frontiers | Frontiers in Sustainable Food Systems

TYPE Community Case Study
PUBLISHED 14 August 2025
DOI 10.3389/fsufs.2025.1638992

OPEN ACCESS

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RECEIVED 31 May 2025
ACCEPTED 22 July 2025
PUBLISHED 14 August 2025

CITATION
Davis AM, Webster AJ, Fielke S, Buono L, Morris S and Abom R (2025) Trust frameworks and technology: water quality engagement with Australian farming stakeholders. *Front. Sustain. Food Syst.* 9:1638992. doi: 10.3389/fsufs.2025.1638992

Trust frameworks and technology: water quality engagement with Australian farming stakeholders

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This paper provides a community case study of the ongoing process of farming stakeholder engagement in a high priority Great Barrier Reef catchment that emphasizes stakeholder co-design and use of sensor technologies in water quality engagement and communication. Provision of near real-time visual evidence of the 'data' (e.g., nitrate-nitrogen readings, rainfall data and river heights at local scales) helped break down historic communication barriers and led to the articulation of farmer trust and confidence in the water quality science as partners in the scientific process. This confidence in interpretation of 'trustworthy' scientific information created the opportunity for growers to share and discuss experiences with neighbors, enabled peer-to-peer leadership, and facilitated on-farm practice changes and experiments. Social research highlighted the importance of investing in building a trust-based environment for dialogue between growers and scientists on a contentious topic, with farming stakeholders reporting 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. The Project 25 framework is now being held up as an industry model for stakeholder engagement, and industry support is emerging for similar programs in neighboring catchments.

KEYWORDS

trust-building, digital technology, co-design, adaptive co-management, nitrate, stakeholder engagement

1 Introduction

Management of diffuse nutrient pollution from agricultural catchments remains an ongoing water resource management challenge in northern Australia's Great Barrier Reef (GBR) catchment area (Waterhouse et al., 2024). Catchment losses of dissolved inorganic nitrogen (DIN) from intensive agriculture specifically remains a key risk to the long-term resilience of the GBR. Decades of investment by different levels of government, farming industries and farmers themselves, have produced only modest progress towards to end-of-catchment DIN reduction targets to the GBR lagoon (Reef Report Card, 2024). Policy and science engagement with key agricultural industries facing numerous, long-standing challenges such as stakeholder distrust of 'top-down', government-driven water quality monitoring programs; long reporting timeframes; often large 'end-of-catchment' monitoring scales (encompassing hundreds of farms); limited accessibility of local water quality data; and an emphasis on catchment water quality models in reporting, communications and engagement (Davis et al., 2021).

Due to GBR water quality science being used to justify policy and regulatory agendas (Waterhouse et al., 2024), scientists, research organizations and policymakers are increasingly required to defend decisions or advice. Similar to the contested character of other 'wicked problems' such as climate change (Patterson et al., 2013; Browman, 2016; Özkundakci et al., 2018), the demand for more transparent GBR water quality science has increased (Larcombe and Ridd, 2018). The specter of government regulatory oversight of farming practices since 2008–2009 has seen repeated pushback from farmers and their representative bodies in the GBR catchment area, driven in large part by questions of the robustness of science underlying policy (Taylor et al., 2012). This contention has resulted in a recent formal Australian Government Senate Inquiry into the robustness of the science-base justifying regulation of farm practices that impact water quality outcomes in the Great Barrier Reef (Commonwealth of Australia, 2020).

The purpose of this study was to document the impact of catchment water quality monitoring program co-design with key agricultural stakeholders in a major GBR catchment area (GBRCA) farming region (initially termed "Project 25" in recognition of its announcement as the 25th, and final, project in a major federal government funding scheme). The study provides a practical 'community case study' example of how to address current research gaps in integrating technical water quality monitoring expertise and science/technology, with agricultural sector co-development of a project to improve sustainability outcomes in the GBR catchment. It was not a formal evaluation, but a qualitative case study aimed at documenting perceptions and engagement outcomes (not project impact). Based on previous literature, we hypothesized promoting stakeholder ownership of water quality monitoring program, integrating the immediacy and accessibility of 'real-time' locally generated data, and co-learning would improve confidence and trust levels in farmers in water quality science (Blackstock et al., 2010; Kennedy et al., 2013; Davey et al., 2020). After providing geographic and historical context, this paper describes the key programmatic details involved in the project's initial design along with its three areas of inquiry and major deliverables and discusses the project's implications, lessons learned, conceptual constraints and methodological limitations.

