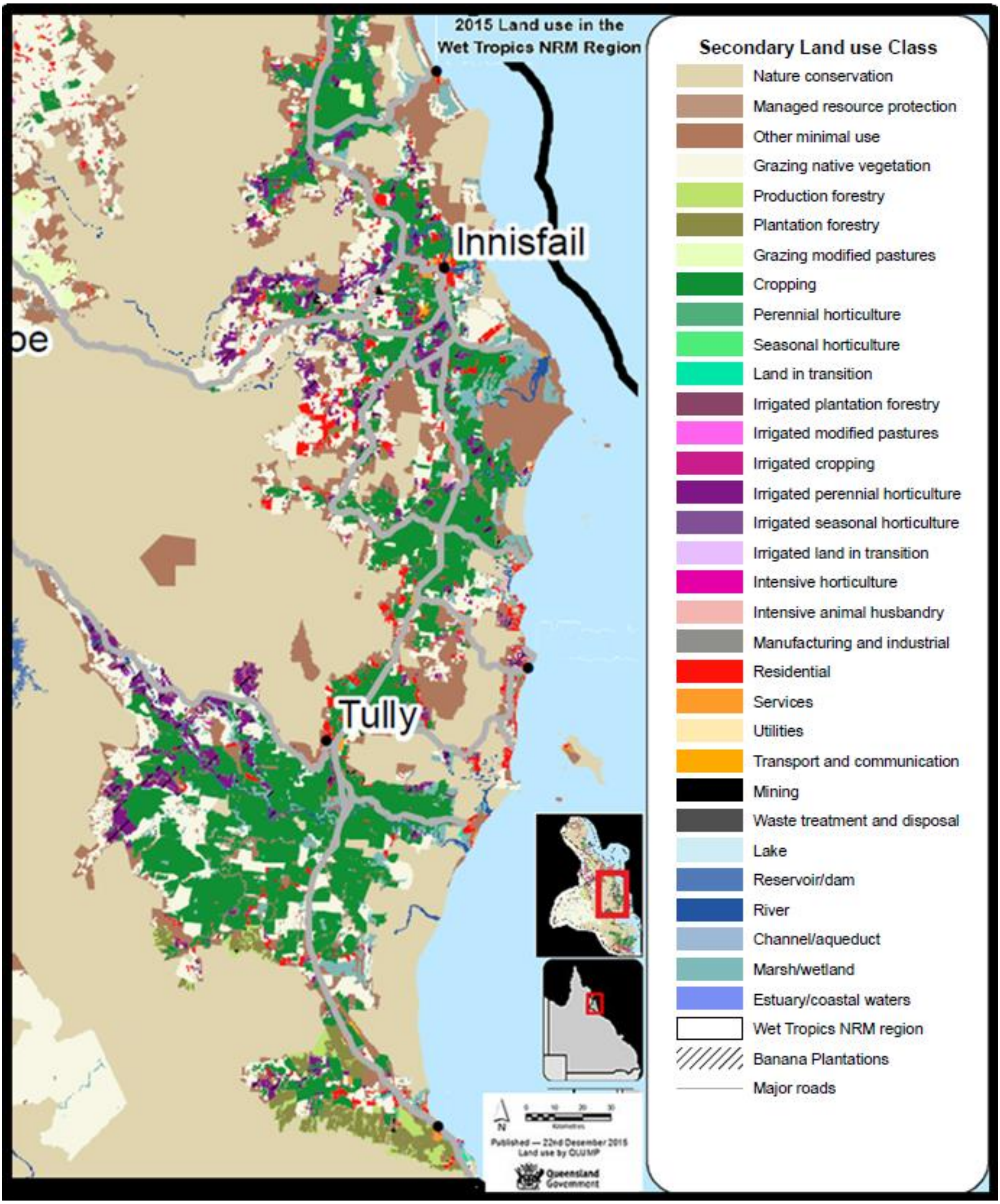

Figure 3: 2015 Land Use in the Innisfail and Tully Region

Source: Department of Science, Information Technology and Innovation, (2016).

2.2 Key economic indicators of profit and performance

Profit is the main economic measure of farm level performance. Profitability measures the difference between the value of goods produced and the costs of the inputs used to produce the goods. Gross margins (GM) is gross revenue minus variable production costs, and is commonly used to measure profitability in the economic analysis of farming activities (Garside *et al*. 2009).

While useful for evaluating changes to farming systems that do not require additional land or fixed capital, gross margins do not take overhead costs into account (Garside *et al*. 2009). Operating profit does incorporate these costs and is total gross margin minus these overhead costs. A whole of farm economic analysis approach describes the process of calculating farm business profit and incorporates these key economic measures.

A change in management practice or farming system may involve a large up-front investment with an associated stream of costs and benefits over time. The value of this investment over time can be estimated using the net present value (NPV) approach which takes into account the value of benefits and costs over time using a discount rate to calculate the present value of the investment. The discount rate is constant and is equal to the interest rate used to discount future cash flows (Wilkinson and Klaes 2012).

The NPV can be used to compare the economic impact of adopting various farm management practices or systems. A positive NPV would indicate that the change of practice is worthwhile as the economic benefit outweighs the costs of implementation. A negative NPV would indicate that the change is not, on its own, financially acceptable as the costs are higher than the benefits. Annualised Equivalent Benefit (AEB), which is the net present value of an investment as a series of equal cash flows for the length of the investment, is used to present the economic results in an annual format for consistency with the timeframes used with the water quality modelling. Another economic measure used to compare investment options is the internal rate of return (IRR), which is the discount rate required to make the NPV equal to zero, sometimes referred to as the break-even analysis.

While NPV is a useful economic measure, it is difficult to incorporate the risk and uncertainty so inherent to agricultural production into NPV calculations. This is because assumptions are made about expected future cash-flows, future output prices, input costs and yields associated with a future management change. The volatility associated with farming, both around price and quantity of inputs and outputs at any given time, means that accounting for this uncertainty in assessing alternative farming systems is particularly important.

Risk can be accounted for using several different methods, including sensitivity analysis and scenario planning. Stochastic simulations are another way to account for the distribution of potential outcomes from particular inputs. The then Queensland Department of Primary Industries and Fisheries developed a stochastic simulation tool; Primary Industries Risk Analysis Tool (PiRisk). The tool conducts random simulations over the various sources of uncertainty producing a cumulative frequency distribution and displays the expected outcomes and their associated probabilities (see, for example, State of Queensland 2011b).

3 Water quality concerns from banana growing practices

Nutrients, pesticides and sediments have been identified as the main pollutants from agricultural land that negatively impact on the quality of water entering the GBR lagoon (Fabricius, 2005; De'ath and Fabricius, 2010; Kroon *et al*., 2012; Brodie *et al*., 2013, Kroon *et al*. 2012). More specifically, nutrients and pesticides are considered the highest risk from banana production systems. Currently pesticides are not identified as a high priority pollutant from banana production in terms of the relative impact on water quality entering the Great Barrier Reef (Terrain NRM 2015). This is because residual herbicides are only occasionally used and those chemicals that are frequently used (insecticides and fungicides) are generally only used in small quantities with a very targeted application (e.g. fungicides are used on leaves and tend to be found at very low concentrations in the environment while bunches are either sprayed or treated via a pesticide impregnated strip) (Terrain NRM 2015). In the 2015-2020 Wet Tropics Water Quality Improvement Plan, it is estimated that pesticide use has reduced by as much as 90 per cent in last 20 years (S. Lindsay, pers. comm. in Terrain NRM 2015).

Subsequently, the main pollutants identified by Terrain NRM (2015) as of concern for the banana industry are nutrients in the form of dissolved inorganic nitrogen (DIN), particulate nitrogen (PN) and total suspended sediments (TSS). Banana growing requires relatively high fertiliser rates as high yielding banana crops (such as the Cavendish variety) extract large quantities of nutrients from the soil (Lindsay *et al*., 1998). There is potential for nutrient losses in the Wet Tropics through a number of pathways including surface runoff, denitrification and in particular for nitrates, deep drainage (Armour *et al*., 2013a). Lindsay *et al*. (1998) note that the two nutrients most readily lost in banana growing are nitrogen and potassium. A recent study demonstrated that there is generally no significant difference in yield between C class and B class practices for nitrogen application and inter-row management (Masters *et al*, 2017).

Armour *et al*. (2013a) measured the deep drainage losses from Banana growing over 1995 – 1997 and found the nitrogen (N) load in deep drainage attributable to N fertilisers was equivalent to 37 and 63 per cent of the fertiliser application for the treatments N400 and N600 (400 and 600 kg/N/ha/yr) respectively over 18 months. In particular, N leached below the root zone in well-drained soils in a high rainfall environment when fertiliser applications exceed crop demand, despite fortnightly application and doses aligning to growth rate (Armour *et al*., 2013a). The same study also recorded oxidised nitrogen (NOx-N) concentrations in deep drainage as high as 180 mgL^{-1} under irrigated bananas (Armour *et al*., 2013a). Rasiah *et al*., (2010) investigated the linkages between N in leachate, groundwater and drain water collected under a banana plantation in the Tully River catchment. The study concluded that the unused/under-utilised nitrate that leached below the root-zone was imported into the groundwater by the percolating rainwater and was exported into the drain via groundwater base-flow discharge. Specifically their results showed that approximately 62 per cent of the nitrate-N that leached below the root-zone was exported to the groundwater and approximately 40 per cent of the nitrate-N in the groundwater was exported to the drainwater (Rasiah *et al*., 2010). This nitrate-N in drainwater can be carried out into the ocean, affecting the GBR.

Catchment modelling of sediment, nitrogen and phosphorus nutrient loads in the Tully-Murray basin by Armour *et al*. (2009) found that bananas contributed eight per cent of the total DIN exported to the coast at 12 kg $ha^{-1}year^{-1}$ with an areal delivery ratio (ADR)[6] of 2.9 (only sugar had a higher ADR at 5.8) from an application rate of 335 kg N ha^{-1} $year^{-1}$. A similar study was undertaken for the Johnstone River catchment over six years by Hunter and Walton (2008) who looked at land use effects on fluxes of sediment, nitrogen (N) and phosphorus (P). They found that there was a three to four fold increase in fluxes of sediment Phosphorus from bananas, with specific fluxes of total P of 6.8 $\pm$ 4.1 kg P $ha^{-1}y^{-1}$ compared with a flux of 2.3 $\pm$ 1.9 kg P $ha^{-1}y^{-1}$ from the other land uses in the lower catchment (excluding sugarcane) and 0.8 $\pm$ 1.0 kg P $ha^{-1}y^{-1}$ from all land uses in the upper catchment (Hunter and Walton 2008, p.141). Specific fluxes of N from areas of bananas were modelled at 42 $\pm$ 21 kg N $ha^{-1}y^{-1}$, the highest of all agricultural land uses modelled in both the lower and upper catchments and approximately four times higher than that modelled for rainforest land – only fluxes of N from unsewered residential areas in the catchment were higher (Hunter and Walton 2008, p.142). While banana growing only accounts for two per cent of the land area in the Johnstone River catchment, Hunter and Walton (2008, p.143) estimate that it accounts for 15 per cent of mean annual flux Nitrate-N from the catchment - second only to sugarcane which accounts for 60 per cent.

Modelling by Hateley *et al*. (2014, p.32) identifies high concentrations and loads of nitrogen reported in the streams and groundwater in the sub-catchments where bananas are grown. In particular, hotspot basins for DIN export load for bananas were the Johnstone (122 t/year) and the Tully (88 t/year) basins (Hateley *et al*. 2014, p.92). The range of DIN for bananas across basins was 2 kg/ha/year in the Barron Basin to 24 kg/ha/year in the Mulgrave-Russell Basin (Hateley *et al*., 2014, p.95) (see Figure 4 for location of basins).

With respect to sediment loss from banana production systems, Lindsay *et al*. (1998, pg.5) state:

> ‘Soil erosion can be a significant problem in banana plantations in north Queensland, especially on steep slopes and in undulating areas. High intensity rainfall produces large amounts of runoff that will remove topsoil and nutrients unless effective runoff control measures are in place.’

The study by Hunter and Walton (2008, p.141) on fluxes of pollutants from the Johnstone River catchment found suspended sediment fluxes from areas of bananas (4.0 $\pm$ 2.5 t $ha^{-1}y^{-1}$) to be around three to four times those from other uses in the lower catchment (excluding sugarcane). As noted previously, banana growing accounts for two per cent of the land area in the Johnstone River catchment, but estimates show that it accounts for eight per cent of mean annual flux suspended sediment from the catchment – the lowest level from agricultural land use in the lower catchment.

Results from modelling reductions of pollutant loads due to improved management practices in the Wet Tropics region by Hateley *et al*. (2014) found that while land used for banana growing only contributed a small proportion to the TSS export load, it exhibited the largest per unit area (square metre) of TSS, Total Nitrogen (TN) and Total Phosphorus (TP) to export 1.8 t/ha/year, 25 kg/ha/year and 3.1 kg/ha/year respectively (Hateley *et al*., 2014, p.iv). This compares with per unit area (square metre) of TSS, TN and TP to export of 1.2 t/ha/year, 22 kg/ha/year and 2.7 kg/ha/year from sugarcane growing.

[6] ADR is calculated as the percentage of DIN contributed by bananas divided by the percentage area of bananas in the catchment.

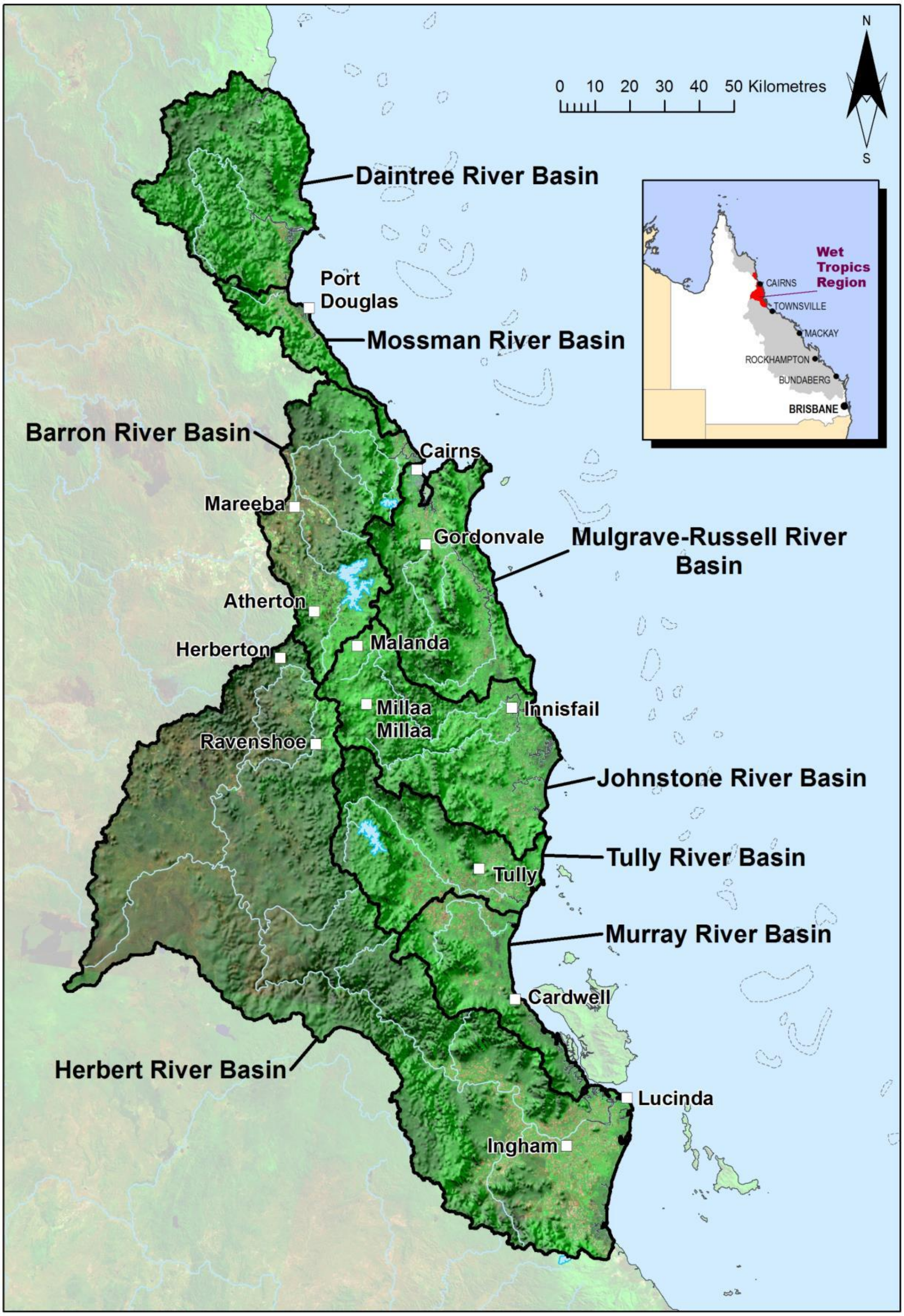

Figure 4: Basins of the Wet Tropics NRM region

Source: Hateley *et al*. (2014)

4 Responses to water quality concerns

4.1 Management practice responses to water quality concerns

The extensive adoption of Best Management Practices (BMP) that improve water quality is considered a vital mechanism in improving the overall health of the GBR ecosystem. The banana industry BMP Environmental Guidelines contains 24 practice categories and 83 key principles and are based on the Freshcare Environmental Code and uses a ‘best, okay, improve’ criteria (King, 2008). Terrain NRM’s *ABCD Management Practice Framework* is based on the industry BMP Environmental Guidelines, however, it has five practice categories with a focus on water quality and 23 key principles which then have ‘A, B, C and D’ classified practices within them (see Appendix 1). The A-class practices are aspirational and sit above best practice – currently there are only 8 A-class practices (see Appendix 1).

In the *Water Quality Improvement Plan 2015-20* (2015, p.44) Terrain NRM state that ‘current options for reducing DIN from bananas include: a targeted nutrient management approach to N applications, more widespread use of fertigation; refinement of surface, banded applications and slow release fertilisers.’ These practices are briefly described below.

