

Engaging with farmers and demonstrating water quality outcomes to create confidence in on-farm decision-making (“Project 25”)

Aaron M. Davis, Bruce Taylor and Simon Fielke



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Australian Government



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in on-farm decision-making (“Project 25”)

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ACRONYMS

BMP	Best Management Practice
DIN	Dissolved inorganic Nitrogen
DoEE	Department of the Environment and Energy
GBR	Great Barrier Reef
N	Nitrogen
NESP	National Environmental Science Program
P2R	Paddock to Reef
RRRC	Reef and Rainforest Research Centre Limited
RTWQM	Real-time water quality monitoring
TWQ	Tropical Water Quality

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EXECUTIVE SUMMARY

Recent monitoring from the Great Barrier Reef (GBR) catchment area suggest current dissolved inorganic nitrogen (DIN) load reduction trajectories fall well below desired targets, despite considerable investment in improved management practise and engagement with agricultural industries. Recent global experiences suggest that spatially identifying and prioritizing landscape ‘hotspots’ of pollutant generation for management intervention, and small catchment-scale water quality monitoring in collaboration with landholders, are among the most promising strategies for reducing diffuse water quality pollution. This report outlines the design, project management, and early results of ‘Project 25’ Engaging with farmers and demonstrating water quality outcomes to create confidence in on-farm decision-making, funded under the National Environmental Science Program’s (NESP) Tropical Water Quality (TWQ) Hub. Initiated through discussions between the Australian Government, and large-scale sugarcane producers in the Russell-Mulgrave River catchment, ‘Project 25’ addresses the expressed need for ‘bottom-up’ water quality research to engage more directly with farmers to establish stronger, and more tangible feedback loops between water quality science and management. While the Project is ongoing, early results indicate:

- Initial project development, but also social interview results of cane industry stakeholders, have identified the importance of establishing robust trust frameworks in delivering desired program outcomes. Interviewees reported improved communication, an improved trust environment with more direct oversight of monitoring data, and ‘space’ to learn and experiment as contributing factors to their engagement. Interviewees also described the presence of meaningful and ongoing two-way communication between science and industry stakeholders, and two-way trust and recognition of the value of bridging on-farm knowledge with water quality monitoring data as critical to engagement.
- The Project has enhanced the capacity of some grower participants to act as leaders and influencers within their local farming community and networks. Members of the Steering Committee regularly advocate the rationale and benefit of the project in public and particularly industry forums, where the project is framed as a means to demonstrate social and environmental responsibility of the local industry to the public; and to contribute to local self-regulation.
- Project 25 has provided clear capacity for dissolved inorganic nitrogen ‘hotspot’ identification in the broader Russell-Mulgrave catchment. Sub-catchment areas consistently responsible for generating relatively high nutrient losses emerged with ~3 years of monitoring effort. These areas have now become Project foci for additional fine-scale monitoring, as well as extension and engagement effort from industry support programs.
- A benefit of meaningful grower involvement in program design, was the advantages and opportunities provided for effective communication of not only basic water quality science, but also government policy aims, back to industry. Knowledge of local communication challenges surrounding water quality allowed project scientists to tailor water quality result presentations to addressing specific challenges and obstacles in industry ownership of particular water quality issues.

1.0 INTRODUCTION

The management of diffuse agricultural water pollution, particularly nutrient eutrophication, remains one of the most significant, pervasive, and costly, global natural resource management challenges (Broussard and Turner, 2009; OECD, 2012, Queensland Government, 2015, Sobota et al., 2013; 2015). With projected increases in crop demand to meet global food security (Tilman et al., 2011), associated expansion and intensification of agricultural land use is likely to escalate already significant pressures on aquatic ecosystems. Policy responses across many industrialised countries are typically marked by reliance on mostly voluntary approaches to address agricultural non-point sources, (Kleinman et al., 2015).

The failures of largely voluntary schemes to foster significant practice change are, however, being used to increasingly advocate increased regulation of farming activities in regions under most pressure (Kleinman et al., 2015; Kroon et al., 2015). Recent appraisals of the cost-effectiveness of some compulsory compliance policies in delivering practice change or water quality improvements are, however, also decidedly mixed (Worrall et al., 2009; Kay et al., 2013). Some of this failure of regulatory policy mechanisms in achieving demonstrable water quality improvement has been attributed to fundamental shortcomings in changing farmer's underlying behaviours (Barnes et al., 2013). Imposition of regulation of farming practices can also have negative ramifications for changing landholder attitudes to management of environmental issues. High levels of resistance to regulatory policy may even lead to negative behavioural feedback loops, even to the point of significantly decreased adoption of voluntary water quality measures within regulated farming regions (Barnes et al., 2013).

Much of this global experience has been recently exemplified in Australia's Great Barrier Reef catchment area (the riverine catchments adjacent to the GBR which discharge terrestrial runoff into the GBR lagoon). Sugarcane (*Saccharum officinarum* L.) is the dominant intensively cultivated crop in the GBR catchment area (~380,000 ha; Furnas, 2003). It is primarily concentrated along the coastal fringe, and is a primary industry posing considerable challenges from a water quality perspective. Dissolved inorganic nitrogen (DIN) export from sugarcane (derived from nitrogenous fertiliser application) has been specifically identified as a key contributor to nutrient loading in GBR flood plumes (Rayment, 2003; Bainbridge et al., 2009, Thorburn et al., 2011). Key management responses by the Australian and Queensland Governments in the GBR catchment area include incentive-based voluntary management initiatives for landholders for adoption of improved land management practices, regulation of sugarcane and grazing management practices in priority areas, agricultural extension programs, and paddock and catchment water quality monitoring and modelling initiatives to both quantify and/or predict water quality improvements associated with specific management change (Brodie et al., 2012; Carroll et al., 2012).

Despite significant long-term government investment in voluntary practice change incentives, and imposition of compulsory regulation (Brodie et al., 2013), recent Reef 2050 Water Quality Improvement Plan (WQIP) Report Cards (2013-2016) suggest current nitrogen load reduction trajectories fall well below desired targets (Queensland Government, 2016; 2017). The results highlight that while landholders have made progress in adopting improved land management practices across the GBR catchment area, pollutant load reduction trajectories fall well below desired target reductions particularly for DIN, a parameter of significant relevance to sugarcane

cultivation in the GBR catchment area. These most recent ‘Report Cards’ highlight the need for identification of priority issues and spatial priorities for investment in water quality improvement initiatives, supported by robust and comprehensive extension, engagement, monitoring and evaluation techniques.

Recurrent themes in global farmer-landholder attitudes (including in the GBR catchment area) to various water quality issues and policies include; scepticism that water pollution problems even exist; aversion to responsibility for creating water pollution problems (frequently instead blaming other activities for environmental degradation); significant underestimation of crop nutrient recovery efficiencies; lack of faith in scientific information/modelling collected by external agencies (particularly government); and absence of local data directly relevant to their farming activities (Ribaud, 1998; Blackstock et al., 2010; Barnes et al., 2009; 2013; Di Bella et al., 2015; Perez, 2015; Yang and Fang, 2015).

Landholder concerns surrounding the credibility of broad-scale water quality monitoring and modelling initiatives in the GBR catchment area are one of the key sugarcane industry engagement challenges for promoting significant farming practice change, and water quality improvements. Reflecting global experiences, scepticism of their relative role in catchment pollution, lack of faith in government water quality monitoring-modelling, and an absence of locally relevant data across many districts, remain common environmental engagement challenges across the Queensland sugarcane industry (Di Bella et al. 2015). Many farmers in key catchments remain unconvinced that their individual farming decisions influence the water quality for the Great Barrier Reef.

Growing appreciation of these landholder engagement challenges is re-aligning watershed monitoring and research in many respects, with increasing numbers of stakeholder-driven environmental research and demonstration programs. While diverse, these programs increasingly focus on integrating water quality management collaborations between farmers, researchers, industry support/extension staff and government at small sub-catchment or commercial farm scales across Europe, the United States (US) and Australia (Kay et al., 2012; Owen et al., 2012; Osmond et al., 2012; Kennedy et al., 2013; Rodriguez et al., 2014; Di Bella et al., 2015; Sharpley et al., 2015). These initiatives place greater emphasis on behavioural and socio-economic dimensions of agriculture, through documenting local environmental impacts, promotion of joint, participatory learning experiences between farmers and researchers, and researching site and time-specific alternative practices to reduce off-farm impacts. Evidence-based outcomes of these programs (i.e., demonstrable water quality benefits from management actions) do exist, but so do failures, uncertain benefits, and a range of emergent lessons (Osmond et al., 2012; Kay et al., 2012).

Emerging recognition of the complex nature of nominally ‘diffuse’, non-point source pollution is similarly highlighting the need for re-scaling of water quality monitoring effort at smaller catchment scales. Despite its nomenclature, non-point source pollution still often originates in ‘hotspots’ or ‘critical source areas’ from a small portion of the landscape, areas that can be targeted for maximum efficiency (Carpenter et al., 1998; Pionke et al., 2000; White et al., 2009; Kleinman et al., 2011; Kovacs et al., 2012; Kalcic et al., 2015). Not only are certain locations more vulnerable to non-point source pollution, but individual conservation/management practices may be more or less suitable in those locations within a given watershed (Tomer et al., 2013). Ignoring these critical source areas can have profound ramifications for cost

effectiveness of water quality improvement practices (Sharpley and Smith, 1994). Unfocused implementation of catchment scale water quality remediation efforts that miss critical source areas of pollutants, can provide minimal end-of-catchment water quality responses. Examples exist where conservation/management practices installed on as much as 50% of the target watershed, resulted in negligible water quality improvement, due to lack of remedial effort on critical source areas that made the dominant contribution to catchment pollutant loads (Kleinman et al., 2011). Spatially targeting the most effective conservation/management practices to locations with the greatest potential for water quality improvement can accordingly decrease the cost of implementation to meet a particular water quality goal (e.g., Veith et al., 2004).

The appropriate mechanisms for industry engagement and ‘buy-in’ in water quality monitoring and improvement, is an important consideration, often overlooked in the design and implementation and communication of water quality monitoring programs, particularly those aimed at driving behavioural-practice change in agricultural sectors. This report outlines the genesis, design, management oversight and early results of ‘Project 25’, funded under the Australian Government’s National Environmental Science Program’s (NESP) Tropical Water Quality (TWQ) Hub. Project 25 was initiated through discussions between Australian Government, and large-scale sugarcane producers in the Russell-Mulgrave River catchment, identifying the need for water quality research to engage more directly with farmers to establish stronger, and more tangible feedback loops between water quality science and management. Based around small, sub-catchment water quality monitoring in a key GBR cane growing region, Project 25 utilises a ‘bottom-up’ approach to integrate sub-catchment monitoring and intervention to identify ‘hot spot’ sub-catchments through localised water quality monitoring. The Project emphasises industry ownership, and enables growers to participate directly in the water quality monitoring design, overall management, and delivery of locally targeted water quality data and extension effort to facilitate practice change within the sugarcane industry. The use of traditional, as well as emerging water quality monitoring approaches, and social research to identify mechanisms to maximise grower engagement with science, will help to enable farmers to directly link their activities with catchment water quality conditions.

1.1 Catchment context for Project 25

North Queensland’s Russell-Mulgrave basin covers an area of 1982 km², and is comprised of the two major catchments of the Mulgrave (1315 km²) and Russell (668 km²) rivers. Situated in the Wet Tropics region, it lies between two World Heritage Areas – the Wet Tropics World Heritage Area and the Great Barrier Reef World Heritage Area. A notable feature of the Russell-Mulgrave catchment (leading in large part to its selection for the Project 25 concept), is its relative simplicity in land-use development along the catchment continuum. The upper catchment headwaters of both the Russell and Mulgrave rivers largely exists within the relatively undisturbed rainforest environments of the Bellenden Ker Range. After leaving the ranges the rivers flow through a narrow area of river floodplains which are bordered to the east by lower coastal ranges.

While the rainforests of the mountain ranges that form the upper catchment of the basin are still relatively undisturbed, much of the former floodplain coastal ecosystems of rainforests, woodlands, grasslands and wetlands, have been heavily modified or removed. The river

floodplains and the lower river valleys are now dominated primarily by intensive sugarcane agriculture and growth of urban centres. Banana horticulture in the lower catchment, particularly of the Russell River, has increased over the last 20 years, but occupies only a relatively small land area when compared to sugar cane production. Intensive urban residential development is mostly confined to the northern end of the basin near Gordonvale, linked to the city of Cairns. Small towns and communities to the south of Cairns such as Babinda and Mirriwinni have maintained stable populations for some time, with economic drivers in this area creating a low likelihood of significant future population growth. Significant future residential expansion servicing Cairns is, however, occurring in the corridor south of Cairns extending to Gordonvale. The Gordonvale township wastewater treatment plant discharges into the Mulgrave River while the Babinda Treatment Plant discharges into the Babinda Creek. Land use changes include removal of coastal ecosystems, significant changes to overland hydrology, introductions of feral species, drainage of wetland ecosystems, and exposure of potential acid sulphate soils. These changes are mostly irreversible and future management needs to be adaptive and innovative (GBRMPA, 2013).