2 Context

2.1 Setting – the Russell-Mulgrave catchment

The Russell-Mulgrave is one of the larger catchments in the GBRCA's Wet Tropics (Figure 1A), in terms of area, rainfall, and discharge to the Reef lagoon (Furnas, 2003). One of the top five 'high risk' basins contributing anthropogenic DIN loads and yields from the GBR catchment area (State of Queensland, 2018; Waterhouse et al., 2024), most DIN comes from sugarcane (*Saccharum officinarum* L.) production, and some banana cultivation. Many of the water quality and agricultural stakeholder communication and engagement challenges evident at both global, and GBR scales, are also readily apparent in the Russell-Mulgrave catchment. It is only relatively recently that local farmers have had access to water quality monitoring data and reporting from their own catchment through the Great Barrier Reef Catchment Loads Monitoring Program (GBRCLMP: Carroll et al., 2012) with two sites in the lower Mulgrave River and Russell Rivers commissioned ca. 2015–16. These two essentially 'end-of-catchment sites', accounting for 522 km^2 (93% of catchment area) and 789 km^2 (98% of catchment area) respectively (Wallace et al., 2014), contain hundreds of individual farms, as well as several other major land uses, which can confound or trivialize perceptions of individual landholder contributions to cumulative water quality impacts. Another notable feature of the Russell-Mulgrave cane growing industry, is the scale of its farming enterprises in comparison to other priority catchments across the GBRCA. The ca. 200 canefarmers in the Russell-Mulgrave catchment generally have smaller

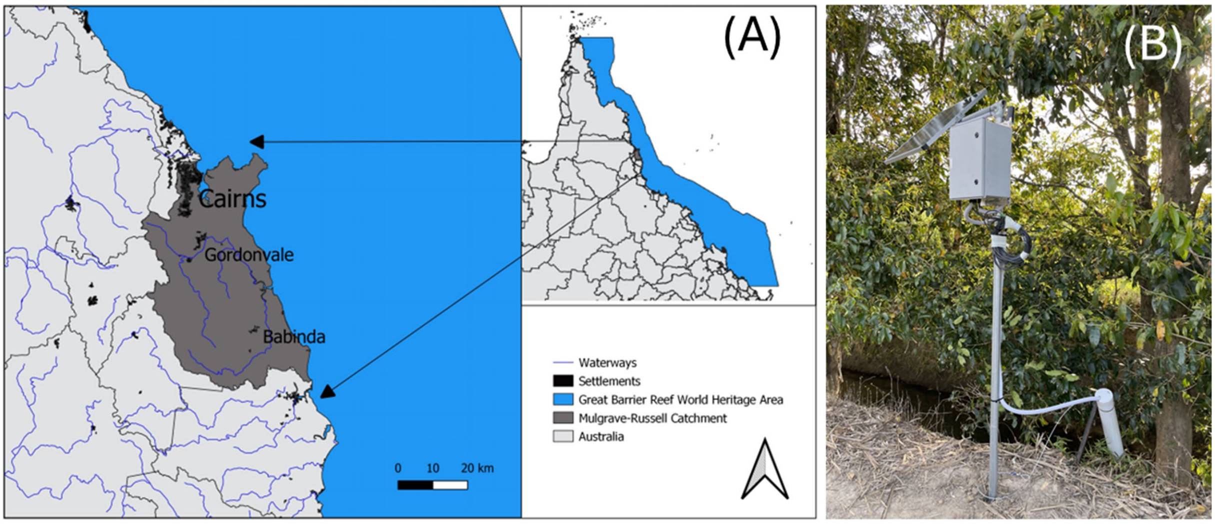

FIGURE 1
Map of the Russell-Mulgrave catchment, Wet Tropics and Great Barrier Reef World Heritage Areas **(A)**; and Project 25 streambank high frequency water quality monitoring installation **(B)**.

farm sizes than other wet and dry-tropical cane farming regions (Davis et al., 2021), but like most other wet-tropical GBRCA sugarcane regions, rely entirely on rainfall to meet crop water demands.