Targeted nutrient management – following this approach mainly involves matching crop inputs to crop requirements. Since 1995, nitrogen application rates followed by industry have reduced by as much as 40 per cent (Sing, 2012). Application frequency is important because of weather conditions and Armour (2013c) found that deep drainage nitrogen losses were lower when fertiliser was applied fortnightly rather than monthly (3kg/ha and 7kg/ha respectively), keeping the total annual rate applied per hectare unchanged. Regular soil and leaf tests are required for accurate assessment of N rates, especially for determining appropriate N requirements at particular crop stages on specific blocks at certain times of the year (Terrain NRM 2015, p.46).

Widespread use of fertigation – Terrain NRM (2015, p.46) note that ‘65 per cent of the industry now has fertigation capacity by changing from overhead to under tree sprinklers’. Fertigation can not only facilitate further reductions in N rates but also reduce the risk for N losses as a result of a high rainfall event (Terrain NRM 2015). Daniells and Armour *et al*. (2003) found fertigation advantages included that nutrients are always readily available to the plant, fertiliser is applied directly where needed, fertiliser losses are much lower and there is no volatilisation losses with urea.

Refinement of surface, banded applications – Terrain NRM (2015) state that surface applications (rather than fertigation) are acceptable when they are accurately banded on the row, applied in small amounts frequently (monthly or more often) and watered in via irrigation or rainfall. Armour *et al*. (2014) found surface applications of fertiliser, if managed correctly, can have DIN losses just as low as those from fertigation.

Slow release and Enhanced Efficiency Fertilisers - Similar to other Wet Tropics agricultural industries, there are trials in progress for these enhanced efficiency fertilisers (EEF) or slow release fertilisers. There is potential for reduction of N losses if they are effective in delivering N over a longer time period and when the crop needs it most. EEF fertilisers look particularly promising for banana growers for their potential use as a wet weather fertiliser to complement fertigation of fertilisers during dry weather (Terrain NRM, 2015, p.46).

Options to reduce TSS include appropriately contoured banana blocks, permanent beds, grassed inter-rows and fallow management (Terrain NRM 2015). Both contoured blocks and permanent beds will help reduce sediment generation and transport during large rain events. Another method to control run off water is constructed wetlands, which can have a significant impact on reducing sediment and nitrogen losses off-farm (Department of Environment and Heritage Protection, 2013).

These options are largely targeted at controlling run off water at the paddock scale. There are currently gaps in knowledge to directly address specific practices occurring within paddocks that may be contributing to sediment and water flows, such as wheel traffic in the inter-row which can create sediment losses once wheel ruts form.

According to Reef Rescue data, 95 per cent of banana grower's applications for water quality grants were to maintain grassed inter-rows, over the initial five year round (Terrain NRM, 2015). In their research, Daniells and Armour (2003) found that grassed inter-rows minimise erosion, leaching and denitrification losses. While grassed inter-rows have been shown to reduce fine suspended sediment (FSS) delivery by up to 60 per cent in plot level trials (Roebeling *et al*., 2007), Armour *et al*. (2013b) have noted that they can be 'difficult to maintain in ratoon crops because of constant traffic and increased shading'.

4.2 Policy to promote adoption for water quality improvement

Policy promoting adoption of management practices for water quality improvement has included a mix of regulation, financial incentives, monitoring, extension and education on improving land management practices on farms in GBR catchments. The Great Barrier Reef Water Science Taskforce review into policy mechanisms to deliver on both the Reef Water Quality Protection Plan and the Reef 2050 Long-Term Sustainability Plan water quality targets in 2016 reiterated that a mix of policy tools will be required, however, a greater focus on innovation, education support for farmers and expanded monitoring of water quality was recommended in the allocation of $90 million dollars over the next four years (Queensland Government, 2016). The recently released Draft Reef 2050 Water Quality Improvement Plan 2017 – 2022 also supports this mix of policy instruments.

4.2.1 Legislation

Legislation that the Queensland Government has implemented for reef protection includes: the *Environmental Protection Act 1994* and the *Chemicals Usage (Agricultural and Veterinary) Control Act 1998.* These two acts were amended by the *Great Barrier Reef Protection Amendment Act 2009* which does not currently apply to banana farmers, but does specify management practices for sugar cane growing and cattle grazing in the priority GBR catchments of the Wet Tropics, Burdekin and Mackay-Whitsundays for sugarcane and Burdekin for grazing.

The Great Barrier Reef Water Science Taskforce review in 2016 recommended implementing staged regulations to reduce water pollution throughout the reef regions supported by extension, incentives, compliance, modelling and monitoring (Recommendation 5). Specifically they stated that 'regulations should apply to agricultural, urban and industrial activities within Reef catchments to meet minimum standards' (State of Queensland, 2016a). The Queensland Government agreed in principle to this recommendation and is currently in the process of consulting with industry[7], including seeking feedback on its *Broadening and enhancing reef protection regulations* consultation regulatory impact statement (RIS) which assesses the costs and benefits of implementing the Great Barrier Reef protection regulation package under the *Environmental Protection Act 1994* to reduce nutrient and sediment pollution across reef catchments (State of Queensland 2017a).

[7] The Office of the Great Barrier Reef established the Agricultural Stakeholder Advisory Group in 2016, which the Australian Banana Growers Council is on.

The regulatory option being considered in the RIS will include load limits at the river basin level across the GBR catchments in the Environmental Protection (Water) Policy 2009. Also the reach of the current reef regulations for agricultural environmentally relevant activities (ERAs) under the *Environmental Protection Act 1994* will be broadened to all reef catchments and extended to cover key agricultural activities (including bananas) with water quality impacts (State of Queensland 2017a). It is proposed that growers accredited against BMP (e.g. the *Banana Best Management Practices: Environmental Guidelines for the Australian Banana Industry*) will be deemed as complying with the minimum regulatory standards. The proposed minimum nutrient standards for existing banana growers:

Sediment loss controls

- All inter-rows have at least 60 per cent ground cover (living or dead)
- Where bananas are grown on land with a gradient greater than 3 per cent:
    - Diversion banks are in place to divert surface water flows away from blocks/areas of exposed soil, OR
    - All drainage structures are wide vegetated spoon drains designed to collect run-off and slow water velocity, OR
    - All drainage water must enter silt trap or similar structure prior to release from farm, OR
    - Uniformly dense vegetated grass buffers with sufficient ground cover of a minimum width are in place, OR
    - Contour banks that intercept run-off before it concentrates; and channel it into stable grassed waterways, or grassed areas adjacent to a paddock, are in place, OR
    - Fallow crops are established prior to wet season maintaining sufficient ground cover.

Soil and leaf sampling and analysis

- Soil testing (for nitrogen [N] and phosphorus [P] content) and leaf testing (for N and P content) are used to determine the N and P requirement for plant and ratoon crops. Soil testing is undertaken:
    - Prior to planting (or as close as possible to the time of applying fertiliser); and
    - On representative soil types/groupings

Calculating the nutrient rate

- Maximum nitrogen application for banana crops
    - Ratoons 350 kg N/ha/year; and
    - Plant crops after a fallow period of at least six months 250 kg N/ha/year
- Maximum phosphorus application for banana crops
    - 60 kg P/ha/year OR
- Nutrient application rates are determined for plant and ratoon crops using adjustment method (using leaf and soil nutrient testing to determine nitrogen and phosphorus application rates) or another method that provides appropriate evidence for the application rates.

Placement of fertiliser

- Banded surface application on the bed if wet weather precludes fertigation

Calibration

- Calibrate fertiliser application equipment six monthly and at each change of product

Record keeping

- Growers are required to keep records of soil tests, use of fertilisers and agricultural chemicals.

Growers will have flexibility in choosing the suite of practices appropriate to meet the standard to take into consideration their specific circumstance and local conditions. Depending on the legislation being passed by parliament, existing banana growers would have 12 months to transition to the new minimum standards.

The Queensland Government has committed to implement two major integrated projects (MIPs) to reduce nutrient, sediment and pesticide loads into waterways in the Wet Tropics and Burdekin regions. The Wet Tropics MIP is focussed on reducing nutrient and pesticide losses off the paddock from cane and banana farms. The project design ran from December 2016 until June 2017 while on-ground delivery of MIPs will run from mid-2017 until June 2020 (Queensland Government, 2017).

4.2.2 Reef Water Quality Protection Plan

In 2003, the Reef Water Quality Protection Plan (Reef Plan) was released to the public for discussion, which resulted in revision and endorsement by the Great Barrier Reef Ministerial Council. In 2007, a Reef Water Quality Partnership was established between five NRM bodies, the national and state governments to facilitate collaboration in target setting, monitoring and reporting arrangements. Since then there have been two more iterations of Reef Plan endorsed by the Australian and Queensland Governments, in 2009 and 2013.

The latest update, *Draft Reef 2050 Water Quality Improvement Plan 2017 – 2022*, was available for public consultation (between 28th August 2017 and 10th October 2017) and supports the delivery of the Reef 2050 Long-Term Sustainability Plan which was introduced in 2015 (see section 4.2.4). This latest iteration has a new name and an expanded scope that now includes all sources of land-based water pollution (i.e. industry urban and public lands) as well as the historical focus on agriculture. It also explicitly incorporates social, cultural and economic values and their influence on adoption actions to improve water quality and has set individual targets for the 35 reef catchments to reduce water pollution by 2025. It is hoped that by moving away from the whole of reef target approach used in the past, these catchment targets will take into account local situations and support better targeting and prioritisation of on ground management and investment (State of Queensland, 2017b).

The draft Reef 2050 Plan 2017-2022 still maintains the 90 per cent target for land in priority areas to be managed using best management practice systems for water quality outcomes. However, it goes further than previous Reef Plans, in stating that minimum water quality practice standards for agricultural practices should be regulated (see section 4.2.1). Pollutant reduction targets for banana growing regions of the Tully and Johnstone River catchments are set out in Table 2 below.

Table 2: Reef 2050 Water Quality Improvement Plan 2017-2022 Wet Tropics targets by 2025

					Particulate nutrients			
	Reduction: Dissolved inorganic nitrogen		Reduction: Fine sediment		Reduction: Particulate phosphorus		Reduction: Particulate nitrogen	
	%	tonnes	%	Kilo tonnes	%	tonnes	%	tonnes
Wet Tropics	60	1700	25	240	30	360	25	850
Johnstone River	70	350	40	100	40	250	40	490
Tully River	50	190	20	17	20	23	20	68

Source: State of Queensland (2017b)

4.2.3 Paddock to Reef monitoring program – Reef Report Cards

The fundamental apparatus for tracking performance against the goals of Reef Plan is the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef Program). The Paddock to Reef program is intended to deliver an impartial, collaborative and ongoing assessment of catchment and GBR water quality and marine ecosystem health which it does through the Reef Report Cards (Queensland Government, 2015b). It is charged with monitoring, modelling and reporting on a range of management practices and water quality aspects from both an environmental and economic standpoint (see Appendix 3). It operates across several levels including the paddock, sub-catchment, catchment and also neighbouring marine areas. Reef Report Cards have been released since the year 2009 (baseline), indicating progress towards water quality targets set out in Reef Plan with the most recent report card released in September 2016 (Queensland Government, 2015b).

4.2.4 Reef 2050 Long-Term Sustainability Plan

The Reef 2050 Long-Term Sustainability Plan, released in 2015, is now the overarching framework for the protection and management of the GBR. As well as incorporating the Reef Water Quality Protection Plan, the Reef 2050 Long-Term Sustainability 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. The Reef 2050 Long-Term Sustainability Plan has water quality targets of achieving reductions of up to 80 per cent in dissolved inorganic nitrogen, at least 20 per cent reduction in particulate nutrients, at least 60 per cent reduction in pesticides and 50 per cent reduction in sediments.

To facilitate this it has also included an investment framework to facilitate public and private investment to maximise reef outcomes (Australian Government, 2015b). The Reef Trust ($140 million over four years) is a critical component of the Reef 2050 Long-Term Sustainability Plan and provides cost effective and strategic investment to address key threats. To date there have been five investment phases which have included targeting the following water quality improvement key actions: promotion of A-class grazing management practice; controlling crown-of-thorns starfish; gully erosion control; coastal habitat and wetland rehabilitation; maintaining water quality improvement momentum in grains, dairy and horticulture; reducing erosion losses from rangeland grazing; supporting cane farmers to move beyond industry best practice; tenders in the Wet Tropics and Burdekin regions; trialling and uptake of EEF's and repeated auctions to reduced nitrogen losses to the Reef; gully and stream bank erosion control (Australian Government, 2016b).

Reef Plan Action Four of the Reef 2050 Long-Term Sustainability Plan requires the Queensland Department of Agriculture and Fisheries (DAF), as well as the local and federal government agencies, to implement innovative management approaches through the Reef Trust for improving water quality (Australian Government, 2015b).

4.2.5 NRM water quality frameworks for management practices

NRM bodies have developed a management practice framework of Aspirational, Best, Conventional and Dated (ABCD) practices to classify regionally specific management practices for industries in their catchments. These frameworks assist in identifying land management practices that maximise water quality improvements. The ABCD framework categorises farming practices on a scale of improvement from 'outdated' to 'cutting edge' practices based on their water quality outcomes.

Terrain NRM has developed an ABCD framework for banana growers in the Wet Tropics region (see Appendix 1) based on the industry's own BMP guidelines. The framework is intended to be a guide for banana growers applying for funding under the Australian Government's Reef Programme (formerly Reef Rescue) to adopt improved farming practices. Reef Programme is administered through the GBR NRM bodies as Water Quality Grants which are accessible to landholders in GBR catchments to commence improved management practices. The ABCD framework hence provides a basis for identifying practices for project consideration.

Eberhard Consulting (2011) reported feedback from twenty-five stakeholders involved with Reef Rescue who commended the program on the basis of the relative size of the investment, the flexibility of the grants model to suit regional contexts, the duration of the commitment of the program, the effective collaboration between NRM groups and industry, and its clearly articulated and ambitious targets. On the other hand, the report identified shortcomings in relation to the complexity in the contractual basis and administration of the program, the lack of established reporting standards from the outset, the conflict between accountability and collaboration, and significant coordination costs.

5 Adoption of improved management practices

5.1 Theoretical concepts of the adoption process

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 financial or market advantage over their current farming system given its specific biophysical and enterprise characteristics. 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 50 per cent 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 on practice (innovation) adoption through a cross disciplinary approach and identified that improved management practices for conservation outcomes 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, p.1408) also highlight that adoption is a learning process which can be divided into three stages:

- 'collection, integration and evaluation of new information to allow better decisions about the innovation'
- learning by doing
- 'improvement in the landholder's skills in applying the innovation to their own situation.'

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. Different avenues for conveying information about management practices may include activities such as viewing websites, reading fact sheets, attending field days and farm visits with a grower group, one on one support with an agronomist or NRM officer or growers' using a decision support tool to work through stylised scenarios representative of their situations. There is often a broad set of drivers for growers that result in a practice change outcome, each with its own sphere of influence and relative timing.

5.2 Adoption of best management practices by banana growers

The Queensland Audit Office (2015) report entitled, Managing water quality in the Great Barrier Reef catchments, found that the horticultural industry had achieved 59 per cent of the land and catchment management targets by 2013 (80 per cent of landholders in agricultural enterprises will have adopted improved soil, nutrient and chemical management practices). The Reef Report Card (September 2016) measured that the area of banana growing lands in the Wet Tropics managed using best management practice systems, as at June 2015, was 56 per cent for nutrients BMPs and 57 per cent for sediment BMPs (State of Queensland, 2016b, p.15). The target is 90 per cent across pesticides, nutrients and soil practices by 2018, as set out in the Reef Plan (2013).

Studies on adoption of best management practices in the Great Barrier Reef catchments have mainly been confined to the grazing and sugarcane growing industries (e.g. Greiner and Gregg 2011; Thompson *et al*., 2014). In 2007 a survey was undertaken amongst rural landholders in the Wet Tropics region with the purpose of investigating 'key social and economic issues affecting landholders' decision making in regard to the use of natural resource management practices and to examine landholders' adoption of and attitudes toward selected currently recommended practices by various industries' (Emtage and Reghenzani, 2008, p.1). The survey collected 320 responses, of which nine responses were from banana growing enterprises that covered a total area of 151 hectares and an average enterprise size of 16.8 hectares (Emtage and Reghenzani, 2008, p.20). While the participation rate of banana growers in this survey was too low to draw any inferences from the pooled results around adoption of management practices for the banana industry in the Wet Tropics, there were specific industry questions around nutrient use.[8] The range of nutrient rates between the six banana growing respondents that answered these questions in the survey was quite large with a minimum of 30 kg/ha/year to a maximum of 500 kg/ha/year for nitrogen, 30 kg/ha/year to 1000 kg/ha/year for potassium and 0.4 kg/ha/year to 2000 kg/ha/year for other nutrients (Emtage and Reghenzani, 2008, p.26).

In 2011 Terrain NRM partnered with ABGC to undertake a survey of 107 banana farms in the Wet Tropics over five months, covering 69 per cent of farms in the region (Sing 2012). The survey consisted of six main questions around management practices, specifically practices ranging from traditional to best practice under cultivation, nutrient rates and timing, nutrient application methods, weed and inter-row management techniques, irrigation method used and sediment management. Information was also collected part way through the survey on practices that had changed in the last two years as well as information on the size of the farm. The majority of farms surveyed were less than 50 hectares (60 per cent), with the next largest groupings being between 51 – 75 hectares (16 per cent) and over 200 hectares (8 per cent).

The main findings were that nearly 80 per cent of growers surveyed were applying less than 350 kg N/ha and 67 per cent applying less than 300 kg N/ha (Sing 2012, p.22). It is likely that the adoption rates from this survey have increased since 2012. Other findings from the survey included:

- 38 per cent cultivate row area only (with or without GPS)
- 34 per cent remove crop by herbicide spraying/injection
- 73 per cent remove crop by full cultivation outside of wet season
- 74 per cent use leaf nutrient testing at least once a year
- 92 per cent use soil nutrient testing at least once a year
- 48 per cent applied N at least fortnightly
- 36 per cent applied one NPK rate based on what have done previously
- 75 per cent use fertigation and banded surface applications when fertigation is unsuitable
- 67 per cent promote ground cover and maintain in the inter-row all the time
- 66 per cent use laser levelling before establishing a plant crop
- 99 per cent use grassed spoon drains where possible
- 80 per cent with deeper drains ensure they are stable and battered to prevent erosion.