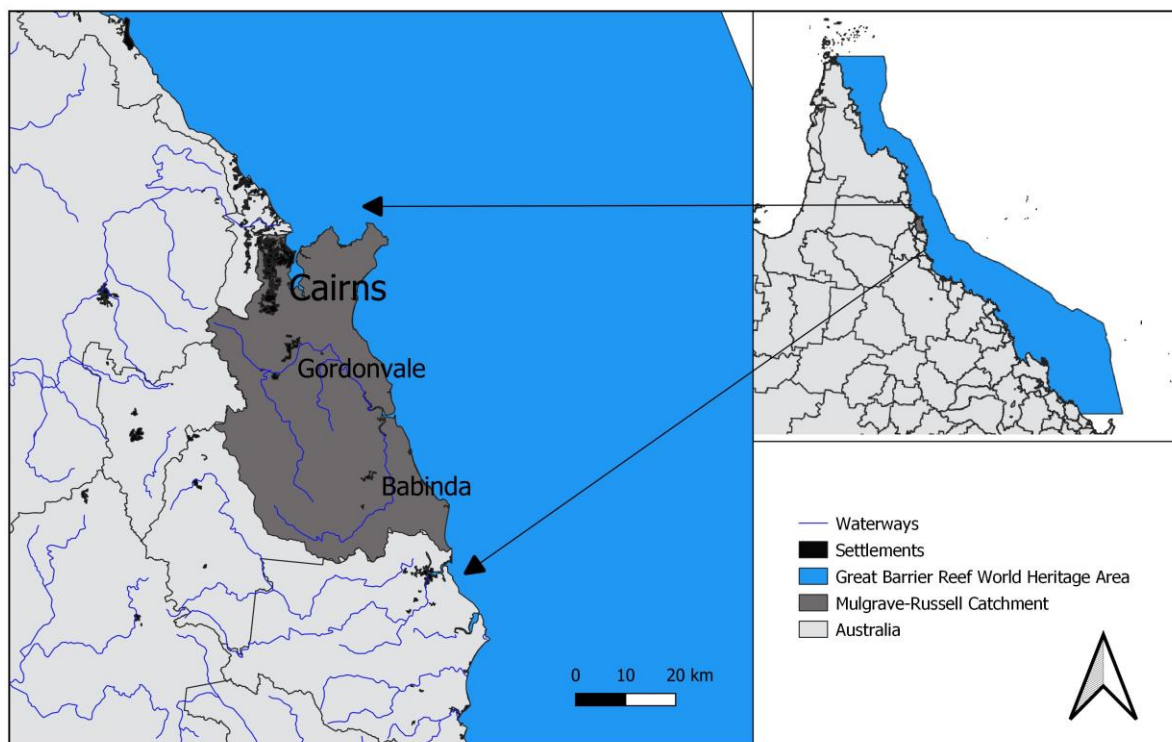


Figure 1: Map of the Russell-Mulgrave catchment, Wet Tropics and Great Barrier Reef World Heritage Areas. Source: Simon Fielke (CSIRO)

The Russell-Mulgrave catchment is one of the larger catchments in the Wet Tropics in terms of area, rainfall, and discharge to the Reef lagoon (Furnas, 2003). The Russell-Mulgrave basin is one of the wettest areas in Australia with high run-off to rainfall ratios and frequent run-off events. The average annual rainfall on the coastal plain in the Russell-Mulgrave exceeds 3,000 mm/year, with 60 per cent of the annual rainfall occurring in the summer wet season (December-March). Due to the steep topography of the region and the close proximity of mountain peaks (Mount Bellenden Ker and Mount Bartle-Frere) to the coastline (<25km),

transit times between coastal rainfall and oceanic discharge are very rapid, suggesting minimal residence times. These major discharges from the combined Russell and Mulgrave rivers contribute to the frequent flood plumes within the Reef lagoon. Recent Scientific Consensus Statements have consistently identified the Wet Tropics NRM region as the priority area for management of nitrogen. These GBR-wide catchment risk assessments identified the Russell-Mulgrave catchment as one of the top three DIN load contributors (with the Herbert and Johnstone) of risk to coral reefs, particularly in the Crown-of-thorns starfish influence area (Waterhouse et al., 2017).

Many of the water quality and agricultural stakeholder communication and engagement challenges mentioned earlier at both global, and GBR scales are also readily apparent in the Russell-Mulgrave catchment. Current GBR water quality monitoring, evaluation and communication is centred around the Queensland Government's Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef program; 'P2R'), integrating data and information on agricultural management practices, catchment indicators, paddock monitoring and modelling; and catchment load monitoring and modelling (Carroll et al., 2012). The catchment load monitoring of P2R centres around the Great Barrier Reef Catchment Loads Monitoring Program (GBRCLMP), managed by the Queensland Government Department of Environment and Science. Initiated in 2005, the GBRCLMP monitors and reports on loads of total suspended solids, nutrients and pesticides exported from major priority river basins adjacent to the GBR, and assists in evaluating progress towards the water quality targets of Reef Plan. While the Great Barrier Reef Catchment Loads Monitoring Program was implemented in 2005, it is only relatively recently (the 2014–2015 monitoring year), that two end-of-catchment sites in the lower Mulgrave River and Russell River were commissioned into the monitoring program. It is only recently, therefore, that local farmers had access to water quality monitoring data and reporting from their own catchment.

The broad scale of traditional catchment-based water quality monitoring programs, however, typically lack the spatial and temporal resolution to inform and convince individual landholders of their role in causing, but also managing catchment-scale pollution at local scales. The two new GBRCLMP monitoring sites on the Russell and Mulgrave rivers are essentially end-of-catchment sites, accounting for 522 km² (93% of catchment area) and 789 km² (98% of catchment area) respectively (Wallace et al., 2016) (see Figure 2). These large monitored catchment areas, containing dozens of individual farms, as well as several other major land uses, can confound or trivialise the perceptions of individual landholder contributions to cumulative water quality impacts. GBRCLMP results are also, for example, typically reported collectively across catchments and land uses. Because of the scale of data collected, delays associated with laboratory sample analysis, discharge data collection, compilation and validation, and quality assurance, reporting of results usually occurs approximately two years after a specific year's monitoring occurs (see Wallace et al., 2016; Huggins et al., 2017). While the current, long-term GBRLMP design is entirely appropriate to its primary aim of monitoring and bench-marking broader, integrated catchment progress toward Reef 2050 Plan targets, site number, scale and reporting delays do present many constraints for use with associated natural resource management (NRM) initiatives, particularly engagement with key stakeholders in the agricultural sector of the Russell-Mulgrave catchment.

Current P2R program water quality risk frameworks also benchmark on-farm management practices for water quality outcomes for each major agricultural industry as part of a

Stewardship – Agricultural management practice adoption program (McCloskey et al., 2017). These frameworks identify the farm management practices with the greatest potential to influence off-farm water quality and to articulate a reasonable best practice level which can be expected to result in a moderate-low risk to off-farm water quality (Australian and Queensland Government, 2018). For intensive crops such as sugarcane, the framework details management practices and systems for managing nutrients-fertilisers, pesticides and soils. Gathering this information across the landscape helps to prioritise areas which need greater support to improve landholders’ management practices. Agricultural practices in the water quality risk frameworks are described in an ‘ABCD framework’ in terms of their relative water quality risk, ranging from “A”-aspirational, cutting-edge practice; “B”-best practice; ‘C’-‘minimum standard’; and “D”-high risk (Table 1). These levels generally align with the “Above Industry Standard” and “Industry Standard” levels described in industry BMP programs. These rankings help prioritise areas which need greater support to improve landholders’ management practices, and also provides data to the Catchment pollutant delivery – Catchment loads modelling program component of the Paddock to Reef program, so the impact of investment on water quality can be estimated.

Table 1: Water Quality Risk Framework for the Reef 2050 Water Quality Improvement Plan (sourced from Australian and Queensland Government, 2018)

Terminology	Practice standard			
Water Quality Risk Framework	Lowest risk, commercial feasibility may be unproven	Moderate-low risk	Moderate risk	High risk
	Innovative	Best practice	Minimum Standard	Superseded
ABCD	A	B	C	D
Industry BMP programs (generalised)	Above industry standard (Typically aligns with moderate-low risk but in some instances aligns with lowest risk state.)	Above industry standard (Typically aligns with moderate-low risk but in some instances aligns with lowest risk state.)	Industry standard	Below industry standard

As an indication of district sugarcane industry engagement with farming practice change for water quality improvement around the initiation of Project 25, approximately 85% of the Russell-Mulgrave catchment area canegrowers were at “C” class standard (minimum standard), with 57% of the Mulgrave area cane currently grown under C class practices (Waterhouse et al., 2014a). A notable feature of Russell-Mulgrave cane growing is its place in the variability in average farm sizes in priority catchments across the Wet Tropics and lower Burdekin sugarcane growing districts. Areas such as the Russell-Mulgrave catchments typically have much smaller farm sizes than neighbouring other Wet and Dry-tropical cane farming regions. This creates associated challenges for farmer practice change– with the relative costs of changes likely to be larger on these smaller farms due to economies of scale (see Poggio et al., 2014; van Grieken et al., 2014; Smith, 2015). Prior to Project 25, the Russell-Mulgrave catchment was an area clearly posing considerable challenges for water quality engagement, and uptake of improved farming practices for water quality.

2.0 METHODOLOGY

2.1 Project inception

The then Federal Minister for Environment, the Hon. Greg Hunt, met with large scale sugar producers in the Russell-Mulgrave River catchment in late 2015, and collectively identified the need for GBR water quality research to engage more directly with farmers to establish stronger and more tangible feedback loops between science and industry. Through discussions with local canegrowers, the Minister proposed an approach that engages growers through a citizen science monitoring program conjoined with a robust scientific monitoring program. The development of more localised, adaptive, targeted and timely feedback loops between water quality information and growers was desired to strengthen the trust relationship between scientific outcomes and decision-making relating to on-farm practices.

Canegrowers would 'steer' the catchment water quality research effort, and collectively use it to identify 'hot spot' sub-catchment sites through comparative analysis of the water quality data. This approach would enable growers to participate directly in the monitoring design and collection of results, ensuring that farmers can recognise themselves as part of the solution to improving catchment water quality. Learnings emerging from this model were then to be used to inform a range of broader extension activities in other districts relating to water quality issues. While emphasising 'canegrower empowerment' in program management, the Project was still developed to ensure clear alignment with stated Australian Government NESP TWQ Hub Research Priorities, namely:

1a) Local scale identification of priority contaminant export loss (hot spots) for better targeting of on-ground works and 'tailored extension' activity.

1c) Develop/evaluate practical on-farm nutrient and sediment loss mitigation and capture and land management practices that will influence behavioural change and improve water quality outcomes –link to field trials.

1e) New methods for encouraging behaviour/practice change/improving compliance with BMP.

A broad underlying philosophy of the project is to provide greater understanding of behaviour change drivers relating to on-farm management practice decision making and water quality outcomes to inform future Reef Plan extension and engagement activities.

2.2 Social setting and project oversight

2.2.1 Establishment of Stakeholder Steering Committee.

The appropriate mechanisms for identifying 'the who' with respect to industry engagement and 'buy-in' is an important consideration, often overlooked in the design, implementation and communication of water quality monitoring programs, particularly those aimed at driving behavioural-practice change in agricultural sectors. The use of people from farming

backgrounds or trusted networks is well-known to enhance message uptake and farmers' inclination to process in-group messages. Farmer-to-farmer programs in Canada and the U.S. have been very effective in delivering conservation practice technical assistance, but usually required additional funding, as did the use of dedicated extension agents to work directly with small groups of farmers to encourage adoption of nutrient management practices (Blackstock et al., 2010; Osmond et al., 2012). Establishment of a 'Integrated Area Wide Management' working groups with local farmers, key service providers (selected peak industry representatives, extension staff and scientists-government agency personnel) were similarly a cornerstone of the cotton industry efforts in achieving demonstrable water quality improvements in central Queensland (Wolfenden and Evans, 2007; Kennedy et al., 2012).

Discussions with disgruntled large sugarcane growers in the Russell-Mulgrave catchment led to the establishment of the Stakeholder Steering Committee for Project 25 well before the project itself was even announced. At this point, growers were being blamed for the poor water quality run-off to the reef from the catchment. The initial invited grower collective that met with the Minister for the Environment in 2015 were specifically identified and recruited for their industry roles as large, influential growers, and broader reputations as industry leaders. Rather than a typical engagement approach previously seen in the GBR catchment area involving interactions with 'the willing' farmers ('low hanging fruit?'), Project 25 specifically targeted and engaged major industry 'players' from the outset of the program development. Part of the subsequent agreement with these growers for their role in Project 25 oversight and management would be their willingness to act as Project advocates and spokespeople at local industry levels.