2.2 Co-design and centering stakeholder values in the monitoring process

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. Longer-term discussions with disengaged and larger sugarcane growers in the Russell-Mulgrave catchment led to the establishment of much of the Stakeholder Steering Committee for Project 25 well before the project itself was even announced. The initial invited grower collective that met with the Australian Federal Minister for the Environment in 2015 were specifically identified and recruited for their industry roles as large, influential growers, and reputations as industry leaders. The research project was initiated by this group of leading farmers who were directed by the Federal Government via their local CANEGROWERS regional office to steer the project. Rather than a typical engagement approach often previously seen in the GBR catchment area involving interactions with 'the willing' farmers (i.e., 'low hanging fruit'), Project 25 specifically targeted and engaged several major industry operators 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 ultimately included local and State-level CANEGROWERS organization members, non-government organizations (NGO), a major banana grower, and science/research members to provide the requisite policy and technical oversight. The collective steering committee met several times in-person each year, initially to formulate program co-design (specific program research questions from agri-industry, monitoring sites, cooperating landholders), and then to review project performance, water quality monitoring results and to provision of contextual insights into observed water quality outcomes (timing and extent of key on-ground farming practices during the preceding period, weather events etc.). Issues such as program quality assurance-quality control (QA/QC) outcomes (sensor performance in relation to discrete laboratory samples, monitoring failures etc.) were also worked through on an as-needs basis at these meetings. Several steering committee members hosted water quality monitoring sites on their own farms, and acted as brokers for site locations with other farmers. Program results were communicated to the wider Russell-Mulgrave sugarcane industry through a variety of mechanisms such as: project scientist presentations at broader CANEGROWERS annual meetings; multiple in-person 'shed' and 'young grower' meetings involving water quality monitoring, agronomic and industry extension staff and farmers; and standard industry newsletters and social media activities.

2.3 Water quality monitoring program design

A key industry aim of Project 25 was to characterize the water quality impacts and relative contributions from 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 local farmer input and advice, sub-catchment waterway sites were identified and selected to represent the major, largely discrete, land uses found across the region, namely sub-catchments dominated by predominantly sugarcane cultivation, urban development, banana cultivation, or natural 'rainforest' (typically the completely undeveloped, upper catchment in the Wet Tropics World Heritage Area).

Water quality monitoring primarily utilized continuous, *in situ*, sensor-based, high-frequency nitrate-N monitoring (TriOS™ Opus and NICO spectral sensors; Davis et al., 2021; Fielke et al., 2020), complemented with manually collected discrete water samples for subsequent laboratory analysis. Stream water stage (river height) at sites was measured continuously using Campbell Scientific CS451 pressure transducers hardwired to a CR310 or CR1000 data logger (Campbell Scientific, Inc., Logan, UT, USA) at all sites. The in-stream components were secured within a PVC pipe extending from the bank to the water (Figure 1B), with all other datalogging, telemetry and power system components contained in an elevated weatherproof electronics enclosure on the streambank (Figure 1). Data were recorded every 15 min and transmitted to online environmental data management portals. A purpose-built, bespoke 'web app' (1,622.farm) provided capacity to communicate sensed nitrate-N and stream height data in a form understandable and accessible to farmers in near 'real time' (Vilas et al., 2020). Russell-Mulgrave farmers were significant contributors of early-stage prototypes, social research and human-centered design (and more specifically user experience) operationalizing catchment sensor data into agricultural technology development (Vilas et al., 2020; Fielke et al., 2022).

2.4 Social and cultural research analysis

An early indication of the engagement success of Project 25 was the willingness of participating farming stakeholders to support additional research into the sociological basis and outcomes from Project 25, undertaken in collaboration with social researchers from Commonwealth Scientific and Industrial Research Organization (CSIRO) (Fielke et al., 2022). The aim of this research was to better understand the human elements of engagement with water quality monitoring technologies in the sugarcane industry. The sociological research methods used in this activity included a range of semi-structured interviews, focus groups and survey instruments with participants, observation at field days or project workshops and other less formal interactions; these methods resulted in data for analysis of participant advice and information network changes over time (Fielke et al., 2020). Twenty in-depth qualitative interviews were conducted for the first phase of analysis in 2018 approved by the CSIRO Social Science Human Research Ethics Committee (106/17).