[8] Findings from the survey for cropping enterprises, of which banana growing accounted for seven per cent, included: over 80 per cent of respondents supported the statement that reduced tillage improves soil health and reduces erosion; approximately half of the respondents agreed that reduced tillage increases the need for herbicides; nearly 80 per cent of respondents think that the high cost of new machinery constrains practice change; in general, respondents reported that the use of the recommended practices surveyed would increase in the future; approximately 18 per cent of irrigators reported using their irrigation set up to apply fertiliser and less than 10 per cent reported using an automated irrigation control system (Emtage & Reghenzani, 2008, p.4).

The main change that survey growers had made in the last two years was to install fertigation (26 per cent) and install permanent beds (23 per cent) (Sing 2012, p.24).

5.3 Decision support tools

There are a number of decision support tools (DSTs) available to the banana industry to support the adoption of improved management practices. DSTs are typically programs or applications on smartphones, tablets or computers that analyse data and presents it so that users can make decisions more easily. There are some DSTs that are designed specifically for banana farming and many others are general tools that can be incorporated into banana farming (See Table 3 below for some examples of DSTs available to banana growers).

Table 3: Decision Support Tools relevant to the banana industry

Area	Description of the decision support tool
Best management practice	*Banana Best Management Practices* - national guideline to encourage continual improvement and adoption of best practice throughout the banana industry.[1] *Bananaman* – helps banana growers improve the management of crop nutrition.[2] *BetterBunch record keeping app* – time-saving device to assist growers in their everyday recording of farm practices to complement their BMP.[3] *Improved Practices Catalogue (IPC)* - hosted by DAF, aimed primarily at extension officers and exists for grazing, sugarcane and bananas. Banana IPC provides information to identify and adopt BMP's and covers nutrient rate and application, pesticide use, soil retention and water infiltration.[4]
Gross margin	*Cavendish Gross Margin* – excel spreadsheet. Farmer may be better able to identify areas within the business where the margins can be improved.[5]
Whole of farm	*Cavendish Whole Of Farm* – excel spreadsheet, attempts to capture whole farm profit and cost to work out NPV, IRR.[a, 5] *Ladyfinger Whole Of Farm* - excel spreadsheet, attempts to capture whole farm profit and cost to work out NPV, IRR etc.[6] *Trellis Economic Analysis Tool* - excel spreadsheet, examines the profitability of trellised relative to conventional tree cropping systems. Although not specific to Banana production, the method of evaluation may help with banana economic analysis.[7]
Irrigation	*EconCalc* – online calculator for irrigation systems that generates improved efficiency, present value, annuity, IRR and benefit/cost ratio etc.[8]
Panama TR4	*On-farm Biosecurity BMP checklist* -will help identify the effectiveness of farmers' current practices[9]. Online system also being developed. *Surveillance app* - rapid collection and analysis of surveillance data in the field and on-the-spot decision making. Only used by Biosecurity Queensland staff involved in surveillance.[9]
Model Simulation	*Agricultural Production Systems* Simulator (APSIM) - results are determined by soil factors, management factors and environmental factors.[10] *HowLeaky* - examines the impact of various land uses and soil management on water quality. The results of these analyses will identify those practices which are likely to maintain or improve farm profitability as well as water quality.[11]
Reef Plan	*MCAS-S* - used for spatial information assessment, conveying complex information in a readily understood manner.[12] *INFFER* - used for developing and prioritising projects designed to address environmental issues.[13]
Climate	*HowWet?* - uses farm rainfall records to estimate plant available water, nitrogen mineralisation and erosion.[14] *Southern Oscillation Index (SOI) values* - provides a seasonal climate outlook by giving an indication of the development and intensity of El Niño or La Niña events in the Pacific Ocean.[15] *Climate ARM* - provides the ability to analyse rainfall and other climate variables at individual locations and taking into account seasonal patterns and forecasts.[16] *Bureau Of Meteorology climate* - view daily and monthly statistics, historical weather observations, rainfall, temperature and solar tables, graphs and data.[17] *Rainman streamflow* - helps farmers to predict rainfall at a specific location within a specified time period.[18]
Soil	*SCAMP* - used to develop nutrient and soil management practices that will assist in minimising off-site losses.[19] *soilMapp* - app that provides access to available soil and land information which can assist with improved land management decisions.[20]

Source: [1] King, N (2008). [2] Armour, Mortimore, Pathania, Wiltshire, Daniells, Masters & Reghenzani (2014). [3] ABGC (2017) [4] See Appendix Two. [5] Johnstone, B (1998). [6] Hinton, A (2001). [7] DAFF (2012). [8] Knowledge Management System for Irrigation (2007) [9] Biosecurity Queensland, (2015). [10] CSIRO, University of Queensland, DAF (2015). [11] McClymont (2011) [12] ABARES (2015a). [13] University of Western Australia and Natural Decisions Pty Ltd. (2015). [14] Freebairn, Hamilton and Cox (1994). [15] Queensland Government (2015a). [16] DAFF (2013). [17] BOM (2015a). [18] Grains Research & Development Corporation (2014). [19] Moody and Cong (2008). [20] CSIRO, DAF, Geoscience Australia (2015).

Notes: a See section 2.2 for definitions of NPV and IRR.

6 Review of economic studies involving management practices on banana farms

Despite the focus on improving water quality from agricultural land in the GBR catchments over the past ten years, banana growing has a noticeable lack of published reports on the economic implications of shifting to improved management practices. For the initial synthesis report, just four studies have been identified that included an economic analysis of moving to specific management practices with improved water quality outcomes (Roebeling *et al*. 2007; Armour *et al*., 2013; Queensland Wetlands Program, 2013) or a farming system that incorporates a number of improved management practices (Poggio and van Grieken 2010). Table 4 below provides an overview of these studies and a more detailed review of the economic findings from these studies follows.

Table 4: Summary of economic analysis on Banana BMPs

Author	Year	Location	Practices	Methodology
Roebeling, Webster, Biggs and Thorburn	2007	Tully Murray Catchment	Grassed vs Bare inter-row management Fertiliser Application rate	Undertaken at the plot level Production simulation model LUCTOR, Hydrological model SedNet/Annex and cost-benefit economic analysis,
Poggio and van Grieken	2010	Wet Tropics	Shift from D to C, C to B and B to A practices modelled (see Table 6)	Net Present Value of shifting from one class of practices to another over a 5 and 10 year period. Whole of farm gross margins and transition capital costs estimated for a representative enterprise of 60 ha. PiRisk used to analyse impact of uncertain parameters.
Queensland Wetlands Program	2013	Between Innisfail and Tully	Environmental code of practice (Freshcare), GrowCom FMS, composting, reduced tillage, reduced and more targeted pesticides, soil and leaf analysis, fertigation and foliar application, machinery to minimise compaction, monitoring soil moisture, slashing rather than spraying inter-rows, longer crop cycles, minimum traffic in wet season, harvest low lying areas before wet season	Case study – estimation of Net Present Value of change in farming system for a 60 ha farm
Armour, Masters and Mortimore	2013	South Johnstone	B vs C practices: Fortnightly fertigation vs monthly broadcasting onto mounds Rate adjusted according to expected growth – 150 kg/ha/year plant and 250 kg/ha/year ratoon vs constant rate of 250 kg/ha/year plant and 375 kg/ha/year Inter-row groundcover – grassed vs bare	Partial economic analysis completed on savings in nitrogen applied and reduced use of tractor and fertiliser spreader for B practice (method and rate of fertiliser application)

In their study, Roebeling *et al*. (2007) simulated the impact on fine suspended sediment (FSS) and dissolved inorganic nitrogen (DIN) of adopting managed grassed inter-rows and matching fertiliser rates to crop requirements. They used the LUCTOR crop growth model to estimate changes to crop production, SedNet/Annex hydrological model to estimate the downstream delivery of sediments and nutrients and a cost-benefit approach to estimate the cost-effectiveness of each management practice modelled at the plot level (i.e. these estimates do not include implementation costs at the farm level).

Plots over three different soil types had gross margins for grassed inter-rows less than bare inter-rows by between three and nine per cent. In contrast, the grassed inter-rows reduced the amount of FSS losses at the plot level by 60 per cent compared with bare inter-rows while there was no impact on DIN delivery (Roebeling *et al*., 2007, p.16). In the fertiliser application trials, application rates ranged from 20 per cent to 100 per cent of the application rate required to realise maximum attainable yield. Results from these trials found that FSS losses declined marginally as fertiliser rates increased, due to increased plant growth, canopy cover and crop residue cover while DIN losses increased considerably, although not equally across all soil types. The largest gross margins were attained at the 100 per cent application rate required for maximum attainable yield at N, P and K rates of 308 kg/ha, 21 kg/ha and 728 kg/ha respectively (Roebeling *et al*., 2007, p.17).

Poggio and van Grieken (2010) found in their analysis of implementation costs and benefits for management practices that the transition to C and B-class practices is worthwhile for banana growers but not to A-class practices. The transition to A-class practices required large capital investment in irrigation systems (167 per cent greater than that for B-class – see Table 4) and there was a small decline in whole of farm gross margins relative to B-class practices, due to the additional costs of composting green waste and spreading in the field, offsetting the reduction in irrigation and fertiliser costs (Poggio and van Grieken 2010). The B-class irrigation system modelled in this analysis invested in an under canopy system and tensiometers to monitor soil moisture. A-class irrigation required investment in automated drip irrigation with fertigation capacity with scheduling based on EnviroSCAN soil moisture probes.

The methodology used in the Poggio and Van Grieken (2010) study involved the authors determining steady state gross margins, capital requirements and a NPV analysis for transition to the next level of farming system. For the water quality modelling, there was no indicator included for bananas as at that time there was no accurate production simulation model available for banana growing.

Specific results from the Poggio and van Grieken (2010) study into banana management practices from the year 2008 are listed below in Table 5.

Table 5: 2008 Banana Management Practices

Farming system	Farm Gross Margin per hectare	Change in farming system	Capital Cost of practice change	Net Present Value: 5 year (10 year)
A	$10 635	B to A	$420 000	-$422 748 ($-424 707)
B	$10 646	C to B	$157 021	$474 475 ($925 185)
C	$8 078	D to C	$0	$759 044 ($1 300 233)
D	$4 993	-	-	-

Source: Poggio and van Grieken (2010)

The management practices considered in the estimation of these gross margins and capital costs are listed below in Table 6. It is worth noting that these practices were based on the Banana ABCD management practice framework for water quality improvement developed in 2007/08 by the Wet Tropics NRM group, and there have been changes between practices since then (see Appendix 3 for comparison).

Table 6: Management practices considered for analysis

Transition	Management practices
D to C	Avoid cultivation during high risk (heavy rainfall) periods. Use of soil and leaf testing (one test per year). Reduction in fertiliser rates (based on historical rates). Fertiliser applied less frequently and on a calendar basis. Spray equipment calibrated. Trash kept but left where it drops. Overhead sprinklers used for irrigation. Irrigation application varies with crop stage only with scheduling based on subjective tools.
C to B	Spray-out fallow with reduced cultivation. Fallow legume crop to improve soil health. Laser levelling used where appropriate. Use of soil and leaf testing on blocks to be planted. Reduced rate of fertiliser according to recommended rates. Shift towards the use of fertigation, banded surface application and soil ameliorants. Banana waste returned to paddock, leaf mulch kept on beds. Chemical application based on monitoring and equipment calibrated. Reduction in the use of residual herbicides. Insecticides and fungicide application is based on monitoring. Irrigation scheduling based on tensiometers. Manually operated irrigation system under canopy irrigation.
B to A	Zonal tillage used for planting preparation, tillage only on the bed area. Fallow crop to improve soil health. Controlled traffic with machinery. Soil and yield mapping. Soil and leaf testing on a regular basis. Slashing of inter-row and ground cover maintained. Leaf mulch composted and returned to paddock. Use of knockdown herbicides instead of residuals. Automated drip irrigation with fertigation capacity and scheduling based on EnviroSCAN. Monitoring of water quality.

Source: Poggio and van Grieken (2010).

Armour *et al*. (2013b) looked at a number of B and C-class management practices over two adjacent treatment plots in South Johnstone. Practices on the B-class plot include: fortnightly fertigation, fertiliser rates adjusted according to the expected growth rate for the following fortnight (N rate capped at 150 kg/ha/crop cycle for plant and 250 kg/ha/crop cycle for ratoons) and grassed inter-rows. The practices on the C-class plot include: monthly broadcast of fertiliser onto the mound between the double rows of bananas, constant rate of urea and potassium chloride (N rate capped at 250 kg/year for plant and 375 kg/year for ratoons) and bare inter-rows. Trials were conducted on Dermosol soil and irrigated by under tree mini sprinklers. The results found that the cost of nitrogen fertiliser under B-class management practices was $145 per hectare less for the plant crop and produced similar yield, fruit characteristics and follower sucker growth to that achieved under C-class management practices (Armour *et al*., 2013b). Results on FSS losses and DIN losses from the two sites were not discussed in the case study but were reported to be measured as part of ongoing monitoring of the site.

The fourth study of interest was a case study on a banana farm between Innisfail and Tully implemented a number of improved management practices including: monitoring to identify water and nutrient needs, fertigation, reduced tillage, slashing rather than spraying rows with herbicide and minimising traffic during the wet season (Queensland Wetlands Program, 2013). A cost benefit analysis comparing the management systems found that the shift to improved management practices will translate to an annualised net present value of $160 000 (Queensland Wetlands Program, 2013). Specifically:

- 30 per cent reduction in the use of granular fertilisers, saving $1,900/ha/year by moving to fertigation
- Save $40/ha/year in irrigation costs from water monitoring
- Ripper and plough used 60 per cent less, saving $660/ha in site preparation costs
- 50 per cent reduction in herbicide use, saving $200/ha/year in herbicides from having grassed inter-rows.

Capital costs incurred with making the change to improved management costs included a new irrigation system to facilitate fertigation, soil analysis and water monitoring equipment and a slasher to maintain grassed inter-rows. There are also ongoing costs associated with identifying plant nutrient requirements, liquid fertilisers, labour and maintenance. The case study did not specify the interest rate or the number of years that the NPV was calculated for. While the expected environmental benefits of adopting the improved management practices were listed, no monitoring of the impacts on FSS or DIN from adopting these practices was undertaken.

While there are no economic studies on the implementation of management practices for improved water quality, the *Tropical banana information kit* by Lindsay *et al*. (1998) and the spreadsheets by Bill Johnston (1998) and Andrew Hinton (2001a,b) provide some insights into the farming systems for Cavendish and Lady Finger bananas in north Queensland. These spreadsheets provide a snapshot in time of the practices and inputs that were used in the banana growing industry prior to the first Reef Plan.

7 Findings from RP140B economics of banana BMP research project

The economic analysis undertaken as part of this project has included grower case studies, economic representative studies, grower surveys and water modelling from practice change at the farm scale. The methodology used for the RP140B project is illustrated in the framework presented in Figure 5.

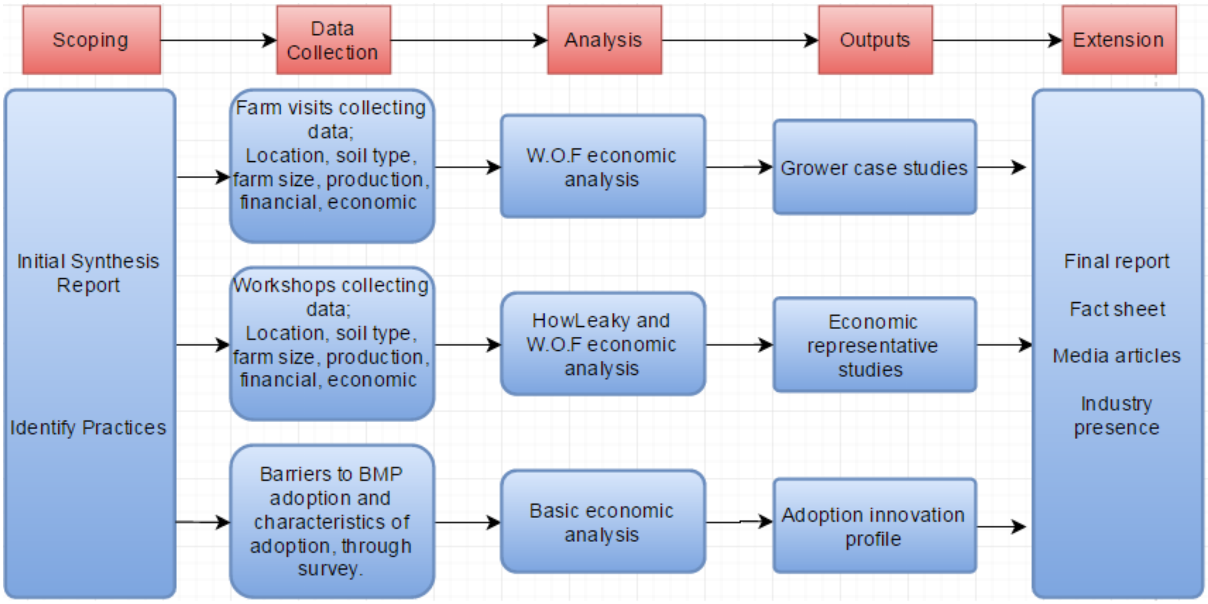

Figure 5: Framework of the RP140B Project

To help identify suitable banana growers for the case studies and narrow down the range of practices that will be modelled in the representative economic analyses, priority rankings from Terrain NRM, Paddock to Reef Program, DAF extension officers and advice from hydrology modellers was used to come up with the list of practices to consider for economic analysis in Table 7 below.