“Increasingly, we hear the concerns about the impact of farming on the Reef. To be honest, we believe some of it but most of the reports we are sceptical about. We are sometimes told that we are the worst polluting catchment and at other times that title goes to Tully or the Herbert. We are told that the information comes from the 'end of catchment' water quality modelling. I can tell you that very few farmers believe that modelling. However, it would be TOTALLY wrong to say that we are NOT committed to improving our region and want it to be the best it can be.”

Sugarcane grower, Babinda

The stakeholder steering committee also includes State-level CANEGROWERS organisation members, non-government organisations (NGO) and science/academic members to provide the requisite policy and technical oversight.

2.2.2 Communication and trust frameworks

A critical part of the early development of the Project 25 model was the industry engagement necessary to establish robust science-industry trust frameworks, particularly industry faith in the overall process. Global extension experiences consistently stress the critical importance of often complex agronomic, technical and/or environmental advice being delivered to involved farmers through trusted, high credibility contacts (i.e., key service providers, extension staff) as a key driver of change (Blackstock et al., 2010; Kennedy et al., 2012; Osmond et al., 2012). High credibility sources are particularly important when messages are complex, there is little

available experience, and/or a message carries a high personal risk (Blackstock et al., 2010). These are all issues characteristic of agricultural sector engagement with water quality and practice change. Given the consistent concerns on the part of the GBR catchment area canegrowers regarding the veracity of current catchment modelling-monitoring initiatives, these trust frameworks became a critical design consideration for Project 25. Use of water quality scientists with established experience and rapport with the sugar industry and water quality issues was accordingly also an important part of the program development.

Appropriate information confidentiality and data dissemination frameworks were similarly a critical consideration in study design for grower engagement and collaboration. While freedom of information considerations may desire immediate transparency of monitoring data, because of the potential immediate accessibility and sensitivity of water quality monitoring programs in particular, lack of context could result in misinterpretation of results made publically available in 'real-time'. Recent experiences within other GBR sugarcane catchments highlight a safe learning environment is essential for data sharing partnerships to consolidate (see Di Bella et al., 2015). While there was stakeholder steering committee agreement that data would eventually become publicly available, interim embargoes or limited access to real-time data streams were established with data presentation limited to directly involved project stakeholders. Recognising industry desires to receive appropriate opportunity to digest and interpret monitoring outcomes, and proactively develop strategies and implement activities to address identified issues are an important component of the trust framework, and one that has been used successfully in similar programs (see Di Bella et al., 2015).

"This project allowed us to monitor the catchment in real-time. More importantly ... it allowed us to place the automatic monitors where we believe we needed the information – like testing the water out of the rainforest and around the towns as well as big farming sites. A big effort was made for us to see the results quickly without the information being used against us. We can now see where the problems are and where they are not."

Sugarcane grower, Babinda

This initial data provision and presentation is an important component for both steering committee growers and scientists involved in the project. It provides scope for local catchment knowledge to be framed into better message delivery from scientists to industry, and also developing consistency in appropriate messaging and data interpretation back to the broader industry. Annual wet season results are then typically disseminated to the broader growing community through a variety of processes such as annual local CANEGROWERS meetings (50-100 growers), through to small-scale shed meetings at a local sub-catchment scale (5-6 growers).

Recognising and cultivating these trust frameworks (which do not happen instantaneously), are a critical and requisite first step required before major effort is made on attempting to significantly change grower behaviour on-ground. Feedback from Project 25 canegrowers includes:

"It has been invaluable that the growers and researchers are communicating, sharing their issues and ideas, understanding each other's challenges and

building a trust framework. This approach can only have a positive effect and because of this, real gains are achieved”.

And,

“Minimising our own impact on the surrounding environment, that is what all sectors of the community strive for. A project such as this, building knowledge and trust, puts the farming sector in a position to best control the impact that they have on water quality”.

A major evolution of Project 25 (and evidence of cane industry faith and comfort in the process and scientists) was stakeholder committee agreement to its recent partnership with CSIRO to include the Project as a key theme (GBR Water Quality) within the CSIRO ‘Digiscape’ Future Science Platform. The Digiscape initiative will identify how canefarmers can best use local environmental information collected through sensing technologies (near real-time water quality, weather, crop production data) to alter management decision-making on farm, and ultimately change farming practices.

2.2.3 Program Water Quality Monitoring Design

A key industry aim of Project 25 was to characterise the water quality impacts and relative signatures of a range of the distinct land-use types found across the Russell-Mulgrave catchment, and quantify the sugarcane industry’s specific role in end-of-catchment water quality. Through grower input and advice, sub-catchment waterway sites were selected to represent the major land uses of the region, namely sugarcane, urban, banana, or natural ‘rainforest’ land use categories. Sites were also selected based on factors such as wet season accessibility to the site and the size of the waterway. A total of nine sites were initially selected for the monitoring program through the period 2016-2019 (Figure 2). Monitoring focused primarily on nutrient (nitrogen and phosphorus) and sediment water quality parameters, as these are typically identified as the most important management challenges for north Queensland industries, and considered most relevant to Great Barrier Reef water quality issues (Brodie et al. 2012). A key cane industry desire voiced in early stages of program design was for local water quality information to be underpinned by high quality data. A substantial proportion of program budget is therefore dedicated to collection of high quality, long-term water quality data at monitoring sites.

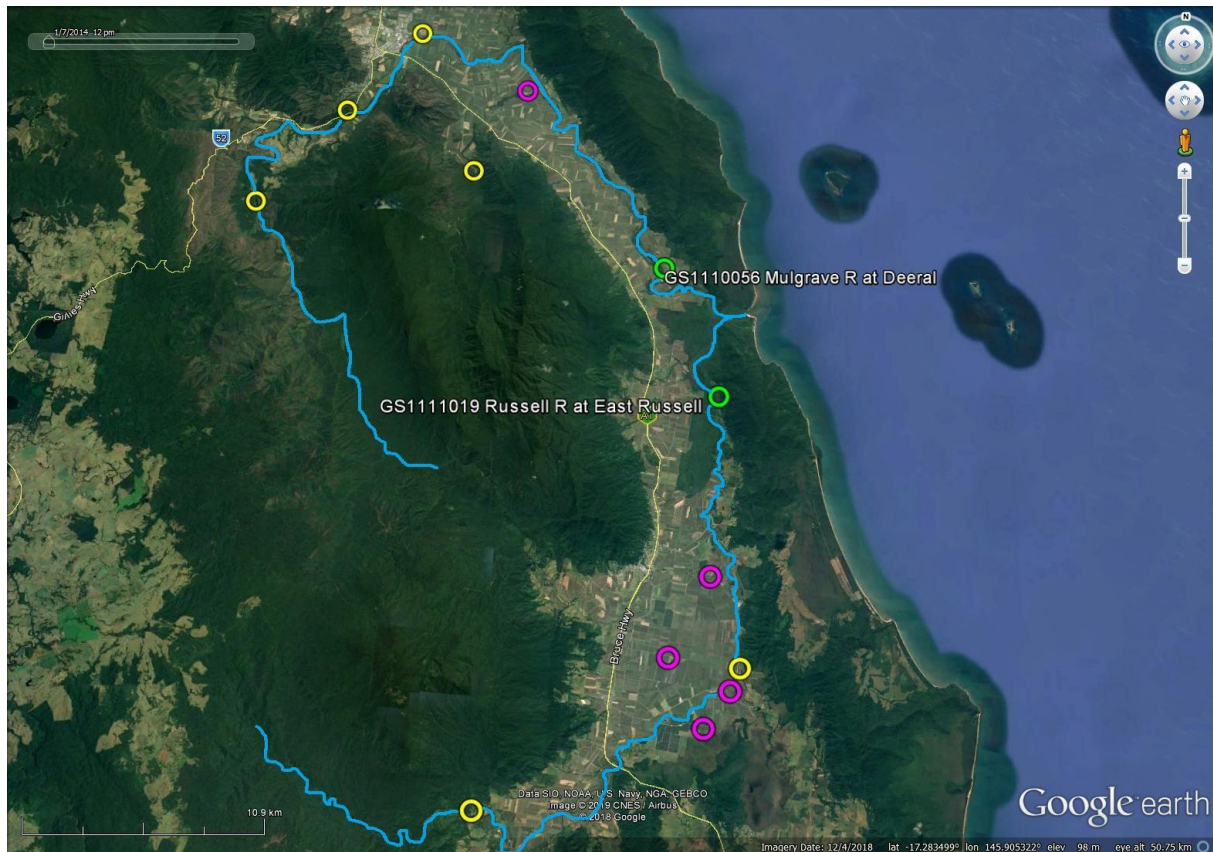


Figure 2: Map of current Project 25 and GBRCLMP water quality monitoring locations in the Russell-Mulgrave catchment. Project 25 Real-time water quality monitoring sites indicated by purple markers, discrete water sample collection sites by yellow. Queensland Government GBRCLMP sites labelled and indicated by green markers.

Water quality monitoring for Project 25 is based around the integration of relatively traditional monitoring approaches used in the GBR catchment area (discrete sample collection for subsequent laboratory analysis), as well as emerging real-time (sensor-based) water quality monitoring approaches (RTWQM). The development of real-time information and feedback on local water quality dynamics is a relatively novel approach to landholder engagement that is yet to be meaningfully explored in natural resource management programs. Project 25 will trial these new technologies from both the perspective of an engagement-extension tool, and also their reliability in water quality monitoring applications across multiple spatial scales (paddock to catchment).

Discrete samples for water quality provided the primary monitoring foundation, and were conducted at all sites on an approximate monthly or bimonthly basis during dry-season low flows. Sampling frequency increased to daily (and occasionally several samples a day) during wet season flood events, particularly the first several early wet season 'first-flush' events, to capture initial high concentration run-off dynamics from the immediate catchment area, events that typically provide the majority of wet season load exports (Davis et al., 2017). Samples were collected either manually or by rising-stage samplers by project scientists, or support staff trained individually in the correct sampling and quality assurance procedures developed in conjunction with the James Cook University TropWATER Water Quality Laboratory.

Water samples were collected in pre-rinsed 1-L polypropylene bottles using an extendable sampling pole. Unfiltered nutrient samples then subsampled into 60-mL polypropylene vials

(Sarstedt, Germany), and filterable nutrients filtered on-site through pre-rinsed filter modules (MiniSart 0.45 µm cellulose acetate, Sartorius, Germany) into six 10-mL polypropylene vials (Sarstedt, Australia). Samples were stored on ice following sampling and on-site processing, for transport to the laboratory for subsequent analysis. Water samples were analysed for total nitrogen, ammonium nitrogen, oxidised nitrogen (nitrate + nitrite), filterable reactive phosphorus and total suspended solids following standard methods (Hosomi and Sudo, 1987; APHA, 2005; Bainbridge et al., 2009). Periodic duplicate samples and field blanks were also collected under both wet and dry season conditions as part of Quality Audit/Quality Control QA/QC procedures.

RTWQM equipment was initially deployed in three selected Russell-Mulgrave sub-catchments in the broader Project 25 monitoring design, identified in discussion with cane industry steering committee personnel. Sensors were current market-ready technologies, in this case TriOS NICO and OPUS optical sensors (<https://www.trios.de/en/>). Optical sensors are susceptible to reduced performance from biofouling and sedimentation of the optical lens (Steven et al., 2013). Optical sensors utilised during Project 25 were initially cleaned utilising an integrated compressed air blast system to automatically clean the optical window. Recent development of automated, externally mounted lens wiper technologies by TriOS saw these new cleaning technologies added to some sites towards the end of 2018 (Figures 2a, b). Lens were also cleaned manually at least monthly, and often more frequently during significant flow events when sites were safely accessible. Calibration checks of each sensor were conducted at least every three months, using 0, 1 mg/L, 5 mg/L and 10 mg/L nitrate calibration standards provided by the TropWATER Water Quality Laboratory. Initial station design in 2016-17 initially involved stream water being pumped into a flow-through cell with the nitrate sensor housed in the sampling station. Some early power issues and equipment failures saw sites re-designed with the sensor installed instream in a PVC pipe, and subsequent measurements taken *in situ* (Figure 2c).

A key theme emerging from both global and local GBR catchment area experiences is the considerable additional investment and monitoring effort required to elevate ‘concentration only’ data collection to more detailed data types (Davis and Waterhouse, 2017). The collection of additional datasets to support concentration data, such as catchment hydrology (streamflow discharge), does require substantial additional monitoring infrastructure and data collection and processing. The broader data formats possible from this investment (pollutant loads, Event Mean Concentrations (EMCs) etc.) are, however, amenable to a much more diverse range of potential uses such as trend analyses, pollutant export coefficients and pollutant loadings from specific land use types. Sampling locations in Project 25 were co-located in several cases with existing streamflow discharge monitoring infrastructure (Queensland Government or Cairns Regional Council gauging stations). In cases where these were not available, stream height-discharge relationships (rating curves) were developed through standard methods wherever possible.



Figure 3: Alternative optical lens cleaning options utilised throughout Project 25. (a). Compressed air blast; (b) Automated, externally mounted lens wiper currently being trialled. (c). Real-time monitoring station during wet season flood event.