The sampling process for sourcing interviews utilized snowball sampling, including invitations from the local Canegrowers association to those involved with the project – with a combined approach to obtain both involved farmers via their industry body and those not involved within the region. Final respondents were mixed in terms of their leadership roles withing the sugarcane industry. Involved growers were more likely to be involved with formal industry bodies and tended to have a greater perceived stake in the future of the industry as a result. It was important to capture both involved and non-involved growers to capture both those guiding the industry forward into the future, and those who were part of the industry but perhaps had different expectations. Participants included growers in the Russell-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. Interviews were conducted primarily face-to-face in the catchment (e.g., on grower's farms or in the workplaces of partnering organizations) or where requested, by telephone. Interviews were semi-structured, exploring several topics through discussion with interviewees. Length of interviews ranged from 40 min to 1.5 h. Informed consent was obtained from participants prior to initiating the interview. With permission, the discussions were 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). Topic-based coding was used to categorize respondents based on their involvement in the project. Three social researchers then coded the data according to these topics and verified their responses collaboratively such that they came to agreement. The results of this analysis are more thoroughly expanded upon in Fielke et al. (2022), but in the interests of brevity for the community case study format we chose just to refer to that paper rather than explain the process in full detail in this work. 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.

A second round of qualitative, semi-structured interviews, followed by a 5 likert-scale question with Project 25 Steering Committee ($n = 6$) and non-involved farmers ($n = 5$), advisors ($n = 4$), and researchers ($n = 3$) were conducted by one of the authors during 2020 ($n = 18$). This round of interviews was conducted to gather perceptions of change in the same cohort of respondents. Interview questions covered farmer experiences: of interactions within their farming peer groups and shifts in local group norms; about water quality data and information; and, about interactions with cane industry and scientific stakeholders participating in the project. Audio recordings of interviews were transcribed for analysis.

The behavioral change logic model outlined in Figure 2 is a useful schematic for situating the social research project team's assumptions about farmer attitudinal and behavioral change generated by Project 25 across the 2-year period captured (2018 to 2020). The authors considered the framing the study within existing theoretical frameworks, but due to the nature of this output (community case study) we focus on the practical co-development of this case with community stakeholders, and subsequent opportunities and challenges. We according have focused heavily on tailoring theoretical framing around recent existing work tied this case study example (e.g., Fielke et al., 2022). The outputs of such a theoretical framing process are shown in the Figure 2 and more detail on that model development can be found in associated literature (Davis et al., 2020; Fielke et al., 2022).

3 Results

3.1 Water quality monitoring results tailored to stakeholders

Key results emerging from catchment water quality monitoring that formed major communication and engagement themes with industry included; the clear increases in nitrate-N concentrations and loading moving from rainforested, upper catchments to intensive sugarcane cultivation; the role of magnitude and timing of first wet season rainfall events (proximity to major fertilizer application periods) on subsequent catchment DIN losses from sugarcane land uses (loosely termed a 'first flush' phenomena); (Davis et al., 2021); and catchment water quality contributions of other land uses such as urban areas. The capacity provided by sensor networks also allowed for novel, and essentially real-time responsiveness to key water quality events (high nitrate-N 'spikes' in early wet season runoff). This in turn allowed connected farmers and scientists to undertake rapid, on-ground surveys that proved critical in identifying specific sources (sub-catchments, farms, and even individual paddocks), and also specific practices or stages of the cropping cycle most contributing to 'diffuse pollution' identified at downstream monitoring sites.