Table 7: Practices to be considered for economic analyses

Key Principle/ Indicator	Practice description by Terrain NRM Practice Description by P2R (in light blue) where different to Industry BMP/Terrain NRM	Terrain NRM [1] and P2R classes
Soil management – crop destruction **Crop removal**	The banana crop is removed by treating with herbicide and plants are left to break down before cultivation. Banana crop is killed with herbicide and plants are left to break down in the row area before cultivation.	B Moderate to Low Risk
	The banana crop is removed by mechanical practices with minimal soil disturbance e.g. light discing / mulching.	C Moderate Risk
Soil management - Land preparation **Tillage – plant crop**	Pre-formed beds using GPS & zonal-tillage. Crop planted into permanent beds. Row area only receives minimum tillage necessary for establishment.	A Moderate to Low Risk
	The row only is cultivated at the times of the year when the risk of erosion is low. Minimum tillage of whole block area, with row area only subject to more cultivation necessary to establish row profile and plant.	B Moderate Risk
	The whole block is cultivated at the times of the year when the risk of erosion is low.	C

Controlling run-off water - Slowing water	All blocks have been designed to slow surface water and direct it to an appropriate waterway capable of carrying high velocity water. Blocks are laser-levelled where required to prevent water from collecting in the paddock and creating wet areas.	B
	Most blocks have been designed to slow surface water and direct it to an appropriate waterway, although some corrective work is still required.	C
Controlling run-off water – contouring	If the farm has areas under banana production with a gradient over 3%, all blocks have been planted along the contour and include diversion banks and constructed waterways which have been accurately surveyed. For gradient over 3% ALL blocks planted on the contour and incorporating diversion banks and constructed waterways.	B Moderate to Low Risk
	If the farm has areas under banana production with a gradient over 3%, most blocks have been planted along the contour and include diversion banks and constructed waterways. For gradient over 3% MOST blocks planted on the contour and incorporating diversion banks and constructed waterways.	C Moderate Risk
Fallow/Crop rotation	A planted fallow crop is grown between banana crop cycles, on all fallow land for a minimum of 12 months. Fallow crop is planted between banana crop cycles or a volunteer grass fallow is maintained between crop cycles.	A Moderate to Low Risk
	Either a grass fallow or a planted fallow crop is grown between banana crop cycles on all fallow land (for less than 12 months).	B
	A weedy fallow grows between banana crop cycles.	C Moderate Risk
Ground cover	(i) At least 60% living ground cover is achieved in areas such as the inter-row space and headlands, excluding major roadways. OR (ii) In very dry areas only, where inter-row cover would have to be watered and where plant waste does not break down readily, greater than 60% inter-row ground-cover is achieved by retention & mulching of banana wastes. Living ground cover is maintained in the inter row space and headlands.	B Moderate to Low Risk
	At least 60% ground cover is achieved by a combination of living & dead matter in areas such as the inter-row space and headlands. This includes mulching banana plant material in the inter-row space, excluding major roadways. Living or dead, at least 60% cover is maintained in inter-row space and headlands.	C Moderate Risk
Nutrient application method	All fertigation, or a combination of fertigation and banded surface applications is used depending on the weather conditions.	B
	Banded surface fertiliser applications to rows only.	C
Fertiliser application frequency	Aim is to apply fertiliser fortnightly during high growth periods and reduce this during low growth periods such as winter. Weather conditions may mean that this is not always possible.	B
	Aim is to apply fertiliser monthly all year round.	C
Fertiliser program – nutrient budgeting	The fertiliser program **is** based on recommended rates for nitrogen and phosphorus.	B
	The fertiliser program **is not** based on recommended rates for nitrogen and phosphorus.	C
Fertiliser program – nutrient rates	The fertiliser program is supported by soil and leaf testing and yield monitoring. The program is revised annually and checked to ensure targets are updated and actually applied.	B
	The fertiliser program is supported by frequent soil and leaf testing and yield monitoring.	C

Source: compiled from Sing and Barron (2014) and Queensland Government (2015c).

Notes: 1.Terrain NRM management practice framework: A: aspirational practice; B: best practice; C: conventional practice and D: dated practice. Terrain NRM management practice classification is almost identical to that of the Industry Best Management practice ratings of best, okay and improve, where Terrain NRM B, C and D class practices is often the equivalent to industry best, okay and improve, respectively. The P2R ranking: MR: moderate risk; MLR: moderate to low risk. Practices with no P2R rankings are not included in the P2R Water Quality Risk Framework.

7.1 Grower case studies

As part of the RP140B project, three growers were selected with the assistance of DAF extension officers for case study analyses using the following selection criteria as a guide:

1. Growers who are willing participants in the project (i.e. willing to provide production data, economic data and consent for case study publication).
2. Growers who have made a change to Banana BMP's, preferably within the last 5 years.
3. Growers with detailed and accurate knowledge of their past and current farming system.
4. Farms from either Innisfail or Tully regions, ideally representing a cross section of business variability (e.g. farm size, location).

In 2016 and 2017, a DAF economist visited the farms of the growers and with their assistance developed a detailed whole farm economic analysis of their banana growing enterprise. Economic measures used to assess the impact of shifting to these BMPs were the annualised economic benefit (AEB) and net present value (NPV) which were discussed in section 'What does this mean for business?'. A summary of the results from the three case studies is presented below in Table 8 and the full case studies can be found online here.

Limited information about the effect of change of management practices on yields is available so it was assumed that yields would remain constant. Sensitivity analyses were undertaken for each case study to see just how sensitive the profitability was in implementing the management practices. Results found that profitability is highly sensitive to yields with both case study one and three becoming unprofitable with a decline in yield of less than one per cent and case study two a decline of 4.7 per cent.

The economic benefit estimate uses information available to estimate a stream of future benefits and costs to determine whether an investment made now will make a positive return on investment. A number of risks highlighted in section 'What about investment risk?' which are currently unknown will influence whether the return on an investment will be positive or negative in the long run and its magnitude.

These case studies offer detailed analysis of these specific banana growing enterprises adoption of particular management practices. Every business is unique and the results shown here will not necessarily apply to all growers considering these practices. However, a greater number of case studies capturing a range of banana growing enterprise characteristics and management practices will still provide insights for the greater farming community to help with the information gathering process.

Table 8: Case study summary results

	Case Study 1	Case Study 2	Case Study 3
Location	Bartle Frere	Tully	South Johnstone
Size (ha)	142	166	81
Management Practices implemented	• Laser levelling & contouring • Stabilised roadways • BMP fertiliser rates • Automated fertigation	• 2 year fallow period with a canola crop rotation[1]	• Improved inter-row management • Stabilised roadways • Laser levelling • Sediment traps
Environmental benefits	• Reduced sediment in run-off (TSS and PN) • Reduced fertiliser loss in run-off (DIN)	• Reduced sediment run-off (TSS and PN) • Reduced Pesticides	• Reduced sediment in run-off (TSS and PN)
Economic benefit ($/ha/year)[2]	$52	$2793	$62
Areas of cost savings	• Fuel & oil ($51/ha/year) • Fertilisers ($63/ha/year) • Labour ($136/ha/year)	• band spraying nematicides • Nematicides ($974/ha/year)	• Improved inter-row management ($125/ha/year) • Vehicle maintenance ($169/ha/year)
Areas of increased costs	• Contouring • Repairs & maintenance ($25/ha/year)	• Planting with canola spreader • Canola seed ($230/ha/year)	• Repairs and maintenance ($151/ha/year)
Capital Costs	$196 018	$2 000	$79 690
Discounted payback period[3]	6 years	Less than 1 year	7 years

Source: Cook *et al*. (2016), Cook and Kukulies (2017a,b)

Notes: 1. Assumed crop following canola fallow would have 10% higher yield and two ratoons more than the plough out replant scenario. 2. Economic benefit here is the annualised equivalent benefit (AEB) which is the net present value of an investment as a series of equal cash flows for the length of the investment. In case studies 2 and 3 an investment horizon of 15 years was used and for case study 1 an investment horizon of 10 years was used. 3. Discount rate used was 7 per cent.

7.2 Representative modelling

In this part of the project, the approach used was to develop representative farm scenarios that could be modelled to explore the economic and water quality implications of adopting stepwise management improvements, as well as exploring the impact of enterprise variability on profitability. In addition, information was gathered on the cost to purchase equipment needed to transition to improved management practices, so that an investment analysis could be conducted. A number of scenarios were analysed specifically for the combined core banana-growing regions of Tully and Innisfail. Data used to parametrise the modelling was collected from publications, industry sources, extension officers and workshops held with growers.

For each management practice scenario, separate models were created to account for the impact of variation in soil type and farm size, and on farm cost structures. Two broad soil types were identified as being the most common for banana farms in Innisfail and Tully: alluvial soils (Dermosols) and red clay (Ferrosols). Three farm sizes were represented in the practice scenario modelling: 15 hectares, 40 hectares, and 100 hectares. The combination of two soil types and three farm sizes results in six representative farms. Each of these farms was modelled for the 19 practice combinations resulting in 114 distinct scenarios.

Models were created with all of the practice groups[9] at B level, C level and D level, and to examine the impact on farm profitability of each practice in isolation, models were created based on all practice groups at C with individual practice groups at B, all practice groups at D with individual practice groups at C and all practice groups at D with individual practice groups at B. The economic modelling did not include any potential yield impacts of BMP adoption as there has been insufficient trial research done in the banana industry to quantify such effects.

The HowLeaky model (Rattray *et al*. 2004, Robinson *et al*. 2010) was used for modelling water quality for bananas because of its capacity to represent the key features of agronomic practices in the Paddock to Reef Water Quality Framework. HowLeaky is a water balance simulation model for exploring the impact of land use and management on water quality and water balance. A daily water balance model accounts for water flows – rainfall, evaporation, runoff, transpiration and deep drainage using simple mathematical relationships. The full report can be found here.

7.2.1 Results

The final results of the economic and water quality modelling found that shifting from all D practices to all C practices and all C practices to all B practices have positive economic and water quality abatement benefits across soil type and farm size (see Table 9).[10] Economic benefits of changing from all D to all C practices increased with farm size for both soil types, capturing likely economies of scale associated with implementing some practices and mostly in the shift from 15 to 40 hectares ($38 - $39/ha/year). Interestingly, the economic benefits of shifting from all C to all B practices decreased by $12/ha/year as farm size increased from 15 to 40 hectares and then increased by $56/ha/year from 40 to 100 hectares on the Dermosol soil. Shifting from all C to all B practices on Ferrosol soil saw economic benefits decrease with farm size, $139/ha/year from 15 to 40 hectares and another $7/ha/year from a 40 to 100 hectares enterprise.

[9] Some of the practices were grouped together where it was considered impractical or unlikely that an individual practice would be changed in isolation.

[10] The shift from D practice to B practice is not shown as it is the sum of D to C and C to B.

Table 9: Cost effectiveness results for whole system change

Original Practice	New Practice	DIN abatement (kg/ha/year)	TSS abatement (t/ha/year)	AEB ($/ha/year)		
				15 hectares	40 hectares	100 hectares
Dermosol soil						
All D	All C	18.6	9.7	492	531	544
All C	All B	12.6	0.3	1,134	1,122	1,178
Ferrosol soil						
All D	All C	21.8	12.7	497	535	549
All C	All B	14.7	0.4	1,506	1,367	1,360

Source: Holligan *et al*. (2017)

Note: DIN runoff and DIN drainage have been combined to provide a single DIN abatement figure. Annualised Equivalent Benefit (AEB), which is the net present value of an investment as a series of equal cash flows for the length of the investment, is used to present the economic results in an annual format for consistency with the timeframes used with the water quality modelling.

The water modelling results were the same per hectare regardless of farm size. The initial shift from all D to all C practices provided the greatest water quality benefits for both soil types, particularly with respect to TSS abatement. On both soil types TSS abatement increased by just 3 per cent when going from all C to all B practices compared with DIN abatement which increased by 67 per cent for the same shift. Overall, the modelling found that water quality benefits were higher for both DIN and TSS for practice change on the Ferrosol soils.

The effect of soil type on the economic results was marginal for practice change from all D to all C at around $5/ha/year for all farm sizes. However, modelling for practice change from all C to all B, Ferrosol soils provided $372/ha/year more for a 15 hectare farm, $245/ha/year more for a 40 hectare farm and $182/ha/year more for a 100 hectare farm than the same changes made on Dermosol soil farms of the same sizes. These results show that changing from all C to all B practices is still profitable for Dermosol soils, but it is even more profitable for Ferrosol soils.

These results indicate that policy efforts for practice change should be targeted at Ferrosol soils moving to B level, DIN abatement practices moving to B level and TSS abatement practices moving to C level. However, as economic benefits will vary based on farm size and soil type, individual analyses by growers considering changing practices should be undertaken to get a better understanding of the potential impact on their enterprise.

The above results (from Table 9) provide an overall picture when all identified improved practices for water quality outcomes are adopted together at the same time. However, this is often not the case in reality and growers will more often invest in practice change on a piecemeal basis depending on a number of factors such as upfront costs of the practices, timing in their crop cycle and available cash flow. Holligan *et al*., (2017) also presented results for changing individual practices to provide insights to which practices involve more costs and benefits from both a water quality and economic perspective. Figure 6 below shows the cost effectiveness in graphical form for only Dermosol soils. Table 10 below shows the results of that modelling from all D practices to individual C practices (and in the brackets from all C to individual B practices). It can be seen that there is quite a variation between practices.

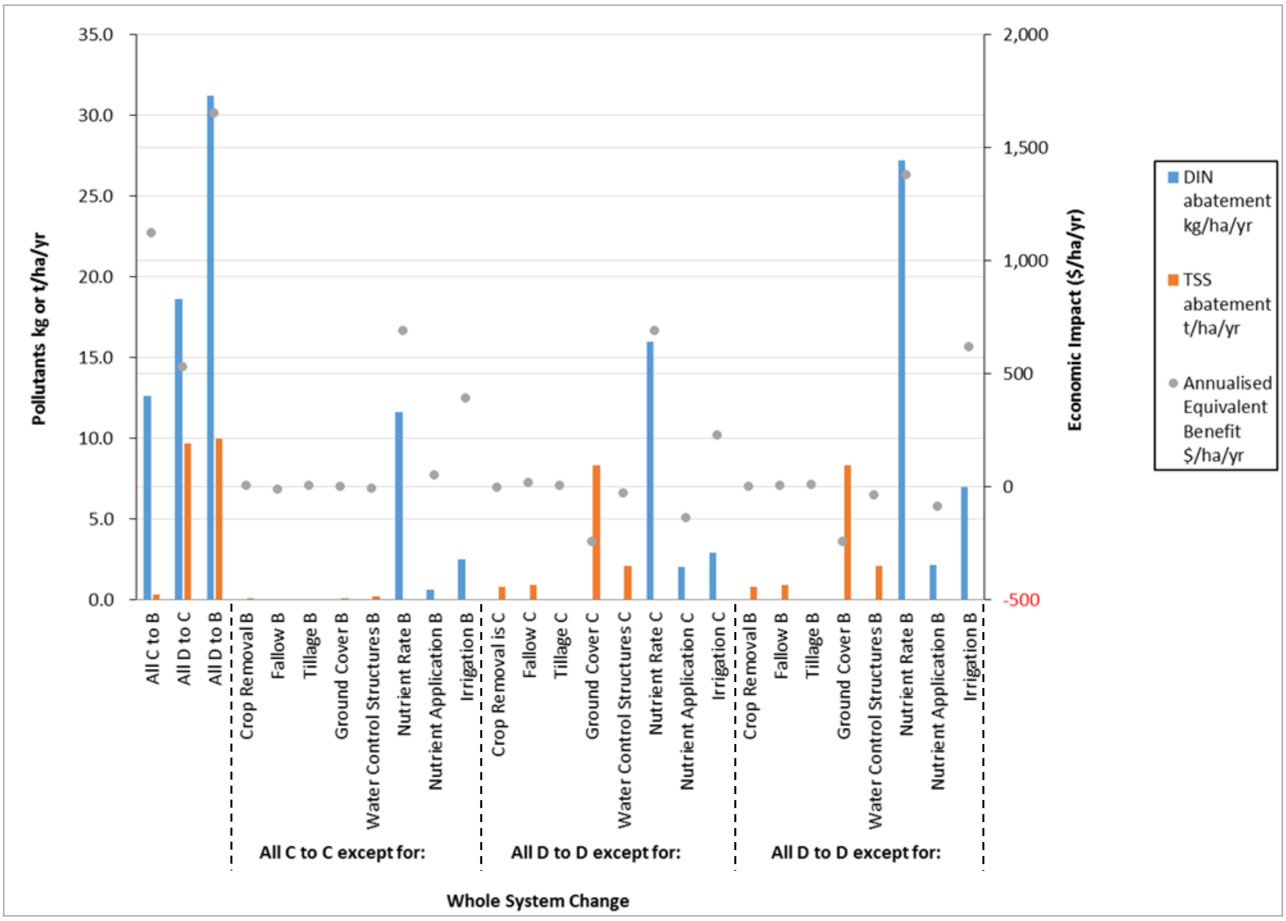

Figure 6: Cost effectiveness 40ha farm Dermosol soil

Source: Holligan *et al*. (2017**)**

Table 10: Cost effectiveness for individual practice changes

Original Practice	New Practice	DIN abatement (kg/ha/year)	TSS abatement (t/ha/year)	AEB ($/ha/year)		
				15 ha	40 ha	100 ha
Dermosol soil						
All D	All D, crop removal C	0.0	0.8 (0.1)	-4 (5)	-4 (5)	-4 (5)
All D	All D, fallow C	0.0	0.9 (0)	18 (-13)	18 (-13)	18 (-13)
All D	All D, tillage C	0.0	0.0	3 (6)	3 (6)	3 (6)
All D	All D, ground cover C	0.0	8.3 (0.1)	-243 (0)	-243 (0)	-243 (0)
All D	All D, water control structures C	0.0	2.1 (0.2)	-33 (-9)	-29 (-7)	-27 (-7)
All D	All D, nutrient rate C	16.0 (11.6)	0.0	690 (691)	690 (691)	690 (691)
All D	All D, nutrient application C	2.1 (0.6)	0.0	-173 (-10)	-140 (50)	-128 (71)
All D	All D, irrigation C	2.9 (2.5)	0.0	227 (464)	228 (391)	228 (425)
Ferrosol soil						
All D	All D, crop removal C	0.0	1.1 (0.1)	-4 (5)	-4 (5)	-4 (5)
All D	All D, fallow C	0.0	1.3 (0.1)	18 (-13)	18 (-13)	18 (-13)
All D	All D, tillage C	0.0	0.1 (0)	-1 (8)	-1 (8)	-1 (8)
All D	All D, ground cover C	0.0	10.7 (0.1)	-243 (0)	-243 (0)	-243 (0)
All D	All D, water control structures C	0.0	3.9 (0.2)	-94 (-29)	-89 (-28)	-88 (-27)
All D	All D, nutrient rate C	18.8 (13.3)	0.0	690 (691)	690 (691)	690 (691)
All D	All D, nutrient application C	2.6 (0.8)	0.0	-173 (-10)	-140 (50)	-128 (71)
All D	All D, irrigation C	3.6 (3.0)	0.0	296 (854)	298 (654)	298 (625)

Source: Holligan *et al*. (2017)

Note: Numbers in brackets represent value for when all C practices undertaken and an individual practice shifts to B practice. Annual Equivalent Benefit (AEB) is the net present value of an investment as a series of equal cash flows for the length of the investment

The water quality modelling results found that reducing fertiliser rates was the single most important driver of DIN abatement on all farms (up to 32.2 kg N/ha/year reduction moving from D to B class rates was responsible for 88 per cent of total DIN reduction on Ferrosol soils) and delivered positive economic benefits of $690/ha/year regardless of farm size or soil type. Irrigation practices also provided some DIN abatement (up to 5.4 kg N/ha/year moving from D to B class) and positive economic benefits of around $228/ha/year for C class/Dermosol/all farm sizes up to $854/ha/year for B class/Ferrosol/15 ha farm. In contrast, improving nutrient application methods from D to C level had economic costs across all farm sizes, only making an economic return at the B level for farms 40 and 100 hectares in size (soil type had no impact). This is likely due to the investment of a spreader capable of banded application (D to C level) and fertigation infrastructure (C to B level). It was also the smallest contribution to DIN reduction of the three practices that targeted it.