Catchment water quality loads across sites were calculated via linear interpolation using the Loads Tool component of the Water Quality Analyser program (version 2.1.1.6; eWater CRC, 2018). Catchment boundaries and land-use coverage data upstream of all monitoring sites were sourced from the Queensland government land use mapping program (QLUMP; <https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/qlump/qlump-datasets>).

2.2.4 Understanding the social and cultural aspects of industry engagement

An early indication of the engagement success of Project 25 was the willingness of participating stakeholders (particularly in industry) to support additional research into the sociological basis and outcomes from Project 25. An important evolution of the program was the addition of a major social science component in 2018 to better understand the human behaviour components to design, implement, and evaluate industry wide programs to understand the day-to-day challenges facing cane farmers and to recognise, value and accelerate their efforts to adopt farming practices that help improve water quality.

The underlying rationale for the Project 25 sociological component is that integrating new engagement models, technologies or monitoring practices within farm businesses and agricultural sectors is widely appreciated as a challenge. Where these new approaches generate information or seek to inform farmer decision-making about environmental performance of their operation, as well as productivity, the difficulty and complexity of that

challenge increases significantly. Insights from the scientific literature on agricultural decision-support systems, technology adoption and agricultural innovation systems underline the importance of effective, local collaboration between farmers, scientists and other service providers (such as extension specialists) in the process of designing, trialling and evaluating the benefits and risks of these approaches and their deployment. The benefits of collaborating in this way can be understood as three propositions:

- i. the use of the new models or technologies can be more readily tailored to local needs and conditions and therefore more successfully embedded in local farming systems;
- ii. it presents an opportunity for farmer and expert, scientific knowledge to be integrated more effectively and for joint-learning between scientists and farmers; and
- iii. improves trust in the data / information source and its application to on-farm and wider decision-making.

The incorporation of a participatory social assessment activity within Project 25 was intended to test all of the above propositions, specifically:

- i. Elicit project participants assumptions, expectations and concerns about the Project 25 process itself, the monitoring technologies;
- ii. Monitor participants (growers, scientists and others) attitudes towards and experiences with the Project 25 model, process, technologies, information and collaboration over time;
- iii. Identify strengths and limitations of the approach to inform ongoing adaptive management and delivery of the project; and
- iv. Identify issues related to scalability and/or transferability of the approach to other locations or farming systems.

The sociological research methods used in this activity included a range of interviews, focus groups or social survey instruments with participants, observation at field days or project workshops or other interactions; and/or social network analysis of participant advice and information networks over time. The study relies predominantly on a qualitative constructivist/interpretivist methodology with data gathered through both participant observation in several project-related forums, and through semi-structured interviews with project participants and stakeholders. Ethics approval for obtaining and incorporating participants' data into the study was granted through the CSIRO Human and Social Research Ethics Committee. Twenty in-depth predominantly qualitative interviews were conducted for the first phase of analysis. These interviews were undertaken between September and November 2018, subject to the availability of participants.

Participants included growers in the Mulgrave catchment area who were participants in the Steering Committee and other growers who were not directly involved in the project; local industry extension officers; industry representative body officers; and, scientists working on

the project. Interviews were conducted mainly face-to-face in the catchment (e.g. on growers farms or in the workplaces of partnering organisations) or where requested, by telephone. Interviews were semi-structured, exploring several topics through discussion with interviewees (see Schedule 1 below). Length of interviews ranged from 40 mins to 1.5 hours. Informed consent was obtained from participants prior to initiating the interview. With permission, the discussion was audio recorded and transcribed for analysis.

Analysis of interviews involved in the first instance a topic-based coding strategy against the main themes of the interview for the different types of participants (e.g. grower; extension; science). This was followed by a secondary coding strategy that identified influential constructs (e.g. trust, knowledge, risk, ownership etc.). This approach assisted in developing an understating of 1) experiences of different types of participants; and 2) some of the more influential factors shaping that experience. Interview topic areas and questions broadly addressed issues such as motivations for involvement and expected benefits; familiarity and experience with the monitoring network; trust in information sources and perceived value of the monitoring data; and participant perceptions on adaptive management and transferability to other catchments.

The below model is a useful device for checking and evaluating the project teams assumptions about change generated through Project 25.

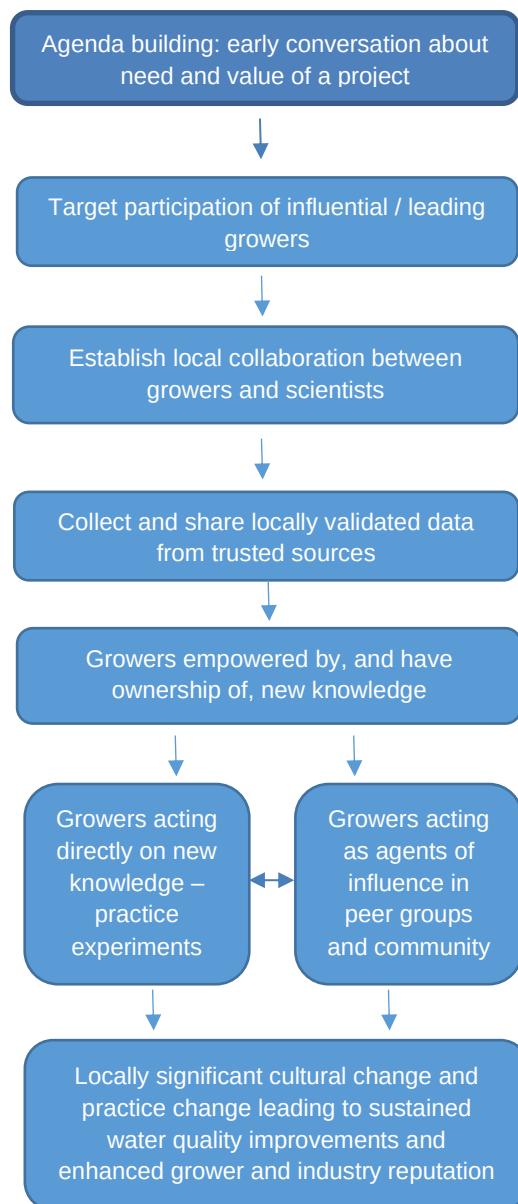


Figure 4: Representation of the Project 25 change logic model (draft). (supplied by Bruce Taylor, CSIRO)

3.0 RESULTS

With Project 25 as an ongoing program, and being cognizant of maintaining trust frameworks, results reported to this point in time are presented as anonymous or aggregated data, focussing on the key learnings or project experiences to this point in time, rather than specific comparative results. Also reported where relevant are stakeholder anecdotes documented throughout the project to this point as qualitative context to more detailed results presented to industry stakeholders.

3.1 Capacity for hotspot identification

Project 25 has provided clear capacity for hotspot identification in local sub-catchments of the Russell-Mulgrave catchment. Even when factoring in the inevitable local scale variability in climate, hydrology and timing of farming operations that can confound identification of water quality patterns, within approximately three years, areas consistently responsible for relatively high nutrient losses emerged rather quickly. Figure 4 contrasts the typical scale of nitrate-N fluxes across the three RTWQM sub-catchments in the Russell-Mulgrave, all presented with the same scale. The site in panel (b) demonstrates both significantly higher, but also more sustained and elevated nitrate-N concentrations throughout rainfall-runoff events. While local variations in catchment land use development (i.e. relative area of sugarcane versus pristine rainforest) does have considerable influence on the observed nitrate-N concentration dynamics, these relationships were also consistent with more integrated and directly comparable data formats such as annual nitrate loadings on a per hectare basis from each catchment (i.e., kg/Ha/year).

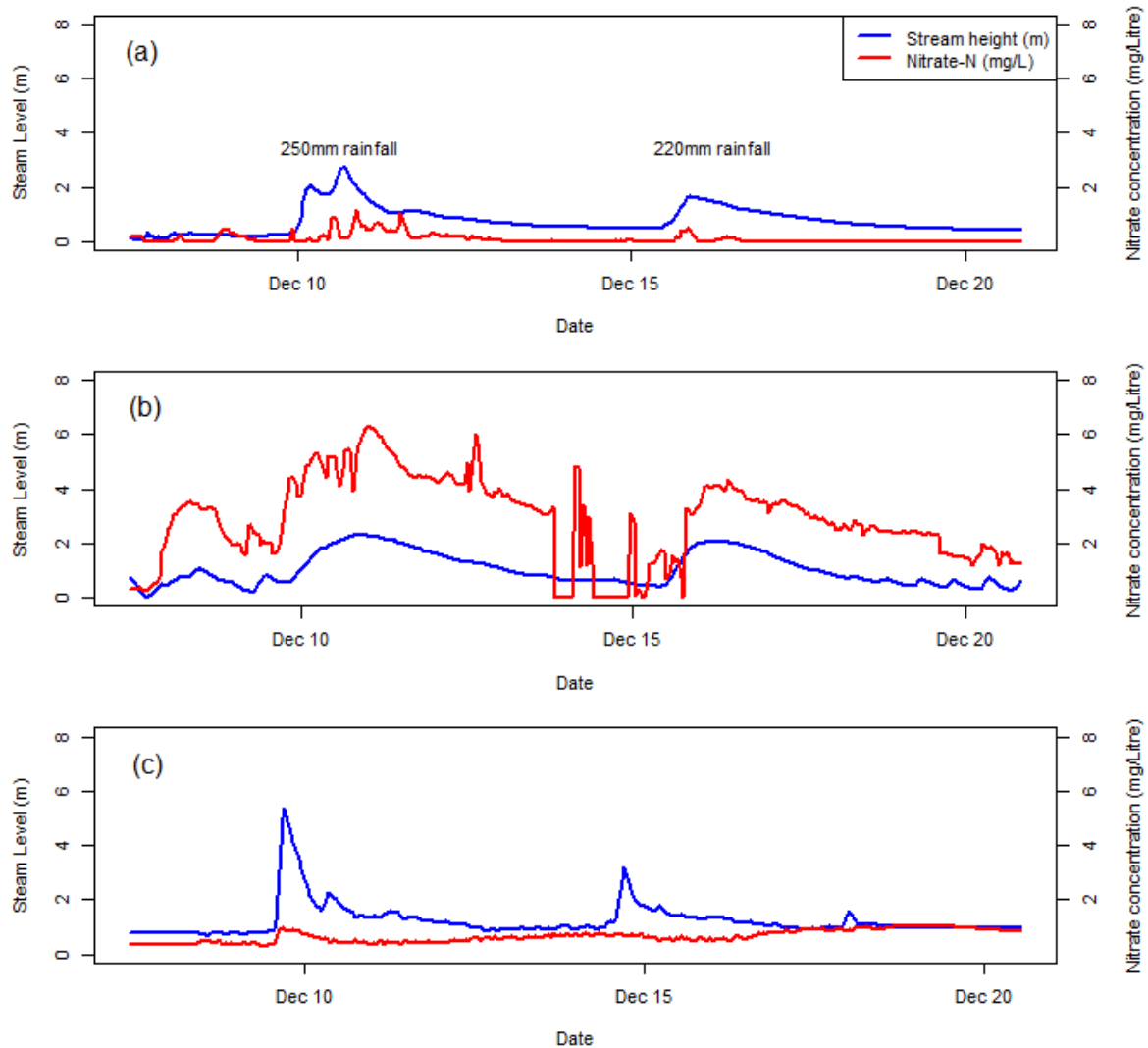


Figure 5: Intensive nitrate-N monitoring from three Project 25 sampling stations during early wet season rainfall events. Approximate daily rainfall totals responsible for flood events are indicated in panel (a).

The consistent presentation of this local pattern to grower stakeholder steering committee members elicited agreement that finer scale water quality monitoring was needed to move ‘up the catchment’ to further understand these hotspots and engage more meaningfully with specific grower collectives. Site locations for additional new monitoring stations were identified in early 2019 following discussions and site appraisals involving steering committee members and local growers in the target catchment. Results underline the value of collaborative approaches where local industry input into program and sampling design, knowledge of district farming practices, coupled with mutual trust frameworks, and locally relevant ‘real-world’ data can be used to identify hotspots for improved on-ground prioritisation of water quality monitoring and extension effort within broader catchment areas.

3.2 Tailoring messages to industry

Another benefit of meaningful grower involvement in program design, is the advantages and opportunities provided for effective communication of not only basic water quality science, but also government policy aims, back to industry. The fundamental foundation of Project 25 was

a local water quality program designed in large part with providing clarity and locally relevant data on particular industry concerns. Discussions with stakeholder committee growers highlighted considerable confusion around GBR catchment monitoring within the broader sugarcane industry, particularly misconceptions around end-of-catchment targets identified in government policy, and issues such as the relative contribution of land-use types such as rainforest to end-of-catchment loads. Local data ('real data, not modelled') to provide clarity on these issues to the broader grower community was identified as a specific information gap to be addressed by Project 25.