Increasing ground cover on inter-rows and headlands was the most important practice in terms of reducing sediment loads in runoff (up to 10.8 tonnes/ha/year reduction moving from D to B class ground cover was responsible for 82 per cent of total TSS reduction on Ferrosol soils). Shifting ground cover from D to C class dramatically reduced soil erosion by a factor ~10, mainly due to addition of grassed inter-rows. In contrast to practices that reduced DIN, most of the practices targeting TSS abatement incur economic costs. While these costs are quite minor for tillage, crop removal, fallow and water control structures they increase substantially for implementing ground cover at the C level ($243/ha/year) which is the most effective practice in reducing TSS. Only level C fallow practices and level C and B tillage practices on Dermosol soil and tillage practices at level B on Ferrosol soils provided positive economic benefits in the modelling scenarios.

Pesticides were modelled for water quality impacts and economic benefits of practice change. In particular, glyphosate, chlorothalonil and glufosinate-ammonium applications were modelled for Dermosol and Ferrosol soils. Pesticide loss behaviour was similar for the three pesticides with most pesticide lost in runoff, compared to leaching. These results imply that management of erosion and sediments would not be effective in significantly reducing pesticide runoff losses. Given that total runoff cannot be managed, the most effective way to reduce pesticide losses via run off into waterways would be to reduce application rates and or frequency of applications.

7.2.2 Limitations and future work

Holligan *et al*., (2017) note the limitations of their work as:

- Only three farm sizes.
- Only two soil types modelled – doesn't account for specific soil type, farm layout, topography, pest pressures, rainfall patterns.
- Grower experience and financial situation, existing infrastructure and farming systems not incorporated.
- Potential effect of BMP implementation on banana yields – no published information available at time of modelling.
- The model assumes that erosion is primarily a sheet erosion process and does not account fully for rill or gully erosion – site monitoring data suggests that rill erosion on wheel track areas may disproportionally contribute to erosion even when high levels of grass cover are present between wheel tracks.
- The water quality effect of the application methods (broadcast, banded, fertigation) could not be represented in the modelling. The capacity to include application method is limited by a lack of data on the implication for off-site loss.
- The impact of management practice changes on DIN in deep drainage is still poorly understood. Modelling DIN in drainage is sensitive to denitrification losses as the other major pathway of loss for excess. Further trials in this area of denitrification losses would be beneficial.

These factors can all influence the operating and investment costs faced by each farming business, which can in turn affect the impact of BMP adoption on farm profitability. Further research may be required to explore the extent that these factors may affect the impact of BMP on profitability.

Holligan *et al*., (2017) note that another avenue for future research is the potential effect of BMP implementation on banana yields to give growers confidence in adoption. Specific BMP changes may be beneficial in terms of yield, such as controlled traffic, permanent beds, improved irrigation, fertiliser practices and improved farm design. However, research to date has been insufficient to include any yield impacts in this analysis. One exception is a recent study, which demonstrates that there is generally no significant difference in yield between C class and B class for N application and inter-row management (Masters *et al*, 2017). In addition, the lack of historical yield data limits our ability to conduct risk analyses.

As previously discussed, improvements to farm design, including water control structures, may lead to numerous cost reductions in a range of areas that are difficult to quantify. Some of these improvements have been examined in the case study component of this project, however further research into this area is still required. Further limitations to the economic modelling are that practice change often occurs progressively over a number of years with the investment analysis not taking this into account and that transaction costs, when adopting BMP, are not accounted for.

7.3 Survey and Adoption and innovation profile report

7.3.1 Methodology

The third part of the survey involved surveys of banana growers. The main objective of the survey study is to report on identified key characteristics of best management practices as perceived by north Queensland banana producers. The aim is to gain a better appreciation of the opportunities and constraints banana growers face in adopting various best management practices. This information collected via a face to face survey in the Tully and Innisfail regions, will assist in understanding the linkages between the types of banana growing enterprises, opportunities and constraints of shifting management practices and possible barriers to adoption.

A key mechanism to improve the water quality entering the Great Barrier Reef (GBR) is the adoption of best management practices by farmers in the GBR catchment area. Management practice adoption is a complex decision-making process motivated by many factors including growers' perceptions of a practice's impact on profitability. The survey focussed on how growers perceive the adoption of a selection of management practices with respect to some key characteristics around production and profitability.

The management practices included in the survey and subsequent analysis were based on the Banana Best Management Practices Environmental Guidelines (King, 2008) and the Paddock to Reef Water Quality Risk Framework for Bananas (Queensland Government, 2015c). King (2008) uses a 'best', 'okay' and 'improve' criteria while the Water Quality Risk Framework (Queensland Government, 2015c) uses 'high risk (superseded), 'moderate risk (minimum)' and 'moderate – low risk (best practice)' criteria. The seven practices were: crop removal, fallow crop, tillage, ground cover, fertiliser rates, fertiliser application, and fertiliser application frequency.

The data analysed in this report is drawn from surveys completed by forty-six banana growers from the two major banana growing areas in north Queensland between May and July 2017. Each grower was asked 13 closed-ended questions (and 2 open-ended) over four separate sections. The duration of the interviews ranged from 30 minutes to 2 hours, depending largely on the extent of additional comments provided by growers regarding their specific farm practices or the level of detail provided in response to open ended questions. The questions were designed to identify grower attitudes towards best management practices, history of practice adoption, as well as a general description of grower characteristics and farm attributes characteristics.

7.3.2 Results

Adoption rates for the seven practices included in the survey were all quite high, ranging from 72% - 87% of those growers surveyed. Each of these practices were analysed separately in terms of impacts on economic implications and the perceived barriers for adopting the practice. Overall, grower perceptions of practice adoption were that positive economic impacts would encourage adoption. Barriers for adopting the practice were perceived to be low and therefore would not generally discourage adoption.

Grower perceptions on the best management practices surveyed were compared. While best practice for crop planting and tillage was perceived to have slightly positive economic impacts, it was the only practice that had more than one characteristic that was perceived to be a barrier to adoption: high capital investment needed and requires new skills and information. The other best management practices that had perceived barriers to adoption were fertiliser application method (fertigation) needing high capital investment and fortnightly fertiliser application frequency with a perceived slight increase to production costs. Living ground cover and fertiliser rates best management practices did not reveal any perceived negative economic impacts from the surveyed growers (although production costs for best management practice living ground cover were ‘no impact’) or perceived barriers to adoption with respect to practice characteristics (although best management practice fertiliser rates were neutral for contractors needed to implement change).

Transaction costs were collected throughout the surveys and these led to the identification of key insights. Those growers who invested low levels of resources before adopting practices may be benefitting from adopting practices that have been well trialled and proven for their farming system or are savvy in accessing resources through ABGC, Terrain or DAF to limit their personal transaction costs in the decision process to adopt. Those who have invested high levels of resources before adopting may be investigating innovative practices or adaption of practices to their particular farming system or conditions, they may be distrustful of organisations knowing about their farming system or have high levels of risk aversion.

For each management practice, growers were classified as either adopters or non-adopters for a particular practice depending on which practices they indicated they had adopted in question 9 of the survey. The perceptions of adopters and non-adopters were analysed to assist in further identifying barriers to adoption.

The differences in perceptions between adopters and non-adopters on economic impacts were significant (at the 0.05 level) for enterprise profitability for the practices of fertiliser rate and method. In addition, production costs has a significant (at the 0.05 level) difference for the practice of fertiliser application frequency. It can be interpreted that fertiliser rate, method and frequency could be practices where there is a disconnect between adopters and non-adopters in terms of their perceived economic impacts.

It can be seen that the practice characteristic; doesn't fit in with current system, differs between adopters and non-adopters significantly (at the 0.01 level) for the practices; fertiliser rate and nutrient application method of fertigation, and significantly (at the 0.001 level) for the practice; crop removal using herbicide. This result may be self-confirming given that adopters have in fact already found a way of incorporating the practice into their system. However, it does underline that adoption is highly dependent on fitting with the broader farming system.

The practice characteristic; contractors needed to implement change, differs between adopters and non-adopters significantly (at the 0.05 level) for the practice of fertiliser rate. This can be interpreted that non-adopters perceive that contractors are needed for fertiliser rate change and slightly discourages adoption, but adopters believe that it is neutral and does not affect adoption.

When analysing farm attributes with adopters and non-adopters, a close relationship was identified (at a significance level of 0.053) for the farm attribute of gradients combined with the practice of fertiliser application frequency. This result suggests that the level of gradient on a farm could influence a grower to adopt the practice of fertiliser application frequency.

7.3.3 Limitations and future work

The survey sampling methodology is subject to self-selecting bias and growers who have engaged in adopting best management practices are more likely to want to participate, which may explain the high rates of adoption of the practices included in the survey. However, even though it was a face to face survey, the rate of participation was good. There were around 30% of total growers in the Tully and Innisfail areas surveyed, although the sample size of 46 is still likely to be too small to fully counter the self-selection bias. At the time the project was trying to get growers interested in taking part in the survey there was a second incursion of Panama disease TR4. As a result this may have had an impact on growers' availability to participate in the survey, and interest in water quality impacts for the reef would have been a lower priority at that time.

Like all surveys, there were only so many questions that could be asked to make it tractable and there will always be other questions that could have been included in hindsight. There will also be variability in how individual growers have interpreted questions. By conducting face to face surveys it was hoped to minimise this, however, most growers struggled to work through the larger questions at the end and the answers given may have been influenced by the project officer conducting the survey.

It is worth noting that this is the first study focused on growers' perceptions of adopting best management practices for banana growing in the Wet Tropics region and it provides a starting point to move forward from.

Several recommendations came out of this study. Firstly, further case study analyses of banana farming systems adopting or adapting practices to reduce their off farm water quality impacts could capture the diversity and complexities in banana farming systems. Secondly, greater funding made available could reduce transaction costs of farmers looking into innovative practices. Lastly, a review of the best management practices could include more innovative practices and make more funding available.

8 Priorities for further work

Research that clarifies and communicates the relative advantage of BMP adoption can aid growers in evaluating the benefits of practice changes that enable water quality improvements and encourage adoption. Further, provision of information that helps growers to improve profitability and save time may position them to research, trial and adopt additional practices that can help improve water quality outcomes. Priorities for future work from the Technical Report and Adoption Innovation Profile Report are listed below:

- Factors that influence the operating and investment costs faced by each farming business (such as farm size and soil type), can in turn affect the impact of BMP adoption on farm profitability. Further research may be required to explore the extent that these factors may affect the impact of BMP on profitability. Trials considering the economic impacts of particular practice changes may complement whole-of-farm economic analyses.
- Researching the potential effect of BMP implementation on banana yields to give growers confidence in practice adoption.
- Improvements to farm design, including water control structures, may lead to numerous cost reductions in a range of areas that are difficult to quantify. Some of these improvements have been examined in the case study component of this project, however further research into this area is still required.
- Further case study analyses of banana farming systems adopting or adapting practices to reduce their off farm water quality impacts could capture the diversity and complexities in banana farming systems.
- Greater funding made available could reduce transaction costs of farmers looking into innovative practices.
- A review of the best management practices could include more innovative practices and make more funding available.

9 Project Key Findings

There are a number of key findings from this project. First, the economic research presented here indicates that over the past decade the banana industry has experienced a number of events that have had negative economic ramifications. The banana growing regions of Tully and Innisfail were severely impacted by tropical cyclones in 2006 and 2011 with many plantations' production severely impacted in the months afterwards. There is also the recent discovery of Panama diseaseTR4 in the Tully region which has resulted in significant investment in farm biosecurity measures to prevent pest and disease incursion across the entire Wet Tropics region.

Second, banana growing practices that contribute to higher than naturally occurring levels of suspended sediments, nutrients and pesticides is of concern to industry, the broader community and government. While the focus for water quality practice change investment and action in the past has been very much on grazing and sugarcane industries, the banana industry is coming under increasing scrutiny for its contribution to pollutants entering the GBR lagoon. The banana growing industry has been proactive in developing a BMP guide that specifically includes components addressing the movement of sediment, nutrients and chemicals off-farm and the Terrain NRM Management Practice and Paddock to Reef water quality risk frameworks draw heavily from this guide. While comprehensive, there are still gaps in the BMPs for water quality outcomes, such as alternatives for managing traffic in inter rows to prevent the forming of wheel ruts which contribute to sediment losses. There have been a number of studies looking at the water quality implications of management practices, particularly grassed inter-rows and fertiliser rates and application methods, however, the focus has mainly been on measuring the hydrological impacts and not quantifying the economics of moving to these BMPs for growers.

Third, this project has made a significant contribution to increasing knowledge around the economic impacts of changing to management practices with improved water quality impacts. The initial synthesis report was only able to find four studies, only one of which included some estimate of the water quality impacts of implementing best management practices. This project has contributed to the body of knowledge by undertaking economic work at the practice level, which integrates water quality data in to the analysis to identify the most cost-effective practices that achieve the desired water quality outcomes. It has addressed the gap in the existing economic literature on banana BMPs by incorporating enterprise heterogeneity in the two main regions of banana production in the Wet Tropics - specifically farm sizes, soil type and management practice characteristics. This project has also assisted in understanding the linkages between the types of banana growing enterprises, opportunities and constraints of shifting management practices and possible barriers to adoption.

10 Appendix 1 – Terrain NRM Wet Tropics Banana Management Practices

The ABCD frameworks for bananas cover: nutrient management, soil management, weed management, irrigation and integrated pest and disease management (see Table 11).

Table 11: Wet Tropics Practice Framework R11, Banana

R11 - Bananas	A	B	C	D	N/A
Soil Management					
BS25.0 Cultivation method and timing - crop Destruction	-	The banana crop is removed by treating with herbicide and plants are left to break down before cultivation.	The banana crop is removed by mechanical practices with minimal soil disturbance eg light discing / mulching.	The banana crop is removed by heavy discing green plant material repeatedly.	
BS1.0 Cultivation method and timing - Land Preparation	Pre-formed beds using GPS & zonal-tillage.	The row only is cultivated at the times of the year when the risk of erosion is low.	The whole block is cultivated at the times of the year when the risk of erosion is low.	The whole block is cultivated at any time of the year.	
BS26.0 Controlling run-off water - Contouring	-	If the farm has areas under banana production with a gradient over 3%, all blocks have been planted along the contour and include diversion banks and constructed waterways which have been accurately surveyed.	If the farm has areas under banana production with a gradient over 3%, most blocks have been planted along the contour and include diversion banks and constructed waterways.	The farm has areas under banana production with a gradient over 3% but there are no control structures in place.	The farm does not have areas under banana production with a gradient over 3%.
BS2.0 Fallow/Crop Rotation	A planted fallow crop is grown between banana crop cycles, on all fallow land for a minimum of 12 months.	Either a grass fallow or a planted fallow crop is grown between banana crop cycles on all fallow land (for less than 12 months).	A weedy fallow grows between banana crop cycles.	There is no fallow period between banana crop cycles or bare fallow is left between crop cycles.	
BS27.0 Riparian Vegetation	Native riparian vegetation at 20m wide for creeks and 50m for rivers along 100% of their length.	Native riparian vegetation is present at less than 20m wide for 100% of the length of all creeks and rivers.	Native riparian vegetation is present for at least 50% of the length of all creeks and rivers.	Native riparian vegetation is present for less than 50% of the length of all creeks and rivers.	No natural water ways on farm so no riparian vegetation.
BS28.0 Controlling run-off water - Silt Traps	-	Silt traps have been designed, constructed and located with expert advice and satisfactorily address the targeted sediment issue.	Silt traps have been designed, constructed and located with expert advice. , however some sediment loss indicates further work is still required.	Silt traps have been designed, constructed and located without expert advice.	No silt traps present on farm.
BS29.0 Controlling run-off water - Drains	All constructed drains on-farm (deep or shallow) are vegetated spoon shaped drains.	Most constructed drains on-farm are vegetated-shallow-spoon drains and any box drains have a batter suited to the soil type so they do not erode.	Most constructed drains on farm are box drains with steep batters & little vegetative cover.	-	No constructed drains on farm.
BS30.0 Ground Cover	-	(i) At least 60% living ground cover is achieved in areas such as the inter-row space and headlands, excluding major roadways. (ii) In very dry areas only, where inter-row cover would have to be watered and where plant waste does not break down readily, greater than 60% inter-row ground-cover is achieved by retention & mulching of banana wastes.	At least 60% ground cover is achieved by a combination of living & dead matter in areas such as the inter-row space and headlands. This includes mulching banana plant material in the inter-row space, excluding major roadways.	Areas such as inter-rows and headlands are bare.	
BS40.0 Mulching	-	Harvested heads and leaves are left on the row or in drier areas harvested heads are mulched in the inter-row space providing ground cover.	Harvested heads and leaves are left where they drop.	Harvested heads and leaves are removed from the row and placed in the inter-row space.	

R11 - Bananas	A	B	C	D	N/A
Nutrient Management					
BN31.0 Soil testing - Pre-Plant	-	100% of blocks are soil tested before planting.	Most blocks are soil tested before planting.	Soil testing before planting is infrequent or not done at all.	
BN32.0 Soil testing - Ratoons	Soil tests are taken on all blocks more than once a year.	Soil tests are taken on all blocks once a year.	Soil tests are taken less than once a year or on fewer than all blocks	No or little soil testing.	
BN33.0 Leaf Testing	-	Paired leaf and soil tests are taken on all blocks at least annually.	Paired leaf and soil tests are taken at indicator sites at least annually or tissue tests taken throughout the year but not paired with soil tests.	Leaf tests are taken less than annually or not at all.	
BN34.0 Fertiliser program – selecting nutrient types and amounts (Nutrient rates)	-	The fertiliser program is supported by soil and leaf testing and yield monitoring. The program is revised annually and checked to ensure targets are updated and actually applied.	The fertiliser program is supported by frequent soil and leaf testing and yield monitoring.	There is no planned fertiliser program and/or the rates applied are not based on soil and leaf test results.	
BN35.0 Fertiliser program – nutrient budgeting	-	The fertiliser program is based on recommended rates for nitrogen and phosphorus.	The fertiliser program is not based on recommended rates for nitrogen and phosphorus.		
BN36.0 Fertiliser application frequency	-	Aim is to apply fertilizer fortnightly during high growth periods, and reduce this during low growth periods such as winter. Weather conditions may mean that this is not always possible.	Aims is to apply fertiliser monthly all year round.	Fertiliser is applied less frequently than monthly.	
BN37.0 Fertiliser application method	-	All fertigation, or a combination of fertigation and banded surface applications is used depending on the weather conditions.	Banded surface fertiliser applications to rows only.	Fertiliser broadcast over rows and inter-row spaces.	
BN22.0 Water and fertiliser distribution efficiency	-	Water uniformity and distribution is tested and above 90%.	Water uniformity and distribution is tested and above 80% but below 90%.	Water uniformity and distribution is tested and below 80% or not tested and therefore unknown.	
Irrigation					
BN19.0 Method of Irrigation	-	100% under-tree sprinklers or drip and an automated system.	100% under-tree sprinklers or drip and a manual system.	Some overhead irrigation.	
BN21.0 Soil moisture monitoring	Irrigation schedules are based on capacitance probes and weather stations and are fully automated.	Irrigation schedules are based on capacitance probes or tensiometers and use a manual system.	Scheduling based on subjective tools e.g. feel, inspection of soil, water availability and area.		
Integrated Pest and Disease Management					
BP38.0 Pest & disease Monitoring	-	Pest and disease levels are monitored on a regular and consistent basis by trained staff or service providers. Records are retained and treatment are applied using monitoring information and relevant threshold levels for each pest/disease.	Pest and disease levels are monitored by general observations when doing other activities and control methods applied accordingly.	Pest and diseases are not monitored on a regular basis. Spray treatments are applied on a calendar basis or in response to severe outbreaks.	
BP39.0 Pesticide Resistance	-	A rotation program is in place to ensure products are applied correctly and rotated according to label instructions, to prevent resistance from developing.	Attempts are made to rotate between chemical groups according to label instructions, but there is no effective rotation program in place.	Chemicals are not rotated to avoid resistance.	
General					
BP16.0 Disposal of shed water	Settlement and filtration ponds used to remove all extraneous material including post harvest chemicals before release into local waterways.	Filtration in place to remove fine particles and larger debris before releasing water into local drains or waterways.	Grates in the shed to remove large debris before water is released into local drains or waterways.	No filtration of any sort in place and water from the packing shed is disposed of into adjacent drainage lines or waterways.	
BR23.0 Record keeping	As in B below, but including automated field data collection from tractor-mounted computers/controllers with associated recording and reporting functions.	Detailed computer-based records of field activities, farm inputs, production results and monitoring data (eg soil analyses, weed-survey, water-quality) & any nutrient/weed management plans	Detailed paper-based records of field activities & inputs (eg nutrient rates in kg/ha, types & rates of herbicides etc) as well as production records	Pocket diary of a limited range of farm operations.	

Source: Sing, N., Barron, F., (2014).

11 Appendix 2 – Improved Practices Catalogue

The Improved Practices Catalogue (IPC) provides information to help producers in reef catchments "identify and adopt better land management practices … The aim is to support agricultural profitability while improving the quality of water in the Great Barrier Reef as part of the Reef Plan initiative." There are guides for the Sugarcane, Grazing and Banana growing industries (Department of Agriculture and Fisheries, 2014).

There are three categories or guides listed for the banana industry under the IPC:

1. Optimise nutrient rate and application;
2. Optimise pesticide use as part of a pest management plan; and
3. Optimise soil retention and water infiltration.

Under each of these categories are a series of management practices that contribute to overall goal captured in the category heading (see Table 12).

Table 12: Improved Practice Catalogue for Banana Industry

Category	Improved Practices
Optimise nutrient rate and application	1. Regular soil, leaf and/or sap nutrient testing to inform nutrient application (e.g. bananas pre-plant soil test and paired leaf and soil tests at least annually).
	2. Multiple applications timed to irrigation and rainfall, including methods of fertigation, foliar and band application
	3. Regular calibration of fertiliser and/or fertigation equipment, particularly by product type and batch.
Optimise pesticide use as part of a pest management plan	Flexible management strategies based on block monitoring and taking into account:
	1. Weed species, stage of weed and crop growth
	2. Pest threshold numbers, populations of beneficial species and levels of crop damage
	3. Block history, prevailing environmental conditions, chemical options, rate and timing of applications, and selection equipment
	4. 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	1. Minimising tillage throughout crop cycle
	2. Maintaining or establish groundcover during high risk periods. E.g. grassed inter-rows and trash placement for bananas
	3. Managing headlands, vegetation buffers, drains and sediment traps to capture and/or filter run-off from the production area (this relates to vegetated headlands that are not highly trafficked by farm equipment).
	4. Mechanically cultivating across the slope
	5. Scheduling irrigation based on soil properties, crop growth requirements, and monitoring of soil moisture and weather forecasts.
	6. Managing fallow with cover or break crop.

Source: Department of Agriculture and Fisheries, (2014).

12 Appendix 3 - 2015 Paddock to Reef Water Quality Risk Framework for Bananas

Table 13: 2015 Paddock to Reef Water Quality Risk Framework for Bananas

Management	Weighting (WQ Risk assessment)	High Risk	Moderate Risk	Moderate - Low Risk
		Superseded	Minimum	Best Practice
Runoff & Soil Loss				
Crop Removal	10%	Banana crop is removed through being knocked down and repeated disc ploughing	Banana crop is removed through mulching and/or light discing which minimises soil disturbance.	Banana crop is killed with herbicide and plants are left to break down in the row area before cultivation.
Fallow management	20%	Land is maintained bare between crop cycles, or there is no fallow period between crop cycles	Weedy fallow grows between banana crop cycles	Fallow crop is planted between banana crop cycles, or a volunteer grass fallow is maintained between crop cycles.
Tillage - plant crop	15%	Whole block is cultivated in preparation for planting	Minimum tillage of whole block area, with row area only subject to more cultivation necessary to establish row profile and plant.	Crop planted into permanent beds. Row area only receives minimum tillage necessary for establishment.
Ground cover	35%	Inter-rows and headlands are sprayed or cultivated bare.	Living or dead, at least 60% cover is maintained in inter-row space and headlands.	Living ground cover is maintained in the inter-row space and headlands.
Controlling runoff - contouring	10%	Production areas with gradient of 3% or more, but no control structures in place.	For gradient over 3%, MOST blocks planted on the contour and incorporating diversion banks and constructed waterways	For gradient over 3%, ALL blocks planted on the contour and incorporating diversion banks and constructed waterways
Controlling runoff - drains	5%	Constructed drains are mostly box drains with straight sides.	Most constructed drains are vegetated shallow spoon drains. Any box drains have a batter suited to the soil type to minimise erosion.	All constructed drains are vegetated shallow spoon drains

Sediment traps	5%	No sediment trapping structures in place.	Some sediment trapping structures. Insufficient capacity and/or design issues mean that significant amount of sediment can leave the farm in heavy events.	Expert advice informs design, construction and location of sediment traps that are effective across the entire production area.
Nutrients				
Soil testing	10%	No soil testing before planting	Soil testing before planting is infrequent and/or does not occur on all blocks being planted.	All blocks are soil tested pre-planting. Fertiliser rates for plant crop are adjusted based on soil test results.
Matching nutrient supply to crop demand	60%	N & P fertiliser rates are based on historical target rates with infrequent testing and/or no adjustment for yield potential	N & P fertiliser rates are supported by soil and leaf testing and yield monitoring.	Fertiliser program based on recommended rates for N & P and supported by leaf and soil testing and yield monitoring. Revised annually to ensure targets are achieved.
Fertiliser application frequency	15%	Fertiliser is applied less frequently than monthly.	Monthly fertiliser applications all year around	Aim to apply fortnightly during high growth periods and less frequently during low growth periods.
Fertiliser application method	15%	Fertiliser broadcast over rows and inter-row spaces.	Banded surface fertiliser application on row area only.	All fertigation. Banded surface application if wet weather rules out fertigation.
Water				
Irrigation method	35%	Some overhead irrigation	All irrigation is drip or micro sprinkler system, manually operated.	All irrigation is automated drip/micro sprinkler system underneath trees
Irrigation scheduling	65%	No soil moisture monitoring tools are used in scheduling irrigation.	Irrigation schedules are based on capacitance probes or tensiometers. Manually operated.	Irrigation schedules are based on capacitance probes and weather stations and are fully automated.

Source: Queensland Government (2015)

13 Appendix 4 - Farm business environment and risk

There are a number of factors that affect the profitability of banana production, including major aspects such as input costs, pest and disease incursions and tropical cyclones. Of particular relevance is the incursion of Panama disease tropical race 4 that has the potential to severely affect production in the Wet Tropics. How these risks are managed can have significant economic implications for growers.

13.1.1 Labour

Labour makes up a large proportion of production costs for most banana growing enterprises. This is due to the heavy labour requirement of banana farms and the price of labour. In 2009-10 this was estimated to be 39 per cent of grower expenditure, excluding contract packing (Hall & Gleeson, 2013). Research by Hall (2014) indicates that a farm's labour use efficiency is a critical determinant of profitability. The labour force is comprised of backpackers, seasonal workers, family and local workers. It is difficult to achieve economies of scale because the labour costs are relatively higher in bananas, compared to other agricultural industries (e.g. sugar, grains) and increasing farm size proportionally increases labour and associated variable production costs (Lindsay, Stewart, pers. comm., 04/11/15). The Horticultural Award 2010 (MA000028) for casual workers aged over 20 years ranged from $22.86 to $26.61 depending on level of experience (Australian Government, 2017b).

13.1.2 Diesel

Another key input into banana production is diesel fuel. Due to the crop being perennial, plants across the farm are usually in different production stages to ensure constant supply; hence activities need to be completed in terms of individual plant, block and farm at any point in time. This results in many vehicle hours in production, such as four-wheel-drive and quad bikes. Figure 7 shows the average diesel price paid by Australian farmers, excluding Good and Services Tax (GST) and farm rebates, but including the fuel tax credit subsidy (Australian Taxation Office, 2016). Over the last three years, the price of diesel has declined in real terms to where it was 20 years ago (Australian Bureau of Agricultural and Resource Economics and Sciences, 2015b). Table 14 shows fuel prices alongside fuel tax credits to show the net of fuel tax credit cost.

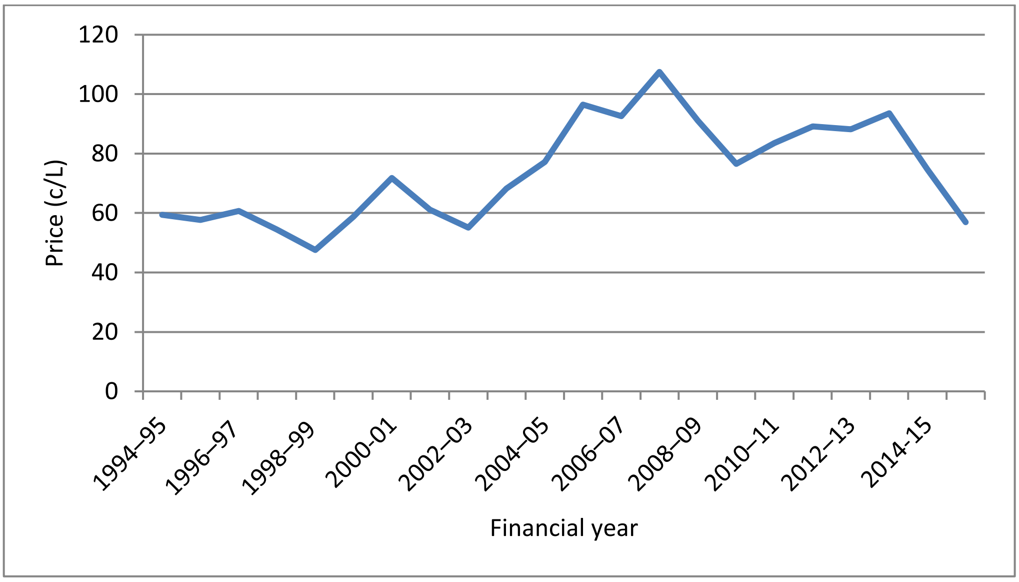

Figure 7: Australian real Diesel price, 1993-94 to 2015-16 (base 2011-12)

Source: Input prices sourced from ABARES, (2016). Prices deflated using Consumer Price Index (CPI) measures sourced from: Australian Bureau of Statistics, (2015).

Table 14: Average diesel prices for Innisfail and Tully, 2012 to 2016

Year	Tully (c/L)	Innisfail (c/L)	Average (c/L)	Net of GST (c/L)	Fuel tax credit (c/L)	Net of fuel tax credit (c/L)
2012	153.1	154.5	153.8	139.8	38.1	101.7
2013	157.8	159.3	158.6	144.1	38.1	106.0
2014	162.6	163.7	163.1	148.3	38.1	110.2
2015	128.3	135.0	131.7	119.7	38.9	80.8
2016	122.6	119.2	120.9	109.9	39.4	70.6
					Average	***93.8***

Sources: Royal Automobile Club of Queensland (RACQ) (2017), Australian Taxation Office (2016)

13.1.3 Fertiliser

Urea fertiliser is the main source of nitrogen used by banana farms. Fertigation often occurs fortnightly in the dry periods, but larger amounts of fertiliser are applied monthly using broadcast applications in the wet periods. Unlike diesel, the trend for the cost of urea in real terms over a 20 year period appears to be relatively flat. The real cost of urea is characterised by falling prices up to 2003-04 which is then offset by a large shock occurring in 2007-08 and 2008-09 when prices significantly increased before falling again in 2011. Figure 8 shows the bagged price from 1992 to 2001 and the bulk price from 2002 onwards.

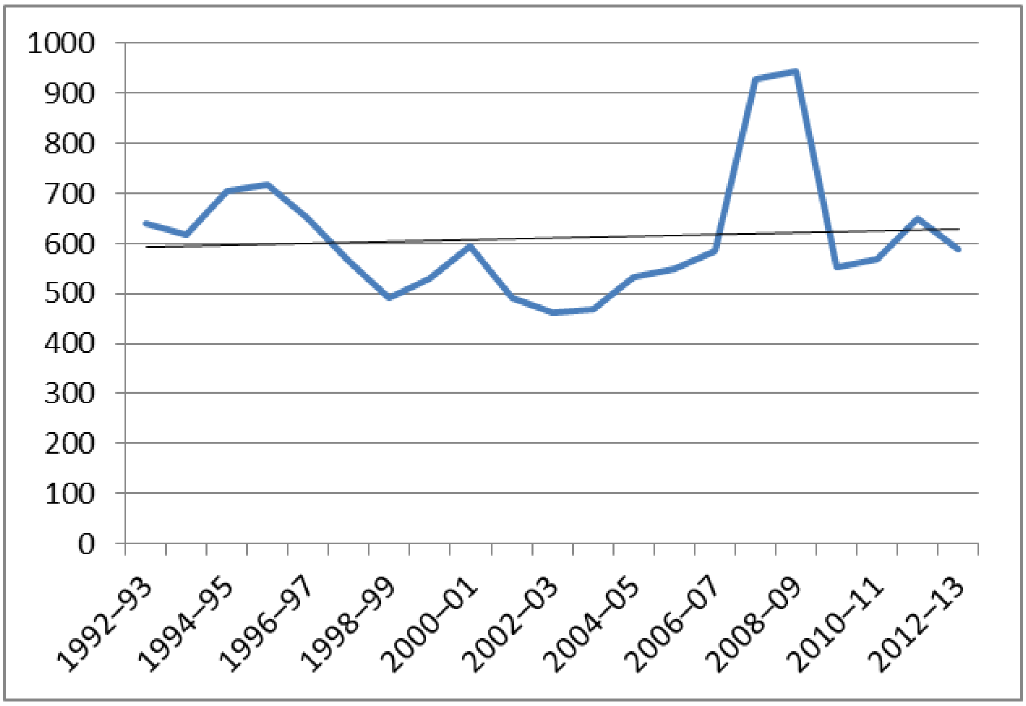

Figure 8: Australian real Urea price ($/t), 1992-93 to 2012-13 (base 2011-12)

Source: Input prices sourced from ABARES, (2016). Prices deflated using CPI measures sourced from: Australian Bureau of Statistics, (2015).

13.1.4 Pesticides

Pesticides are used as part of an Integrated Pest Management (IPM) program on farm. Pesticides are not deemed a high priority for water quality improvement and are not included as part of the Paddock to Reef Risk Framework due to the characteristics of use within the banana production system. This includes only occasional use of residual herbicides and that frequently used insecticides and fungicides are generally used in small quantities with very targeted application such as spot spraying (Terrain NRM 2015: 48).