One of the strengths of the Russell-Mulgrave catchment, is the relative simplicity of the catchment and defined spatial extent of specific land-uses. The 'before and after' program design to capture land use water quality signatures as they change along the rainforest-sugarcane continuum, provides powerful capacity to quantify and communicate the impact of anthropogenic land uses back to stakeholders in several ways. Figure 6 outlines an example of typical Project 25 feedback to industry from one monitored catchment, partitioning the end-of-catchment nitrate-N load changes documented using local rainforest and sugarcane water quality data collected through a wet season, into a 'natural' and 'anthropogenic' component. Knowledge of land-use areas upstream of monitoring locations also allows conversion of load data in per hectare load losses from farming inputs (in this case ca. 9-10 kg/Ha/year), but also theoretical load reduction targets (50% reduction, which equates to 4-5 kg/Ha/year) desired under Reef 2050 Plan targets for canegrowers to achieve.

Working through the data collection process, the underlying concepts, and presenting data in this way, with local data from familiar sites, and in units more familiar to the farm input language of canegrowers (kg/Ha), proved an effective method for engagement, and addressing the confusion and scale of issues in ways more digestible to growers. The presentation of data in this format to both Project Steering Committee canegrowers, but also larger cane growing audiences proved a powerful tool for framing and communicating local water quality issues in a coherent, and understandable manner.

Feedback directly from Project Steering Committee members included:

"we'd hear at every local meeting about GBR water quality that rainforests contribute most of the nitrate to the Reef. After seeing some of this data, we can put those issues to bed now".

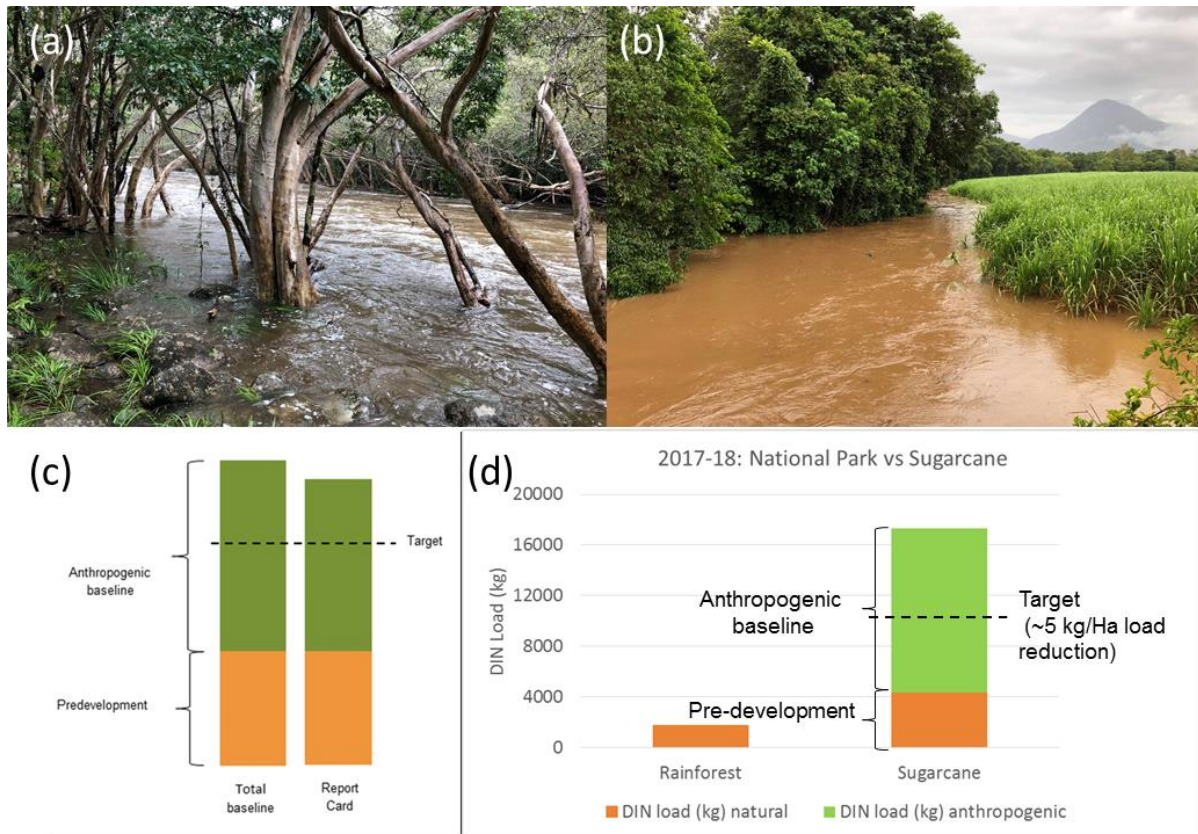


Figure 6: Example data presentation from a Project 25 catchment back to industry stakeholders, contrasting rainforest-sugarcane water quality impacts. Panels a) and b) outline sampling locations (upstream rainforest and downstream sugarcane). Panel c) the Reef Plan load reduction target concept (sourced from Reef Plan 2013). Panel d) 2017-18 wet season data compiled and presented in the same format as Reef Plan, tailored to the local catchment and sugarcane industry.

The underlying process for data generation and interpretation even allows scope to present data in the context of historically contentious topics such as Paddock to Reef (P2R) modelling of sugarcane inorganic nitrogen losses across different districts (not shown here). Grower anecdotes from the Project 25 steering committee include observations such as:

“amongst growers there was a lot of apprehension about the results that were presented from modelling. It has been a learning experience for both the growers and the researchers comparing the modelled data to the actual data”.

Presentation of real, locally developed data is clearly a very effective tool for addressing known challenges or points of contention in sugarcane industry understanding of water quality issues.

3.3 Providing clarity to target industries on the relevant local-scale water quality issues.

The communication and media landscape of Great Barrier Reef water quality science is often emotive, imprecise, with considerable confusion or messaging across all catchment stakeholders. Growers in the Russell-Mulgrave catchment have, for example, been directly implicated by either media or government communications in significant losses of water quality

pollutants such as sediment and phosphorus to the Great Barrier Reef marine environment. A key consideration in Project 25 design involved ‘upstream and downstream’ collection of samples from major urban centres in the catchment. Results identified consistently elevated filterable reactive phosphorus (a measure of orthophosphate, the soluble, inorganic fraction of phosphorus directly taken up by plants) as a key signature of the urban water quality footprint, compared to other major land uses in the catchment, such as sugarcane (Figure 7).

This was an outcome generating considerable interest and debate from local canegrowers;

“I’ve received letters from Queensland government saying canefarmers in my area are responsible for losing significant amounts of phosphorous to the Reef. It’s good to see data showing this doesn’t seem to be the case, or at least that people in towns need to be more aware of their impact on water quality. I want to know what I’m most responsible for, not get blamed for other issues”.

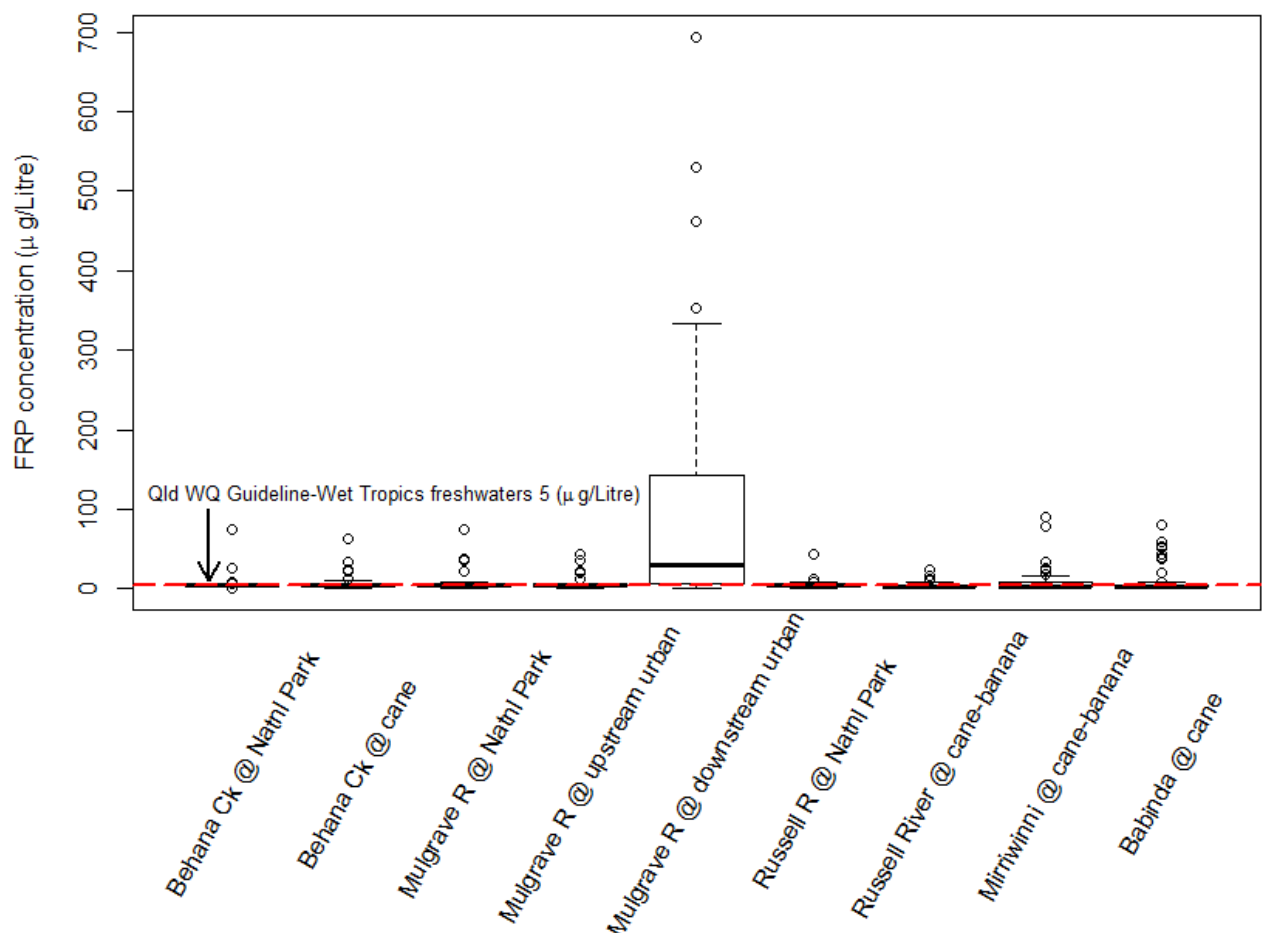


Figure 7: Summary boxplots of Filterable Reactive Phosphorus (FRP) concentrations ($\mu\text{g/Litre}$) across Project 25 sampling locations (2016-2018). Site boxplots depict median values (denoted by the horizontal line), with the box representing the inter-quartile range (containing 50% of the data). The whiskers extend from the box to the highest and lowest concentrations, excluding outliers (circles), which are defined to be outside 1.5 box-lengths (outside the 25th and 75th percentiles).

These sorts of results have considerable value in highlighting the specific local water quality issue the industry should focus attention on, while also building trust in the Project framework

in addressing industry concerns about the water quality impacts of other land uses. This provides actual evidence for the industry to respond to, and to counteract future external claims about local water quality issues, and also makes industry stakeholders more amenable and comfortable discussing their own land-use-water quality challenges.

Positive feedback is also similarly an essential element in encouraging any form of behaviour change by farmers, and positive feedback has been shown to be more effective than negative feedback (OECD, 2017; Pickering et al., 2018). Promoting ‘good news’ stories in results and providing positive recognition around cane industry practice changes also encouraged more open dialogues around all water quality issues. Soil erosion rates from conventionally cultivated sloping cane lands in wet-tropical north Queensland had, up until the 1980’s, been measured in the range of 47-505 t/ha/yr (av. 148 t/ha/yr) (Prove et al., 1986; 1995). Subsequent industry uptake of conservation practices such as reduced tillage and harvest residue retention (green cane trash blanketing) reduced these losses significantly. The presentation of locally collected suspended sediment data across different land use types underline the success of these collective industry responses to historic water quality challenges to Project 25, and other canegrowers (Figure 8).

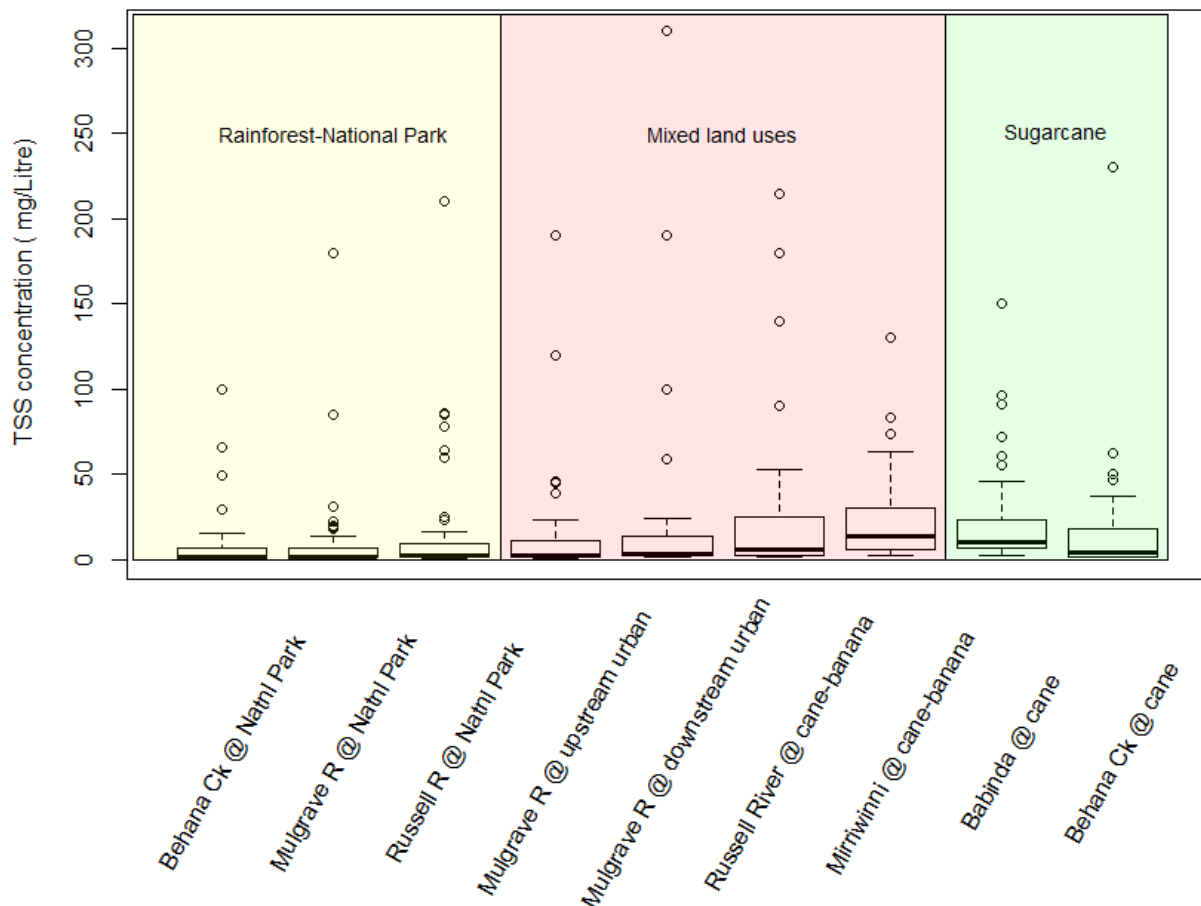


Figure 8: Summary boxplots of Total Suspended Solids (TSS) concentrations (mg/Litre) across Project 25 sampling locations (2016-2018). Site boxplots depict median values (denoted by the horizontal line), with the box representing the inter-quartile range (containing 50% of the data). The whiskers extend from the box to the highest and lowest concentrations, excluding outliers (circles), which are defined to be outside 1.5 box-lengths (outside the 25th and 75th percentiles).

3.4 Value of investment in high quality data provision.

It becomes quickly apparent in discussions and water quality data presentation with canegrowers that they are interested in water quality across a broad range of spatial scales, timeframes and issues. Investment in data quality allows data presentation across a diversity of different issues, from local water quality conditions and ecosystem guidelines (Figure 7), through data delivery in real time as events or particular processes occur (early wet season 'first flushes'; Figure 4). In addition to the natural versus anthropogenic partitioning described earlier, annual load calculation also allows presentation and discussion of temporal partitioning of catchment load dynamics. Figure 9 outlines one of the typical temporal load export dynamics emerging across several of the sugarcane sub-catchments monitored in Project 25. The dominant proportion of nitrate-N export through catchments often occurs in the first 2-3 major wet season events (particularly if occurring in close timing with farm operations such as fertiliser application), with larger, often major wet season floods (March onwards) contributing lower loads. How this smaller, coastal catchment scale loss dynamic is reflected in larger, whole-of-catchment load losses during the largest annual flood discharge events (where the entire catchment receives significant rainfall) is yet to be fully explored. It could, however, have important implications for design, use and ultimate effectiveness of other water quality improvement measures (bioreactors, on-farm and off-farm constructed wetlands), and their capacity for capturing nitrate losses from particular landuses. Regardless, this quantification of linkages between timing of catchment farming activity and the first significant wet season floods has proved useful to highlighting specific risk periods to growers.

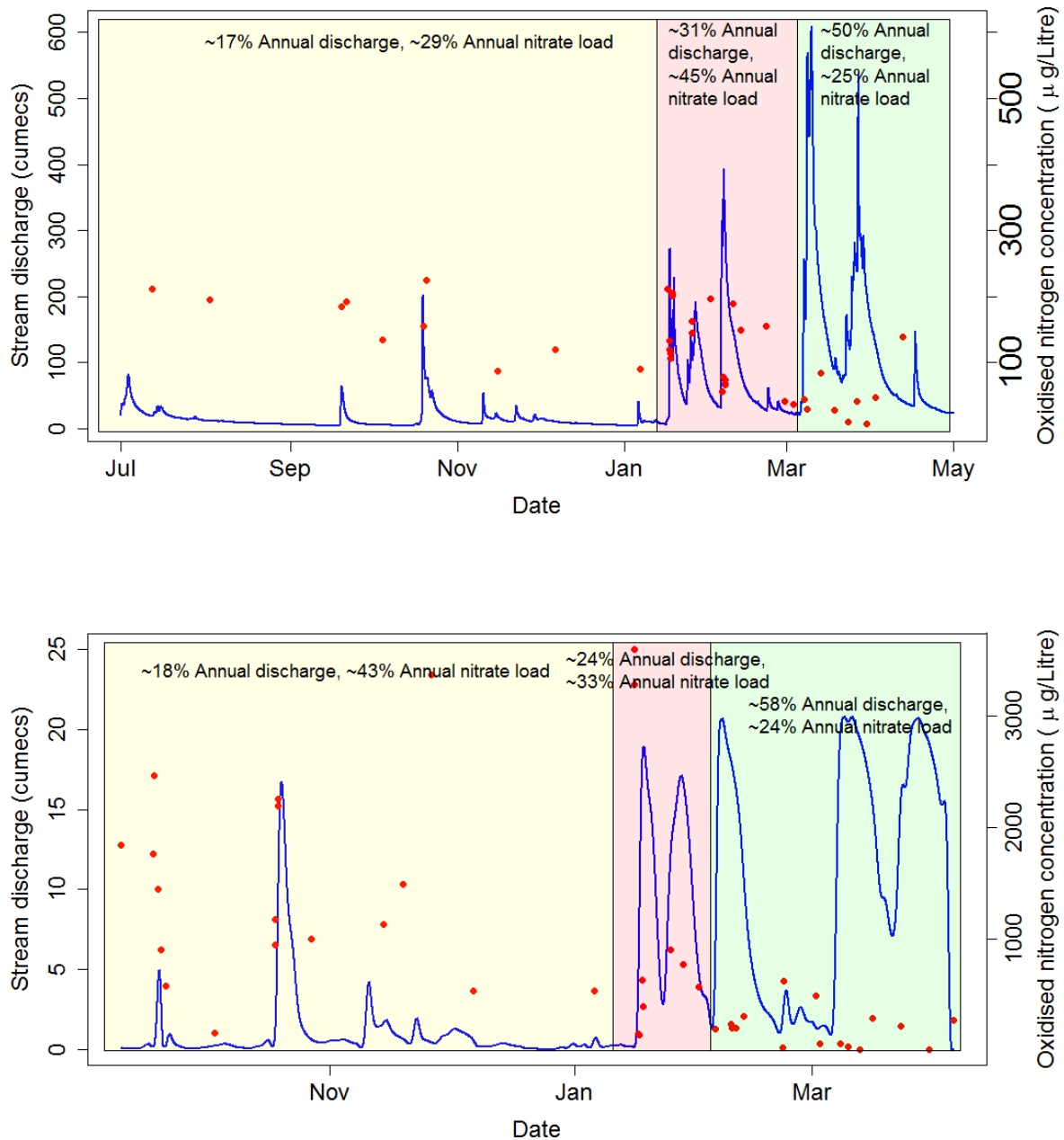


Figure 9: Characteristic Oxidised-N annual load export dynamics emerging from Project 25 monitoring sites, and communicated to local canegrowers. Oxidised nitrogen (DIN) concentrations, stream discharge hydrographs and temporal partitioning of DIN loads through different parts of the year are indicated by shaded boxes.

3.5 Early social and cultural dimensions of Project 25.

Results of initial Project 25 stakeholder interviews are an integral part of benchmarking perceptions and attitudes to the Project and GBR water quality science, and how they change through time. While this temporal change or evolution of attitudes is yet to be assessed, early outcomes also provide valuable context to motivations and attitudes of industry stakeholders toward the Project itself. Some relevant early summary findings include:

Importance of building a trust-based environment for communication.

Interviewees report improved communication, an improved trust environment with more direct oversight of monitoring data, and 'space' to learn and experiment as contributing factors. Interviewees described the presence of meaningful and ongoing two-way communication between science and industry stakeholders, and two-way trust and recognition of the value of bridging on-farm knowledge with water quality monitoring data. One grower reported:

“you take the growers with you and you will get more uptake... more of an outcome because you'll get more belief in the science.”

Shed meetings, working together in the paddock and discussion at Steering Committee meetings has also provided opportunities for open discussion, helped to create a 'safer' space for growers, and, for researchers to reach new audiences.

Local water quality data reinforcing personal contribution to improved farming practices

Growers have described the benefit of having access to locally collected data to help validate or test the effectiveness of changes they have made to nutrient application and other practices on farm:

“I've spent hundreds of thousands of dollars changing implements and practices. Well, I want to know whether I'm... making a difference... am I just pouring money down the drain?”

Collaboration between Project 25 and Digiscape Future Science Platform has produced interpretive materials that help growers understand the relationship between run-off/stream flow following major rainfall events and the presence of nitrogen in local waterways. This material is being discussed amongst growers and in community forums, challenging thinking on the timing and efficacy of farming practices such as debates of merits of early versus late season split applications in the catchment.

Value of Project 25 in supporting peer group leaders

To date, the project has enhanced the capacity of some grower participants to act as leaders and influencers within their local farming community and networks. Members of the Steering Committee have been observed speaking to the rationale and benefit of the project in public forums. Here the project is framed as a means to demonstrate social and environmental responsibility of the local industry to the public; and to contribute to local self-regulation by identifying parts of the catchment *“where we have nutrient problems, and where we are managing well”* and plan targeted intervention in those areas with the relevant growers.

Sugarcane industry perception of science

The initial interviews and observations suggest there is emerging evidence of the project supporting peer leadership and informing practice improvement. Growers' expectations about the role of locally generated scientific knowledge in establishing 'truth' about their individual

and collective contribution to nutrient pollution in the catchment is still somewhat unresolved. The strong differences of opinion expressed by grower participants pose a potential risk that will require further dialogue and exploration within the Steering Committee. Some growers stress the value of the science in providing transparent, trusted data on the status and distribution of nutrient management issues in the catchment while others view the data as central to maintaining industry reputation – effectively by ‘proving others wrong’. Developing protocols that balance the needs of grower ownership and control over the data with transparency in reporting is a critical area for future project effort.

4.0 DISCUSSION

The essentially global disconnections between farmer-landholder perceptions and agricultural water quality impacts suggest fundamental changes are required in communicating water quality science and information in a medium that is relevant and useful to farmer decision-making.

Project 25 utilises a different principle to traditional ‘top-down’ water quality monitoring, instead emphasizing a ‘ground-up’ approach where local canegrowers ‘steer’ program design and subsequent research and extension efforts in identified sub-catchment hotspots. While existing GBR water quality monitoring programs have tended to focus monitoring at spatial and temporal scales largely removed or irrelevant to farmer decision-making, Project 25 focuses on locally targeted water quality information delivery directly to relevant landholders. While there are clearly divergent over-arching aims for both monitoring program models, there is clear scope for the two to become more integrated and coordinated programs, each informing the other.

“We are often told that a lot of money has already been spent on farmers to improve water quality going to the Reef but there has been very little improvement. We agree – a lot of time and a lot of money has been wasted with some of the programs that the government has put forward... Don’t just blame the farmers for this... rarely have the growers themselves had input into how to solve this issue – we haven’t been asked about what local solutions are needed. I understand that this approach doesn’t often suit the big policy makers in Brisbane and Canberra but one thing is for certain – that unless the strategies are practical and sensible for our region and are well understood by the growers... THEN THE PROGRAM WILL FAIL.”