13.1.5 Other inputs

Irrigation is supplied to the whole banana farm and can be scheduled based on soil properties, crop growth requirements, monitoring of soil moisture and weather forecasts (Department of Agriculture and Fisheries, 2014). Electricity used to power irrigation and other aspects of the farm (e.g. in the packing shed) is an important input to banana growing. Since 2006-07 electricity prices in Queensland have increased by 87 per cent in real terms (Queensland Productivity Commission, 2016). In addition to these overall price increases across the state, irrigators are moving from transitional and obsolete tariffs (65 and 66) to a standard tariff (22A and 20 for small users less than 100MWH and 45 for larger users). Figure 9 below illustrates the annual percentage change in these tariffs since 2007-08. Analysis by the Queensland Competition Authority predicted 19 per cent of small irrigators on Tariff 65 would see their bills increase by 50 to 100 per cent when switching to Tariff 22A and no small irrigators on Tariff 66 are predicted to have price increases greater than 50 per cent when switching to Tariff 20 (QPC 2016, p.263). The analysis also predicted half of all small irrigators on both Tariff 65 and 66 will face no change or a reduction to their bill when they switch over. The date to phase out transitional and obsolete tariffs is currently set at 1 July 2020.

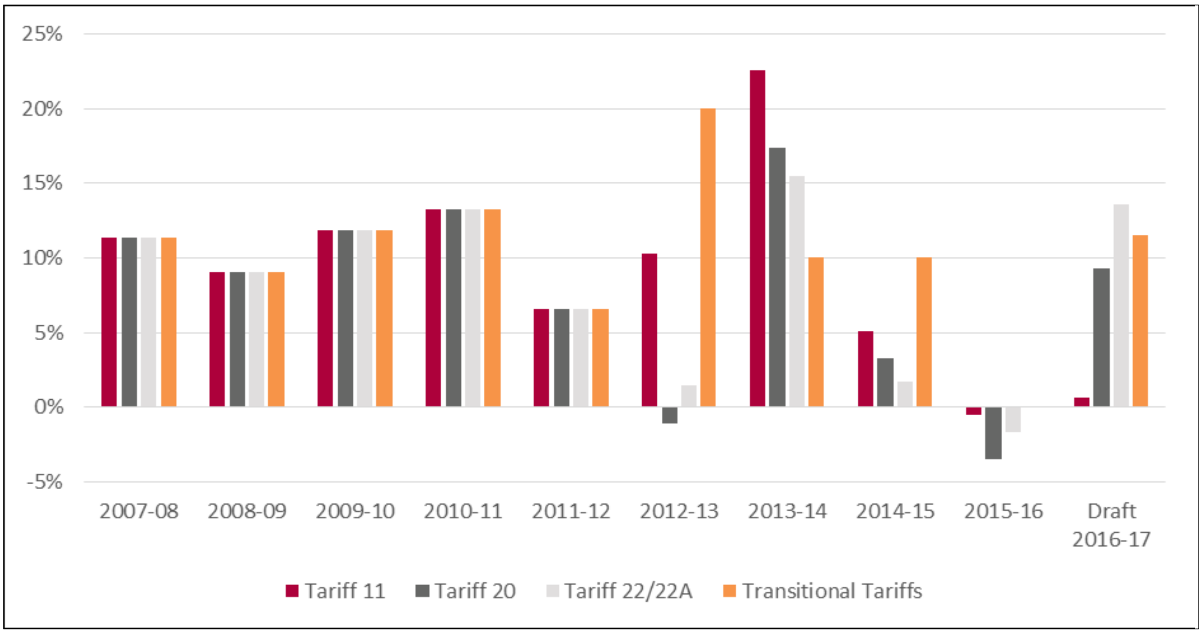

Figure 9: Annual percentage change in electricity prices (QLD tariffs)

Source: QPC (2016, p.258)

13.1.6 Panama disease

There are a multitude of pests and diseases that hamper banana plantations in north Queensland, such as aphids and spider mites. However, the largest risk is currently Panama Disease (*Fusarium oxysporum* f. sp. cubense), specifically the tropical race 4 strain of the disease, which has the potential to severely impact Cavendish banana production in the Wet Tropics.

Panama disease is easily spread through the movement of infected planting material, soil, water and contaminated equipment. Fungal spores can survive in the soil for several decades which makes prevention the most effective control method. Panama disease has a number of identified races: 1, 2, subtropical race 4 and the most serious threat to the Queensland banana industry, tropical race 4. This was initially detected on Cavendish plants in the Tully Valley in March 2015, with a second detection in July 2017, and a third detection in February 2018.

A heavy reliance on one variety of plant exposes the banana industry to potential negative outcomes from disease incursions. The Cavendish cultivar makes up the largest majority of Australian bananas and as such Panama disease tropical race 4 has potential to seriously impact the monoculture industry. Replacing Cavendish as the main variety would constitute a major change to current production systems. However, alternative varieties that have increased tolerance to the disease have unfortunately been found to be less productive in trials to date (Department of Agriculture and Fisheries, 2015).

Several new biosecurity management practices have been adopted in the wake of Panama disease tropical race 4 being detected in Queensland to prevent the spread of the disease (Biosecurity Queensland, 2015). These practices cover nearly all aspects of the farm including: personnel movement, vehicle and machinery movement, wash down facilities, fencing, tools and equipment, water management, waste management, farm-based animal movement, crop production and fruit movement. An on-farm biosecurity banana best management practices guide contains information to help growers implement effective on-farm biosecurity practices and reduce the risk of spreading pests and diseases (Kukulies, 2017).

13.1.7 Tropical cyclones

Bananas are a crop of the humid lowland tropics, which makes the Wet Tropics an ideal production region. However, as can be seen from Figure 10, extreme weather events during summer months, such as cyclones, can have a huge bearing on banana production and supply chains, including consumers. From 1969-70 to 2015-16 there have been 12 tropical cyclones that have struck the major banana growing area within 50km of Tully, which is a tropical cyclone every four years on average.

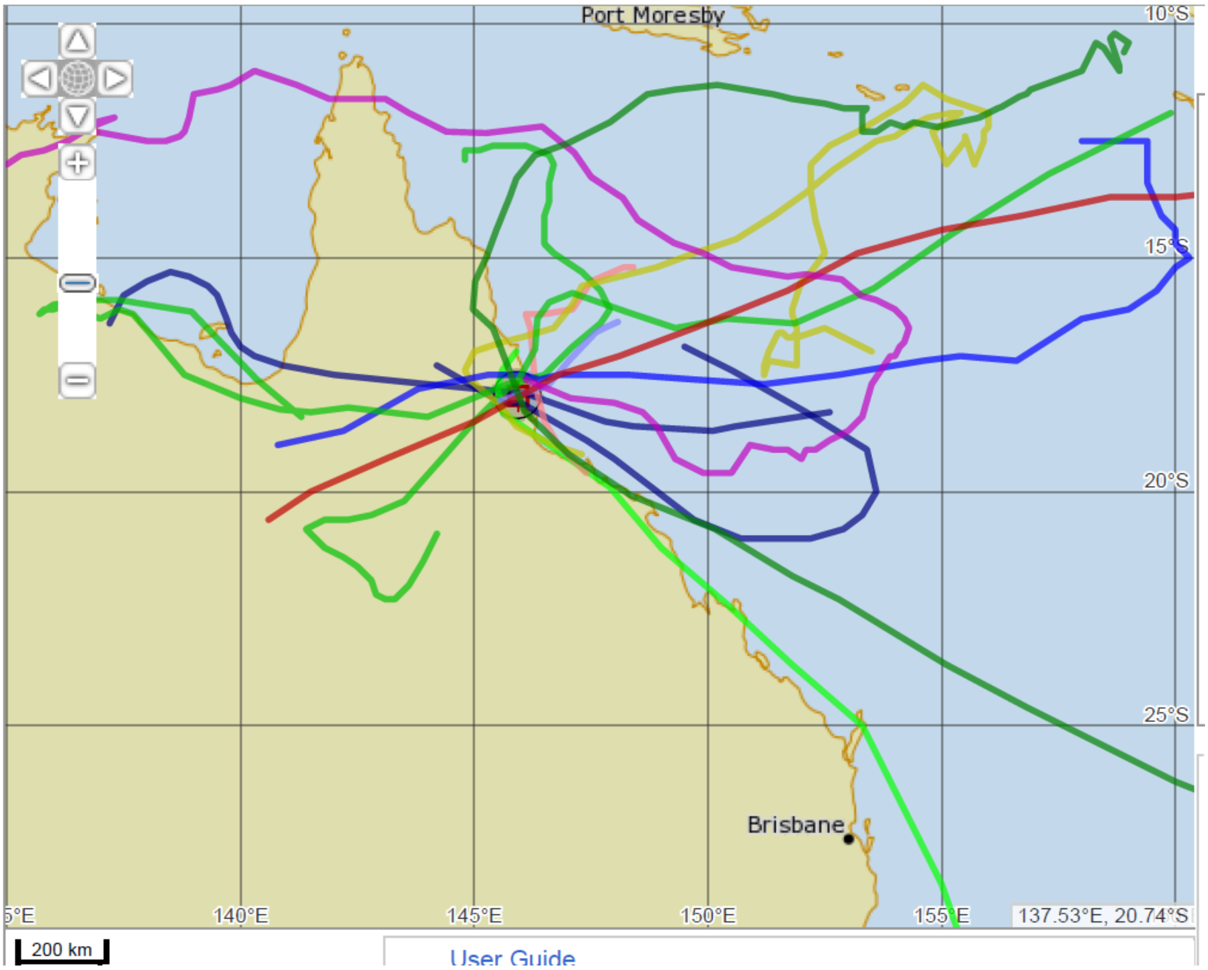

Figure 10: Track Maps for cyclones within 50km of Tully from 1969-70 to 2015-16
Source: Australian Government, (2017a)**.**

Without any pre-cyclone management practices implemented, considerable periods of undersupply and oversupply will occur in the market. Pre-cyclone management allows an earlier return to fruit production. This management is done by partially or completely removing the plant canopy prior to an impending cyclone. This helps to reduce damage by lowering wind resistance and helps anchor the plant into the ground.

Post-cyclone management recommendations include using nurse suckering and replanting crops over a period of time, rather than all at once, to provide a more even supply of bananas. Economic analysis shows that an average grower implementing post-cyclone management practices after Tropical Cyclone Yasi (2011) would have benefited by a minimum of $9703 per hectare compared to those who did nothing (Australian Banana Growers Council, 2012).

Apart from tropical cyclones, other extreme weather events that can affect banana production in Queensland include severe storms and floods. The Tully and Innisfail regions are renowned for rainfall events that cause heavy erosion, floods and months of saturated soils in the wet season. Bananas are best suited to the humid lowland tropics, therefore these are the best banana production regions in Australia however severe weather events can widely vary production levels.

14 References

Armour, J.D., Hateley, L.R., and Pitt, G.L. (2009) *Catchment modelling of sediment, nitrogen and phosphorus nutrient loads with SedNet/ANNEX in the Tully-Murray basin.* Marine and Freshwater Research, Vol 60: 1091-1096.

Armour, J.D., Nelson, P.N., Daniells, J.W., Rasiah, V. and Inman-Babmer, N.G. (2013a) *Nitrogen leaching from the root zone of sugarcane and bananas in the humid tropics of Australia*. Agriculture, Ecosystems and Environment Vol 180: 68 – 78.

Armour, J., Masters, B. and Mortimore, C., (2013b), *Grassed inter-rows in bananas in the Wet Tropics region*. 2013 Paddock Case Study, Horticulture, Reef Water Quality Protection Plan. Available from: http://reefplan.qld.gov.au/measuring-success/case-studies/assets/case-study-horticulture-grassed-inter-rows.pdf (accessed 16.11.15).

Armour, J., Masters, B. and Mortimore, C. (2013c) *Monitoring nitrogen losses from bananas in the Wet Tropics Region*, Reef Water Quality Protection Plan. Available from: http://www.reefplan.qld.gov.au/measuring-success/case-studies/assets/case-study-horticulture-nitrogen-losses-bananas.pdf (accessed 10.12.15).

Armour, J., Mortimore, C., Pathania, N., Wiltshire, N., Daniells, J., Masters, B. and Reghenzani, J. (2014) *Minimising off -farm movement of nitrogen in the north Queensland banana industry*. Report to the Reef Rescue Research & Development Program. Reef and Rainforest Research Centre Limited, Cairns (32 pp).

Australian Banana Growers Council, Lindsay, S. and Comiskey, S., (2012), *Scheduling Banana Production after Tropical Cyclones*. Available from: https://abgc.org.au/wp-content/uploads/2017/03/Scheduling-Banana-Production-After-Tropical-Cyclones.pdf (accessed 27.01.16).

Australian Banana Growers Council (2017), *BetterBunch Phone Application*. Available from: https://records.bmp.abgc.org.au/ (accessed 20.11.17).

Australian Bureau of Agricultural and Resource Economics and Sciences (2015a) *Multi-Criteria Analysis Shell for Spatial Decision Support (MCAS-S)*. Available from: http://www.agriculture.gov.au/abares/aclump/multi-criteria-analysis/mcas-s-tool (accessed 06.11.15).

Australian Bureau of Agricultural and Resource Economics and Sciences (2016) *Agricultural commodity statistics 2016*. Available from: http://www.agriculture.gov.au/abares/research-topics/agricultural-commodities/agricultural-commodities-trade-data#2016 (date accessed 30.08.17).

Australian Bureau of Statistics (2011) *Average Retail Prices of Selected Items, 2004-2011*, Cat no. 6403.0.55.001. Available from: http://www.abs.gov.au/ausstats/abs@.nsf/mf/6403.0.55.001 (accessed 03.11.15).

Australian Bureau of Statistics (2015) *Consumer Price Index, Australia Sep 2015*, Cat no. 6401.0. Available from: http://www.abs.gov.au/ausstats/abs@.nsf/mf/6401.0 (accessed 08.11.15).

Australian Bureau of Statistics (2017a) *Agricultural Commodities, Australia, 2007-08 to 2015-16*, Cat no. 7121.0. Available from: http://www.abs.gov.au/ausstats/abs@.nsf/mf/7121.0 (accessed 30.08.17).

Australian Bureau of Statistics (2017b) *Value of Agricultural Commodities Produced, Australia*, *1997-98 to 2015-16*, Cat no. 7503.0. Available from: http://www.abs.gov.au/ausstats/abs@.nsf/mf/7503.0 (accessed 320.08.17).

Australian Government, Biosecurity Australia (2008) *Final Import Risk Analysis Report for the Importation of Cavendish Bananas from the Philippines, Part C*. Available from: http://www.agriculture.gov.au/SiteCollectionDocuments/ba/plant/bananas-philippines/PART_C_-_FINAL_-_COLOUR_COVER_AND_B-W_REST_-_John_081106.pdf (accessed 05.11.15).

Australian Government, Biosecurity Australia (2009) *Biosecurity policy determination for bananas from the Philippines*. Available from: http://www.agriculture.gov.au/SiteCollectionDocuments/ba/plant/bananas-philippines/banana-determination-fact-sheet-090303-updated04-02-2011.pdf (accessed 25.01.16).

Australian Government, Bureau of Meteorology (2017a) *Southern Hemisphere Tropical Cyclone Data Portal*. Available from: http://www.bom.gov.au/cyclone/history/tracks/ (accessed 06.09.17).

Australian Government, Fair Work Ombudsman (2017b) *Award Calculator*. Available from: https://calculate.fairwork.gov.au/findyouraward (accessed 08.11.17).

Australian Government, Department of the Environment (2015b) *Reef 2050 Plan – Implementation Strategy*. Available from: https://www.environment.gov.au/system/files/resources/2cb646bb-2738-4743-a41d-e2cd0ce8832c/files/reef2050-implementation-strategy-edition2.pdf (accessed 28.01.16).

Australian Government, Department of the Environment (2015c) *Reef Rescue Research and Development, RRRD054 – Development of a banana modelling capability to enhance reporting of Reef Rescue outcomes*. Available from: http://www.reefrescueresearch.com.au/research/all-projects/23-final-reports/184-rrrd054-final-report.html (accessed 01.02.16).

Australian Government, Bureau of Meteorology (2016a) *Tropical Cyclone Information for the Australian Region*. Available from: http://www.bom.gov.au/cgi-bin/silo/cyclones.cgi (accessed 29.01.16).

Australian Government, Department of Environment (2016b) *Reef Trust Investments*. Available from: https://www.environment.gov.au/marine/gbr/reeftrust/investments (accessed 31.05.16).

Australian Taxation Office, (2016), Fuel tax credit rates for liquid fuels. Available from: https://www.ato.gov.au/business/fuel-schemes/fuel-tax-credits---non-business/rates---non-business/1-july-2015-to-30-june-2016/ (accessed 22.01.16).

Biosecurity Queensland (2015) *On-farm biosecurity checklist*. Version 1, June 2015. Available from: https://publications.qld.gov.au/dataset/ff0ce12a-2703-434b-b406-72eab8e7270a/resource/4a8f2cae-c388-4460-bae9-1c00558d7cc9/download/pdgkonfarmbiosecuritychecklist.pdf (accessed 21.01.16).

Brodie, J., Waterhouse, J., Schaffelke, B., Johnson, J., Kroon, F., Thorburn, P., Rolfe, J., Lewis, S., Warne, M., Fabricius, K., McKenzie, L. and Devlin, M. (2013) *Reef Water Quality Scientific Consensus Statement 2013*, Department of the Premier and Cabinet, Queensland Government, Brisbane. Available from: http://www.reefplan.qld.gov.au/about/assets/scientific-consensus-statement-2013.pdf (accessed 03.05.16).

Cook, S., Kukulies, T. and Rattray, D. (2016) The economic impact of banana best management practice adoption of growers in the Wet Tropics: RP140B Case Study One: Brad Finch. Department of Agriculture and Fisheries (DAF) Queensland. Accessed at https://publications.qld.gov.au/dataset/862d67fd-9069-44ec-9e73-7354e6f20a64/resource/88f4a423-7bea-4a5a-bd72-6dba16308178/download/rp140b-project---pilot-case-study-160916.pdf (accessed 09.11.17)

Cook, S. and Kukulies, T. (2017a) The economic impact of banana best management practice adoption of growers in the Wet Tropics: RP140B Case Study Two: Cameron Mackay. Department of Agriculture and Fisheries (DAF) Queensland. Accessed at https://publications.qld.gov.au/dataset/862d67fd-9069-44ec-9e73-7354e6f20a64/resource/f5ec399d-04f0-4973-95ab-92c38caa2d5d/download/rp140b-2nd-case-study.pdf (accessed 09.11.17)

Cook, S. and Kukulies, T. (2017b) The economic impact of banana best management practice adoption of growers in the Wet Tropics: RP140B Case Study Three: Gavin Devaney. Department of Agriculture and Fisheries (DAF) Queensland. Accessed at https://publications.qld.gov.au/dataset/862d67fd-9069-44ec-9e73-7354e6f20a64/resource/9ab24ddf-3d94-41f8-bbb7-881fbf975e76/download/rp140b-3rd-case-study.pdf (accessed 09.11.17)

CSIRO, University of Queensland and the Department of Agriculture and Fisheries (2015), *Agricultural Production Systems Simulator (APSIM)*. Available at: https://www.apsim.info/ (accessed 27.01.16).

Daniells, J.W. and Armour, J. (2003) *Managing Crop Nutrition in Banana Production*, Queensland Department of Primary Industries.

De'ath, G. and Fabricius, K. (2010) *Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef*. Ecological Applications Vol. 20, pp. 840 – 850.

Deloitte (2017) *At what price? The economic, social and icon value of the Great Barrier Reef*. Available from: https://www2.deloitte.com/content/dam/Deloitte/au/Documents/Economics/deloitte-au-economics-great-barrier-reef-230617.pdf (accessed 02.12.17)

Department of Agriculture and Fisheries (2014) *Bananas: Improved Practices Catalogue*. Available from: https://www.daf.qld.gov.au/environment/sustainable-agriculture/reef-water-quality-protection-plan/improved-practices-catalogue/bananas (accessed 08.10.15).

Department of Agriculture and Fisheries (2015) Panama Disease Overview. Available from: https://www.daf.qld.gov.au/plants/health-pests-diseases/a-z-significant/panama-disease2/panama-disease (accessed 29.01.16).

Department of Agriculture and Fisheries (2017) *AgTrends 2016-17 Forecasts and Trends*. Available from: https://www.daf.qld.gov.au/business-trade/agtrends (accessed 17.11.17).

Department of Agriculture, Forestry and Fisheries (2012) *Trellis Economic Analysis Tool*, Excel spreadsheet.

Department of Agriculture, Forestry and Fisheries (2013) *Agricultural Risk Management (ARM) tools – Climate ARM*. Available from: http://www.armonline.com.au/#/ (accessed 05.11.15).

Department of Environment and Heritage Protection (2013) *Banana farming for healthier wetlands.* Queensland Wetlands Program Available from: http://wetlandinfo.ehp.qld.gov.au/resources/static/pdf/resources/reports/farming-case-studies/cs-bananas-12-04-2013.pdf (accessed 25.10.15).

Department of Science, Information Technology and Innovation (DSITI) (2016) *2015 Land use in the Wet Tropics NRM Region*. Available from: http://www.qld.gov.au/environment/land/vegetation/mapping/qlump-datasets/ (accessed 25.01.16).

Eberhard Consulting (2011) *Caring for our Country-Reef Rescue as a program delivery model for natural resource management*. An issues paper commissioned by the Australian Department of Sustainability, Environment, Water, Population and Communities.

Emtage, N. and Reghenzani, J. (2008) *Wet Tropics Sustainable Agriculture Survey Interim Report. A Survey of Landholders Within the Wet Tropics Natural Resource Management Region.* Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns (81pp.). Available from: http://rrrc.org.au/wp-content/uploads/2014/06/494-UQ-Emtage-et-al-2008-Sustainable-Agriculture-Survey.pdf (accessed 11.11.15).

Fabricius, K. (2005) *Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis*. Marine Pollution Bulletin, Vol 50, 125 – 146.

Freebairn, D.M., Hamilton, A.H., and Cox, P.G (1994) *HowWet*? Available from: https://www.apsim.info/how/howwet/HowWet%20Fact%20Sheet.pdf (accessed 27.01.16).

Garside, A.L., Poggio, M.J., Park, G., Salter, B., and Perna, J. (2009) *Long-term Ingham and Mackay farming system experiments: comparisons between permanent non-tilled beds and re-formed beds*. *Proc. Aust. Soc. Sugar Cane Tech.,* **31**, 282- 295**.**

Good Fruit and Vegetables (2015) *NT shows Panama can be lived with*. Available from:

http://www.goodfruitandvegetables.com.au/story/3511636/nt-shows-panama-can-be-lived-with/# (accessed 28.01.16).

Grains Research & Development Corporation (2014) *Climate Kelpie – Rainman Streamflow*. Available from: http://www.climatekelpie.com.au/manage-climate/decision-support-tools-for-managing-climate/rainman-streamflow (accessed 27.01.16).

Greiner, R. and Gregg, D. (2011) ***Farmers' intrinsic motivations, barriers to the adoption of conservation practices and** effectiveness of policy instruments: Empirical evidence from Northern Australia*. Land Use Policy, Vol 28, 257 - 265. Available from: http://www.sciencedirect.com/science/article/pii/S0264837710000682 (accessed 05.10.15).

Hall, H., and Gleeson, J. (2013). Value of the Australian Banana Industry to Local and National Economies. Horticulture Australia Limited.

Hall, H. (2014). Banana Enterprise Performance Comparison. Horticulture Australia Limited.

Hateley, L.R., Ellis, R., Shaw, M., Waters, D., and Carroll, C. (2014) *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Wet Tropics NRM region*, Technical Report, Volume 3, Queensland Department of Natural Resources and Mines, Cairns, Queensland (ISBN: 978-0-7345-0441-8).

Hinton, A. (2001a) *Cavendish Banana Farm Model FNQ (based on MDIA)* - excel spreadsheet (edited by Johnston, B.) Department of Primary Industries and Fisheries, Queensland (accessed 13.12.15).

Hinton, A. (2001b) *Lady Finger Banana Farm Model FNQ (based on MDIA)* - excel spreadsheet (edited by Johnston, B.) Department of Primary Industries and Fisheries, Queensland (accessed 13.12.15).

Hinton, A. (2013) *Cavendish Banana Farm Model – Far north Queensland*, Excel spreadsheet.

Holligan, E., Cook, S., Poggio, M. and Rattray, D. (2017) Economic assessment of best management practices for banana growing, Report to the Department of Environment and Heritage Protection through funding from the Reef Water Quality Science Program, RP140B Technical Report. Department of Agriculture and Fisheries (DAF) and the Department of Natural Resources and Mines (DNRM), Queensland.

Horticulture Australia Limited (2014) *Australian Banana Industry – Strategic Investment Plan 2014/15 – 2018/19:* 22. Available from: http://horticulture.com.au/wp-content/uploads/2015/12/HortInn-SIP-Banana.pdf (accessed 12.12.15).

Hunter, H.M. and Walton, R.S. (2008) *Land-use effects on fluxes of suspended sediment, nitrogen and phosphorus from a river catchment of the Great Barrier Reef*, Australia. Journal of Hydrology Vol 356, 131 – 146.

Johnston, B. (1998) *Gross Margin for Cavendish Bananas (Gulf and Coastal regions) – north Queensland*, Excel spreadsheet. Department of Primary Industries and Fisheries, Queensland. Available at: https://www.daf.qld.gov.au/__data/assets/excel_doc/0005/83822/cavendish-banana-gm-nq.xls (accessed 14.10.15).

King, N. (2008) *Banana Best Management Practices: Environmental Guidelines for the Australian Banana Industry.* Department of Agriculture and Fisheries. Available from: https://abgc.org.au/projects-resources/best-management-practices-bmp/ (accessed 13.12.15).

Kukulies, T., Veivers, S., (2017), Banana best management practices: On-farm biosecurity. Department of Agriculture and Fisheries. Available from: http://horticulture.com.au/wp-content/uploads/2017/06/On-farm-Biosecurity-Manual.pdf (accessed 03.07.17).

Knowledge Management System for Irrigation (2007) *EconCalc, South East Queensland Irrigation Futures project*. Available from: http://econcalc.ncea.biz/ (accessed 25.10.15).

Kroon, F.J., Kuhnert, P.M., Henderson, B.L., Wilkinson, S.N., Kinsey-Henderson, A., Abbott, B., Brodie, J.E. and Turner, R.D.R. (2012) *River loads of suspended solids, nitrogen, phosphorus and herbicides delivered to the Great Barrier Reef lagoon*. Marine Pollution Bulletin, Vol 65, 167 – 181.

Lindsay, S., Campagnolo, D., Daniells, J., Evans, D., Goebel, R., Gunther, M., Lemin, C., Pattinson, T., Peterson, R., Pinese, B., Wharton, D. and Kernot, I. (1998) *Tropical banana information kit. Agrilink Series: your growing guide to better farming QAL9807*. Queensland Horticulture Institute and Department of Primary Industries, Queensland. Available from: http://era.daf.qld.gov.au/1656/ (accessed 27.11.15).

Masters, B., Mortimore, C., Tahir, N., Fries, J., and Armour, J. (2017) *Paddock-scale water quality monitoring of banana cropping management practices*. Available from: http://qldgov.softlinkhosting.com.au/liberty/opac/search.do?mode=ADVANCED&corporation=DERM&action=search&anonymous=true&queryTerm=421333&includeNonPhysicalItems=true&operator=AND# (accessed 09.11.17)

McClymont, D. (2011) *HowLeaky, Decision Support Software*. Available from: http://www.howleaky.net/ (accessed 27.01.16).

Miles, S. (2015) *Mobile app for banana growers to protect Great Barrier Reef and fight disease, Media Statement*. Available from: http://statements.qld.gov.au/Statement/2015/8/12/mobile-app-for-banana-growers-to-protect-great-barrier-reef-and-fight-disease (accessed 20.10.15).

Moody, P.W., Cong, P.T. (2008) *Soil Constrains and Management Package (SCAMP) – Guidelines for sustainable management of tropical upland soils*, Australian Centre for International Agricultural Research. Available from: http://aciar.gov.au/files/node/8946/MN130%20full%20text.pdf (accessed 10.01.16).

Northern Territory Government, Department of Primary Industry, Fisheries and Mines (2007) *Primary Industries Technical Annual Report 2006-07*. Available from: https://dpir.nt.gov.au/__data/assets/pdf_file/0020/227720/0607_ar_dpifm.pdf (accessed 28.01.16).

Pannell, D.J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F., & Wilkinson, R. (2006) *Understanding and promoting adoption of conservation practices by rural landholders,* Australian Journal of Experimental Agriculture, Vol 46, 1407–1424. Available from: http://www.publish.csiro.au/paper/EA05037.htm (accessed 14.10.15).

Ploetz, R.C. (2015) *Fusarium wilt of Banana.* Phytopathology Review*,* Vol. 105 (12) 1512 – 1521.

Poggio, M. and van Grieken, M. (2010) *MTSRF Project Report: Economic Analysis of Banana ABCD Management Practices in the Tully Region.* Department of Employment, Economic Development and Innovation, Queensland.

Queensland Audit Office (2015) *Managing water quality in Great Barrier Reef catchments: Report 20 2014-15.* Available from: https://www.qao.qld.gov.au/sites/qao/files/reports/rtp_managing_water_quality_in_great_barrier_reef_catchments.pdf (accessed 20.10.17).

Queensland Government (2013) *Reef Water Quality Protection Plan 2013*. Available from: http://www.reefplan.qld.gov.au/resources/assets/reef-plan-2013.pdf (accessed 25.10.15).

Queensland Government (2014) *Reef Water Quality Protection Plan 2013 – Prioritisation project report*. Available from: http://www.agriculture.gov.au/SiteCollectionDocuments/natural-resources/reef-water.pdf (accessed 20.11.15).

Queensland Government (2015a) *The Long Paddock – Latest Southern Oscillation Index SOI values*. Available from: https://www.longpaddock.qld.gov.au/ (accessed 09.11.15).

Queensland Government (2015b) *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program*. Available from: http://www.reefplan.qld.gov.au/measuring-success/paddock-to-reef/assets/paddock-to-reef-overview.pdf (accessed 25.10.15).

Queensland Government, Reef Plan (2015c) *Paddock to Reef Water Quality Risk Framework for Bananas*. Currently unpublished.

Queensland Government, Trade & Investment Queensland (2015d) *Hong Kong Commissioner helps NQ exports*. Available from: http://www.tiq.qld.gov.au/hong-kong-north-queensland/ (accessed 25.01.16).

Queensland Government (2016) Great Barrier Reef Water Quality Science Taskforce: Clean Water for a Healthy Reef. Final Report, May 2016. Available at: https://www.ehp.qld.gov.au/assets/documents/reef/gbrwst-finalreport-2016.pdf (accessed 31.05.16).

Queensland Government (2017) Major Integrated Projects in Wet Tropics and Burdekin. Available at: https://www.qld.gov.au/environment/agriculture/sustainable-farming/reef-major-projects (accessed 11.12.17).

Queensland Productivity Commission (2016) Electricity Pricing Inquiry. Final Report 31 May 2016 https://qpc.blob.core.windows.net/wordpress/2017/06/EPI-Final-Report.pdf (accessed 06.09.17)

Queensland Transport and Logistics Council (2015) *Supply Chain Perspective – Horticulture*. Available from: http://www.qtlc.com.au/wp-content/uploads/2013/01/QTLC-Supply-Chain-Perspective_Horticulture.pdf (accessed 27.01.16).

Queensland Wetlands Program (2013) *Nurturing the soil and neighbouring wetlands on a banana farm in the Wet Tropics*. Available from: http://wetlandinfo.ehp.qld.gov.au/resources/static/pdf/resources/reports/farming-case-studies/cs-bananas-12-04-2013.pdf (accessed 15.11.15).

RACQ, (2017), Annual Fuel Price Report 2016. Available from: https://www.racq.com.au/-/media/pdf/racq%20pdfs/cars%20and%20driving/racq%20annual%20fuel%20price%20report%20-%202016.ashx (accessed 23.06.17)

Rasiah, V., Armour, J.D., Cogle, A.L. and Florentine, S.K. (2010) *Nitrate import-export dynamics in groundwater interacting with surface-water in a wet-tropical environment.* Australian Journal of Soil Research, Vol 48, 361 – 370.

Rattray, DJ, Freebairn, DM, McClymont, D, Silburn, DM, Owens, JS, Robinson, JB (2004), 'HOWLEAKY? The journey to demystifying 'simple' technology', in *Conserving soil and water for society: sharing solutions, The 13th International Soil Conservation Organization Conference*, SR Raine, AJW Biggs, NW Menzies, DM Freebairn & PE Tolmie (eds), ISCO, Brisbane, July 2004.

Robinson, JB, Silburn, DM, Rattray, D, Freebairn, DM, Biggs, AJW, McClymont, D, Christodoulou, N (2010), Modelling shows that the high rates of deep drainage in parts of the Goondoola Basin in semi-arid Queensland can be reduced with changes to the farming systems. *Australian Journal of Soil Research* 48(1), 58-68*.*

Roebeling, P.C., Webster, A.J., Biggs, J. and Thorburn, P. (2007) Financial-economic analysis of current best-management practices for sugarcane, horticulture, grazing and forestry industries in the Tully-Murray catchment. CSIRO sustainable ecosystems Report for the Tully-Murray Water Quality Improvement Plan. Available from: http://rrrc.org.au/wp-content/uploads/2014/06/375-CSIRO-Roebeling-_2007_-Tully-CCI-BMP-Analysis.pdf (accessed 20.10.15).

Rogers, E. M. (2003), *Diffusion of Innovations (5th edition).* Free Press, New York.

Sing, N., and Barron, F. (2014) *Management practice synthesis for the Wet Tropics region – August 2014*. Wet Tropics Water Quality Improvement Plan, Terrain NRM, Innisfail.

Sing, N.C. (2012) *Banana Voluntary Adoption Survey Results*, Terrain NRM, March 2012.

State of Queensland (2011b) *Providing Economic Support to project Catalyst - Burdekin Wet Tropics 2011*.

State of Queensland (2016a) *Final Report: Great Barrier Reef Water Science Taskforce: Clean water for a healthy reef,* prepared by The Great Barrier Reef Water Science Taskforce and the Office of the Great Barrier Reef, Department of Environment and Heritage Protection, May 2016.

State of Queensland (2016b) *Great Barrier Reef Report Card 2015 Results* prepared by the Australian and Queensland governments.

State of Queensland (2017a) *Broadening and enhancing reef protection regulations* Consultation Regulatory Impact Statement, September 2017. Available from: http://www.ehp.qld.gov.au/assets/documents/reef/enhancing-reef-protection-regulations-ris.pdf (accessed 20.09.17).

State of Queensland (2017b) *Draft Reef 2050 Water Quality Improvement Plan 2017-2022 for public consultation* prepared by the Australian and Queensland governments and published by the Reef Water Quality Protection Plan Secretariat. Available from: http://www.reefplan.qld.gov.au/about/assets/reef-2050-water-quality-improvement-plan-2017-draft.pdf (accessed 20.09.17).

Su, Hong-Ji., Hwang, Shin-chuan. and Ko, Wen-hsiung. (1986), *Fusarial Wilt of Cavendish Bananas in Taiwan*. Plant Disease, Vol. 70 (9), 814 – 818.

Terrain NRM (2015), *Wet Tropics Water Quality Improvement Plan: 2015-2020*, Version 10, Available from: http://www.wettropicsplan.org.au/content/download/788/6563/version/3/file/Terrain-WQIP-combined.pdf (accessed 30.11.15).

Thompson, M., Collier, A., Poggio, M., Smith, M. and van Grieken, M. (2014) *Adoption Innovation Profile Report*. Department of Agriculture, Fisheries and Forestry (DAFF), Queensland.

University of Western Australia and Natural Decisions Pty Ltd (2015), *Investment Framework for Environmental Resources (INFFER)*. Available from: http://www.inffer.com.au/ (accessed 29.11.15).

Wageningenur (2015) *Panama Disease*. Available from: http://www.fusariumwilt.org/index.php/en/the-problem/ (accessed 27.01.16).

Waterhouse, J., Schaffelke, B., Bartley, R., Eberhard, R., Brodie, J., Star, M., Thorburn, P., Rolfe, J., Ronan, M., Taylor, B. and Kroon, F. (2017) 2017 Scientific Consensus Statement: Land use impacts on Great Barrier Reef water quality and ecosystem condition. The State of Queensland.

Wilkinson, N., and Klaes, M. (2012) An Introduction to Behavioural Economics, 2nd Edition, Palgrave Macmillan.