Canegrower, Babinda

There are well-documented justifications for focussing water quality monitoring and engagement specifically at agricultural producers within catchments. Community members (and landholders) participating in environmental monitoring commonly show increased scientific literacy and ‘interactional expertise’ to discuss with experts; greater awareness and interest in local and wider environmental issues; stronger social networks including engagement with government; and greater interest in conservation planning (Storey et al., 2016). Similarly, the willingness of farmers to implement pollutant control practices appears directly related to how land managers perceive the seriousness of the pollution problem (or to pollutants ‘they can see’). Accepting responsibilities, awareness of environmental damage, positive environmental stewardship attitudes and proneness to adopt agro-environmental and water quality-relevant action programmes are closely related to a sound perception of such problems, particularly at local scales (Vanslebrouck et al., 2002; He et al., 2008; Knowler and Bradshaw, 2007). Control measures to combat highly visible soil erosion, for example, not surprisingly tend to gain greater traction and uptake, whereas communicating the rationale for control measures aimed at more ‘invisible’ forms of diffuse pollution from agriculture (such as excessive nitrogen or phosphorus losses) remain a challenge (Blackstock et al., 2010; Osmond et al., 2012).

Awareness of the environmental consequences of fertilizer over-application has consistently emerged as a consistent gap in farmer’s knowledge of the impacts of farming operations on the environment, suggesting that the concept of “awareness of consequences” needs to be further developed for this issue (Floress et al., 2018). Project 25 specifically addresses these sorts of knowledge gaps within key stakeholder demographics. Demonstration of locally specific farm-scale impacts on the environment, loss of nutrients (itself a dominant economic input cost for many agricultural commodities) and capacity for active management may, however, provide powerful landholder motivations for practice change. Moreover, many farming environments are also currently characterized by considerable variability or uncertainty in what are locally appropriate water pollution control measures (Kleinman et al., 2015). In some cases what are prescribed ‘best management practices’ in one farming context can produce perverse environmental outcomes in others (Kleinman et al., 2015). The capacity for farmers to monitor, adaptively trial and develop their own innovative and locally specific farming practices would provide much of this empowerment and confidence in adopting meaningful practice change. Translating this new quantum of data and information into a form accessible, coherent and understandable to target stakeholders such as farmers will also represent a significant challenge, and require substantial collaboration between water quality scientists, farmers, information systems experts, and extension staff.

Simply providing local water quality data is also no guarantee of engendering significant practice change on the part of informed landholders. It is important to manage expectations about what fine-scale, real-time monitoring can truly achieve, particularly in isolation. The fact that provision of genetic data relating to an individual’s specific disease-health risks often does little to provoke behavioural lifestyle changes in an individual (Holland et al., 2016) should temper expectations that simply providing local environmental data will automatically result in landholder practice change. The underlying drivers of farmer practice change across most agricultural sectors almost invariably involves a complex interplay between economic, social, risk management and environmental considerations (McGuire et al., 2013; Yang and Fang, 2015).

Recent experiences advise against policy reliance on single modes of control or management mechanisms (regulated versus voluntary compliance), and small sub-catchment scale monitoring approaches will almost certainly need to be part of a broader, coordinated policy landscape (see Worrall et al., 2009; Osmond et al., 2012). Yet, examples also exist of environmental improvements in the notoriously challenging regions and cultural contexts, where farmer-based groups, water management agencies and conservation organizations have improved environmental quality and redefined the role of agriculture in environmental management (Shoreman and Haenn, 2009). Understanding the motivations and appropriate mechanisms for better engaging catchment stakeholders in ownership of agri-environmental issues should provide a template for more meaningful and cost-effective GBR water quality management into the future.

REFERENCES

- APHA., 2005. Standard Methods for the Examination of Water and Wastewaters. American Public Health Association, American Waterworks Association and Water Environment Federation: Washington, USA.
- Australian and Queensland Government, 2018. Agricultural Land Management Practice Adoption Methods. Reef Water Quality Report Card 2017 and 2018. Reef 2050 Water Quality Improvement Plan.
https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0020/82901/report-card-2017-2018-results-agricultural-mpa.pdf
- Barnes, A.P., Willock, J., Hall, C., and Toma, L., 2009. Farmer perspectives and practices regarding water pollution control programmes in Scotland. *Agricultural Water Management*, 96, 1715e1722.
- Barnes, A.P., L. Toma, J. Willock, and C. Hall. 2013. Comparing a “budge” to a “nudge”: Farmer responses to voluntary and compulsory compliance in a water quality management regime. *Journal of Rural Studies* 38, 448–459.
- Blackstock, K.L., J. Ingram, R. Burton, K.M. Brown and B. Slee. 2010. Understanding and influencing behaviour change by farmers to improve water quality. *Science of the Total Environment* 408, 5631-5638.
- Bainbridge Z.T., Brodie J.E., Faithful J.W., Sydes D.A., Lewis S.E. 2009. Identifying the land-based sources of suspended sediments, nutrients and pesticides discharged to the Great Barrier Reef from the Tully-Murray Basin, Queensland, Australia. *Marine and Freshwater Research* 60, 1081–1090.
- Brodie, J., Waterhouse, J., Lewis, S., Basnett, A., Davis, A., Alexander, F. and Ginders, M. 2011. Comparative effectiveness of community drainage schemes and EVTAs in trapping PS11 herbicides from sugarcane farms. Stage 1 Report. Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University, Townsville.
- Brodie, J.E., F.J. Kroon, B. Schaffelke, E.C. Wolanski, S.E. Lewis, M.J. Devlin, I.C. Bohnet, Z. T. Bainbridge, J. Waterhouse, and A.M. Davis. 2012. Terrestrial pollutant runoff to the Great Barrier Reef: an update of issues, priorities and management responses. *Marine Pollution Bulletin* 65, 81-100.
- Broussard, W., and Turner, RE. 2009. A century of changing land-use and water-quality relationships in the continental US. *Frontiers in Ecology and the Environment*, 7, 302–307.
- Burton, E., T.J. McShane, and D. Stubbs D. 2014. A Sub Catchment Adaptive Management Approach To Water Quality in Sugarcane. Burdekin Bowen Integrated Floodplain Management Advisory Committee (BBIFMAC). 42pp.

- Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., and Smith, V.H. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications* 8, 559–568.
- Carroll, C., Waters, D., Vardy, S., Silburn, D.M., Attard, S., Thorburn, P.J., Davis, A.M., Halpin, N., Schmidt, M., Wilson, B., and Clark, A. 2012. A paddock to reef monitoring and modelling framework for the Great Barrier Reef: Paddock and catchment component, *Marine Pollution Bulletin* 65, 136–149.
- Cowie, B., Shaw, M., Davison, L., Tang, W., DiBella, L., Benson, A., and Nash, M. 2013. Comparing runoff loss of knockdown and residual herbicides in the Herbert catchment. Reef Water Quality Protection Plan Secretariat, viewed 17-may-2013, <www.reefplan.qld.gov.au/measuring-success/case-studies/case-studies-sugarcane/comparing-runoff-loss.aspx>. Department of Natural Resources and Mines, Herbert Cane Productivity Services Ltd, Terrain Natural Resource Management, Tropwater James Cook University, Queensland.
- Davis A.M., R.G. Pearson, B. Butler, and J.E. Brodie. 2017. Review and conceptual models of agricultural impacts and water quality in waterways of the Great Barrier Reef catchment area. *Marine and Freshwater Research*, 68, 1-19.
- Davis, A.M., Waterhouse, J. 2016a. Sub-catchment scale monitoring, modelling and extension design to support reef water quality improvement in sugarcane catchments: NESP Project 1.8. Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns (117 pp.).
- Davis, A.M., Tink, M., Rohde, K., and Brodie, J.E. 2016b. Urea contributions to dissolved 'organic' nitrogen losses from intensive, fertilised agriculture. *Agriculture, Ecosystems and Environment* 223, 190-196. <http://dx.doi.org/10.1016/j.agee.2016.03.006>
- Di Bella, L., D. O'Brien, M. Nash, and C. Wegscheidl. 2015. Targeted extension strategies to improve water quality outcomes in the Australian sugarcane industry. *Rural Extension and Innovation Systems Journal* 11, 184-191.
- eWater Cooperative Research Centre. 2016. Water Quality Analyser v2.0.0 User Guide; eWater Cooperative Research Centre, Canberra, Australia, 2011; ISBN: 978-1-921543-47-0.
- Furnas, M. 2003, Catchments and corals: terrestrial runoff to the Great Barrier Reef, Australian Institute of Marine Science, Townsville.
- Floress, K, S. García de Jalón, S. P. Church, N. Babin, J. D. Ulrich-Schad, and L. S. Prokopy. 2017. Toward a Theory of Farmer Conservation Attitudes: Dual Interests and Willingness to Take Action to Protect Water Quality. *Journal of Environmental Psychology*, 53, 73–80.
- Great Barrier Reef Marine Park Authority. 2013, Mulgrave-Russell basin assessment: wet tropics natural resource management region, GBRMPA, Townsville.

He, X., Li, F. and Cao, H. 2008. Factors influencing the adoption of pasture crop rotation in the semiarid area of China's Loess Plateau. *Journal of Sustainable Agriculture*, 32, 161–180.

Hollands, G.J., D.P. French, S.J. Griffin, A. Toby Prevost, S. Sutton, S. King, and T.M. Marteau. 2016. The impact of communicating genetic risks of disease on risk-reducing health behaviour: systematic review with meta-analysis. *BMJ* 2016: 352:i1102

Hosomi, M., Sudo, R., 1987. Simultaneous determination of total nitrogen and total phosphorus in freshwater samples using persulfate digestion. *International Journal of Environmental Studies*, 27, 267-275

R. Huggins, R. Wallace, D. N. Orr, B. Thomson, R. A. Smith, C. Taylor , O. King, R. Gardiner, S. Wallace, B. Ferguson, S. Preston, S. Simpson, J. Shanks, M. St. J. Warne, R. D. R. Turner, R. M. Mann. 2017. Total suspended solids, nutrient and pesticide loads (2015–2016) for rivers that discharge to the Great Barrier Reef – Great Barrier Reef Catchment Loads Monitoring Program. Department of Environment and Science. Brisbane.

Kalcic, M.M., Frankenberger, J., Chaubey, I., Prokopy, L., and Bowling, L. 2015. Adaptive Targeting: Engaging Farmers to Improve Targeting and Adoption of Agricultural Conservation Practices. *Journal of the American Water Resources Association*, 51, 973-991. DOI: 10.1111/1752-1688.12336

Kay, P., R. Grayson, M. Phillips, K. Stanley, A. Dodsworth, A. Hanson, A. Walker, M. Foulger, I. McDonnell, and S. Taylor. 2012. The effectiveness of agricultural stewardship for improving water quality at the catchment scale: Experiences from an NVZ and ECSFDI Watershed. *Journal of Hydrology*, 422-423, 10-16.

Kennedy, I., M. Rose, A. Crossan, and M. Burns. 2013. Research and practice: environmental action for improving water quality in cotton catchments since 1990. *Crop and Pasture Science*, 64, 1095-1111.

Kleinman, P.J.A., A.N. Sharpley, R.W. McDowell, D.N. Flaten, A.R. Buda, L. Tao, L. Bergstrom, and Q. Zhu. 2011. Managing agricultural phosphorus for water quality protection: principles for progress. *Plant and Soil*, 349, 169-182.

Kleinman, P.J.A., Sharpley, A.N., Withers, P.J.A. et al. 2015. Implementing agricultural phosphorus science and management to combat eutrophication. *AMBIO* 44(Suppl 2), 297. doi:10.1007/s13280-015-0631-2

Kovacs, A., Honti, M., Zessner, M., Eder, A., Clement, A. and Blöschl, G. 2012. Identification of Phosphorus Emission Hotspots in Agricultural Catchments. *Science of the Total Environment*, 433, 74–88.

Kronvang, B., Andersen, H. E., Børgesen, C., Dalgaard, T., Larsen, S. E., Bøgestrand, J., and Blicher-Mathiasen, G. 2008. Effects of policy measures implemented in Denmark on nitrogen pollution of the aquatic environment. *Environmental Science and Policy*, 11, 144–152.

- Knowler, D. and Bradshaw, B. 2007. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. *Food Policy* 32, 25–48.
- Kroon, F.J., B. Schaffelke, and R. Bartley. 2014. Informing policy to protect coastal coral reefs: Insight from a global review of reducing agricultural pollution to coastal ecosystems. *Marine Pollution Bulletin*, 85, 33–41.
- Margules, C. R., and Pressey, R. L. 2000. Systematic conservation planning. *Nature*, 405, 243–253.
- McCloskey, G. L., D. Waters, R. Baheerathan, S. Darr, C. Dougall, R. Ellis, B. Fentie and L. R. Hateley (2017). Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments: updated methodology and results. Technical Report for Reef Report Card 2014, Queensland Department of Natural Resources and Mines
- McGuire, J., L.W. Morton, and A.D. Cast. 2013. Reconstructing the good farmer identity: shifts in farmer identities and farm management practices to improve water quality. *Agriculture and Human Values*, 30, 57–69.
- Melland, A.R., D. Ryan, G. Shortle, and P. Jordan. 2012. A cost:benefit evaluation of in-situ high temporal resolution stream nutrient monitoring, World Congress on Water, Climate and Energy, Dublin, 13–18 May 2012.
- Mellander, P-E., A.R. Melland, P. Jordan, D.P. Wall, P.N.C. Murphy, and G. Shortle. 2012. Quantifying nutrient transfer pathways in agricultural catchments using high temporal resolution data. *Environmental Science and Policy*, 24, 44–57.
- Nakasone E, Torero M, and Minten B. 2014. The power of information: The ICT revolution in agricultural development. *Annual Review of Resource Economics* 6, 533 –550.
- O'Brien, D., Davis, A.M., Nash, M., Di Bella, L. and Brodie, J.E. 2014. Herbert water quality monitoring project: 2011–2013 results. Proceedings of the 36th Conference of the Australian Society of Sugar Cane Technologists. In: ASSCT 2014: 36th Annual Conference of the Australian Society of Sugar Cane Technologists, 28 April - 1 May 2014, Broadbeach, QLD, Australia
- OECD 2012. Water quality and agriculture: meeting the policy challenge OECD Studies on Water OECD Publishing, Paris 2012; <http://www.oecd.org/tad/sustainableagriculture/waterqualityandagriculturemeetingthepolicychallenge.htm#obtain>, (accessed 14.12.15).
- Osmond, D., D. Meals, D. Hoag, M. Arabi, A. Luloff, G. Jennings, M. McFarland, J. Spooner, A. Sharpley, and D. Line. 2012. Improving conservation practices programming to protect water quality in agricultural watersheds: Lessons learned from the National Institute of Food and Agriculture-Conservation Effects Assessment Project. *Journal of Soil and Water Conservation*, 67, 122A-127A.

Owen, G.J., M.T. Perks, C.M.H. Benskin, M.E. Wilkinson, J. Jonczyk, and P.F. Quinn. 2012. Monitoring agricultural diffuse pollution through a dense monitoring network in the River Eden Demonstration Test Catchment, Cumbria, UK. *Area*, 44, 443–453.

Outram, F.N., Lloyd, C.E.M., Jonczyk, J., Benskin, C.M.H., Grant, F., Perks, M.T., Deasy, C., Burke, S.P., Collins, A.L., Freer, J., Haygarth, P.M., Hiscock, K.M., Johnes, P.J., and Lovett, A.L. 2014. High-frequency monitoring of nitrogen and phosphorus response in three rural catchments to the end of the 2011–2012 drought in England. *Hydrology and Earth System Sciences*, 18, 3429–3448. DOI: 10.5194/hess-18-3429-2014.

Pearson, R. G., Crossland, M., Butler, B., and Manwaring, S. 2003. Effects of cane-field drainage on the ecology of tropical waterways. ACTFR Report No. 03/04-1. James Cook University, Townsville.

Pellerin, B. A., Bergamaschi, B. A., Downing, B. D., Saraceno, J. F., Garrett, J. A., and Olsen, L. D. 2013. Optical techniques for the determination of nitrate in environmental waters: Guidelines for instrument selection, operation, deployment, maintenance, quality assurance, and data reporting, U.S. Geological Survey Techniques and Methods, 1-D5, 37 pp.

Pellerin, B.A., B.A. Stauffer, D.A. Young, D.J. Sullivan, S.B. Bricker, M.R. Walbridge, G.A. Clyde Jr, and D.M. Shaw. 2016. Emerging tools for continuous nutrient monitoring networks: sensors advancing science and water resources protection. *Journal of the American Water Resources Association*, 52, 993-1008.

Perez, M.R. 2015. Regulating farmer nutrient management: a three-state case study on the Delmarva Peninsula. *Journal of Environmental Quality*, 44, 402–414.

Pickering, J. A., Hong, J., Hong, D., and Kealley, M. (2017). Applying behavioural science to the Queensland sugar cane industry and its relationship to the Great Barrier Reef. *Rural Extension and Innovation Systems Journal*, 13(2), 1-10.

Pickering, J., Hong, J., Stower, R., Hong, D., and Kealley, M. (2018). Using psychology to understand practice change among sugar cane growers. *Rural Extension and Innovation Systems Journal*, 14(1), 62-72.

Pionke, H.B., Gburek, W.J. and Sharpley, A.N. 2000. Critical Source Area Controls on Water Quality in an Agricultural Watershed Located in the Chesapeake Basin. *Ecological Engineering*, 14, 325–335.

Poggio, M., Smith, M., van Grieken, M. and Shaw, M. 2014. The Economics of Adopting Pesticide Management Practices Leading to Water Quality Improvement on Sugarcane Farms. Department of Agriculture, Fisheries and Forestry (DAFF), Queensland.

Prove, B.G., Truong, P.N. and Evans, D.S. 1986. Strategies for controlling cane land erosion in the wet tropical coast of Queensland. *Proceedings of the Australian Society of Sugar Cane Technologists*, 77-84.

Prove, B.G., Doogan, V.J. and Truong, P.N.V. 1995. Nature and magnitude of soil erosion in sugarcane land on the wet-tropical coast of north-eastern Queensland. *Australian Journal of Experimental Agriculture*, 35, 641-649.

Queensland Government. 2017. Reef Water Quality Protection Plan: Report Card 2016. State of Queensland, 2016.

Rayment, G. E. 2003. Water quality in sugar catchments in Queensland. *Water Science and Technology*, 48, 35–47.

Ribaudo, M. 1998. Lessons learned about the performance of USDA agricultural non-point source pollution programs. *Journal of Soil and Water Conservation*, 53, 4-40.

Rodriguez, H.G., Popp, J., Gbur, E., and Pennington, J. 2014. A Stakeholder-Guided Collaborative Approach to Improve Water Quality in a Nutrient Surplus Watershed. *Journal of Water Resource and Protection*, 6, 571-582.
<http://dx.doi.org/10.4236/jwarp.2014.66056>

Rozin, A. G. 2014. In situ optical sensors for measuring nitrate in Florida waters. Masters of Science Thesis. University of Florida. 78 pp.

Ruiz-Garcia, L., L. Lunadei, P. Barreiro, and I. Robla. 2009. A review of wireless sensor technologies and applications in agriculture and food industry: state of the art and current trends. *Sensors*, 9, 4728–4750.

Sharpley, A.N., and Smith, S.J. 1994. Wheat tillage and water quality in the Southern Plains. *Soil Tillage Research*, 30, 33–48

Sharpley, A., M. Daniels, L. Berry, C. Hallmark, and J. Hesselbein. 2015. Arkansas Discovery Farms: documenting water quality benefits of on-farm conservation management and empowering farmers. *Acta Agric Scand Sect B*, 65, 186–198.

Sharpley, A.N., Bergström, L., Aronsson, H. et al. 2015. Future agriculture with minimized phosphorus losses to waters: Research needs and direction. *AMBIO* 44(Suppl 2), 163, doi:10.1007/s13280-014-0612-x

Shoreman, E.E. and Haenn, N. 2009. Regulation, conservation, and collaboration: ecological anthropology in the Mississippi Delta. *Human Ecology*, 37, 95-107.

Smith, M., Poggio, M. J., Thompson, M. and Collier, A. 2014. The Economics of Pesticide Management Practices on Sugarcane Farms: Final Synthesis Report. Department of Agriculture, Fisheries and Forestry (DAFF), Queensland.

Snazelle, T. 2011. An Evaluation of Four Field Deployable Nitrate Analyzers: Phase I. U.S. Department of the Interior, U.S. Geological Survey, Water Mission Area. WMA Instrument news. Issue No. 134, Spring 2012, pp. 1-12.

Snazelle, T.T., 2015, Results from laboratory and field testing of nitrate measuring spectrophotometers: U.S. Geological Survey Open-File Report 2015–1065, 35 p., [dx.doi.org/10.3133/ofr20151065](https://doi.org/10.3133/ofr20151065).

Sobota, D.J., J.E. Compton, and J.A. Harrison. 2013. Reactive nitrogen inputs to US lands and waterways: how certain are we about sources and fluxes? *Frontiers in Ecology and the Environment*, 11, 82–90.

Sobota DJ, Compton JE, McCrackin ML, and Singh S. 2015. Cost of Reactive Nitrogen Release from Human Activities to the Environment in the United States. *Environmental Research Letters*, 10, 025006.

Steven, ADL, Hodge, J, Cannard, T, Carlin, G, Franklin, H, McJannet, D, Moeseneder, C, Searle, R, 2014. Continuous Water Quality Monitoring on the Great Barrier Reef. CSIRO Final Report to Great Barrier Reef Foundation, 158pp.

Storey, R.G., A. Wright-Stow, E. Kin, R. Davies-Colley, and R. Stott. 2016. Volunteer stream monitoring: Do the data quality and monitoring experience support increased community involvement in freshwater decision making? *Ecology and Society*, 21, 32.

Thorburn, P.J., Biggs, J.S., Attard, S.J., Kemei, J., 2011. Environmental impacts of irrigated sugarcane production: nitrogen lost through runoff and leaching. *Agriculture, Ecosystems and Environment*, 144, 1–12.

Tilman, D., C. Balzer, J. Hill, and B.L. Befort. 2011. Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Science USA* 108: 20260–20264.

Tomer, M.D., Porter, S.A., James, D.E., Boomer, K.M., Kostel, J.A. and Mclellan, E. 2013. Combining Precision Conservation Technologies into a Flexible Framework to Facilitate Agricultural Watershed Planning. *Journal of Soil and Water Conservation* 68, 113A–120A.

Turner, R., Huggins, R., Wallace, R., Smith, R., S., and Warne, M. St.J. 2013. Total suspended solids, nutrient and pesticide loads (2010–2011) for rivers that discharge to the Great Barrier Reef: Great Barrier Reef Catchment Loads Monitoring Program 2010–2011. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Van Grieken, M., Lynam, T., Coggan, A., Whitten, S. and Kroon, F. 2013. Cost effectiveness of design-based water quality improvement regulations in the Great Barrier Reef Catchments. *Agriculture, Ecosystems and Environment*, 180, 157–165.

Vanslebrouck, I., van Huylenbroeck, G. and Verbeke, W. 2002. Determinants of the willingness of Belgian farmers to participate in agri-environmental measures. *Journal of Agricultural Economics*, 53, 489–511.

Veith, T.L., Wolfe, M.L. and Heatwole, C.D. 2004. Cost-Effective BMP Placement: Optimization Versus Targeting. *Transactions of the American Society of Agricultural Engineers* 47, 1585–1594.

Wallace, R., Huggins, R., Smith, R., Turner, R., Vardy, S., and Warne, M. St. J., 2014. Total suspended solids, nutrient and pesticide loads (2011–2012) for rivers that discharge to the Great Barrier Reef – Great Barrier Reef Catchment Loads Monitoring Program 2011–2012. Department of Science, Information Technology, Innovation and the Arts. Brisbane.

Wardropper, C.B., Chang, C., and Rissman, A.R. 2015. Fragmented water quality governance: constraints to spatial targeting for nutrient reduction in a Midwestern USA watershed. *Landscape and Urban Planning*, 137, 64–75

Waterhouse, J., Brodie, J., Tracey, D., Lewis, S., Brinkman, R., Tonin, H., Furnas, M., Fabricius, K., Schaffelke, B., Wolff, N., Devlin, M., McKenzie, L. 2014. Assessment of the relative risk of water quality to ecosystems of the Wet Tropics Region, Great Barrier Reef. A report to Terrain NRM, Innisfail. TropWATER Report 14/27, Townsville, Australia.

Waterhouse, J., Brodie, J., Tracey, D., Smith, R., Vandergragt, M., Collier, C., Petus, C., Baird, M., Kroon, F., Mann, R., Sutcliffe, T., Waters, D., Adame, F., 2017. Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 3: The risk from anthropogenic pollutants to Great Barrier Reef coastal and marine ecosystems. State of Queensland, 2017.

Waterhouse, J., Schaffelke, B., Bartley, R., Eberhard, R., Brodie, J., Star, M., Thorburn, P., Rolfe, J., Ronan, M., Taylor, B., Kroon, F., 2017. 2017 Scientific Consensus Statement: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 5: Overview of key findings, management implications and knowledge gaps. State of Queensland, 2017.

Wolfenden, J., and Evans, M. 2007. Change at the irrigation area scale: an exploration of integrated area wide management (IAWM) for irrigation communities, Toowoomba: CRC for Irrigation Futures.

Worrall, F., E. Spencer, and T.P. Burt. 2009. The effectiveness of nitrate vulnerable zones for limiting surface water nitrate concentrations. *Journal of Hydrology*, 370, 21-28.

White, M.J., Storm, D.E., Busteed, P.R., Stoodley, S.H., and Phillips, S.J. 2009. Evaluating Nonpoint Source Critical Source Area Contributions at the Watershed Scale. *Journal of Environmental Quality*, 38, 1654–1663.

Yang, X. and Fang, S. 2015. Practices, perceptions, and implications of fertilizer use in East-Central China. *AMBIO*, 44, 647. doi:10.1007/s13280-015-0639-7

Zia, H., N.R. Harris, G.V. Merrett, M. Rivers, and N. Coles. 2013. The impact of agricultural activities on water quality: A case for collaborative catchment-scale management using integrated wireless sensor networks. *Computers and Electronics in Agriculture*, 96, 126-138.