3.2 The creation of peer group leaders

Interview analysis indicated that the capacity of farmers involved in the project to act as leaders and influencers within their local farming networks increased and continued to grow over the course of the project. Having near real time and visual evidence in the form of 'data' (e.g., nitrate-nitrogen readings, rainfall data and river height at various points in the catchment) led to articulation of farmer trust and confidence in water quality science as partners in the Project 25 experiment. This confidence in interpretation of 'trustworthy' scientific information created the opportunity for farmers to share and discuss experiences with neighbors, enabling peer-to-peer leadership:

> *"At first everybody was a bit negative towards it [the link between nitrogen fertilizer and water quality], but now everybody's starting to accept it to a certain degree… I know when it [the water quality*

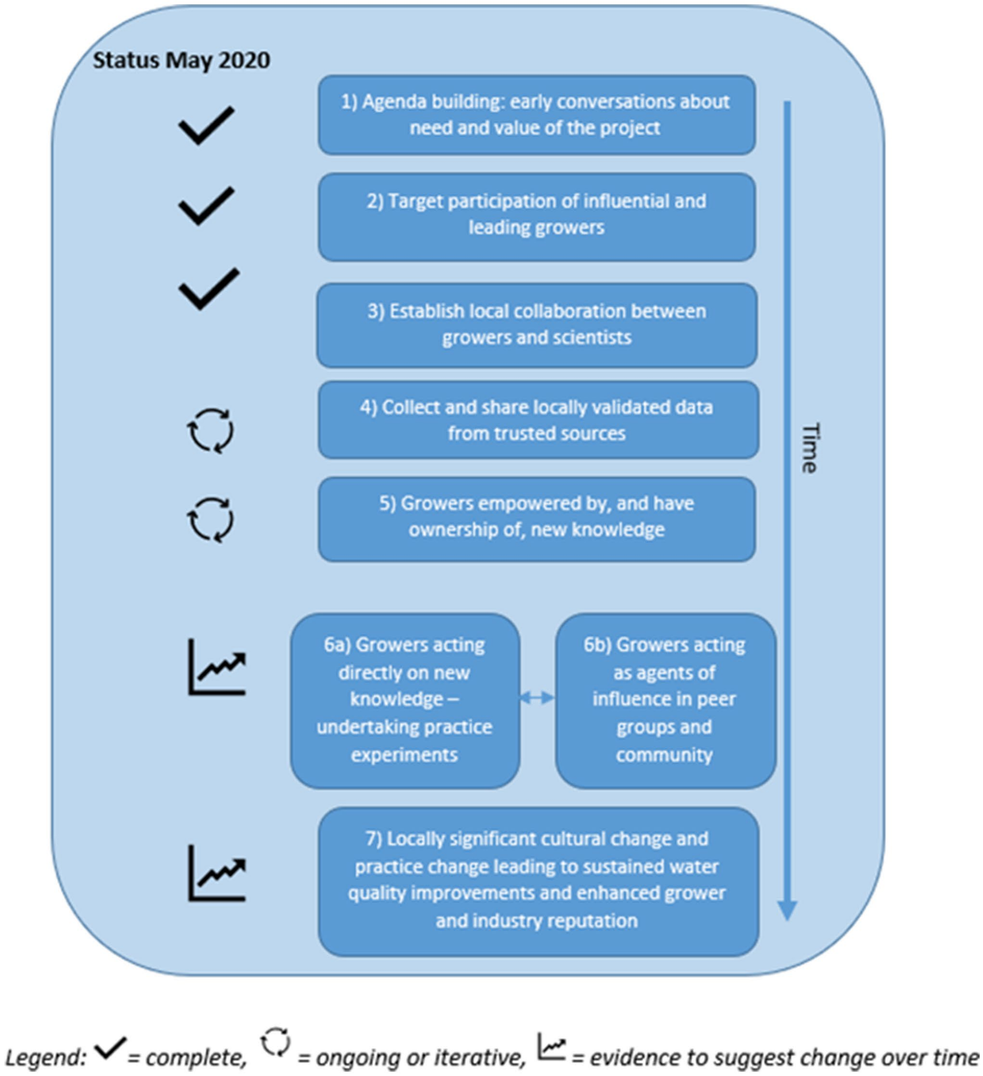

FIGURE 2
Synthesis of findings against the Project 25 change logic from the two rounds of interview analysis, observations and interactions with the project stakeholders and participants (supplied by Bruce Taylor, CSIRO).

> *sensor] first went in, one of my neighbours, he just threw fertiliser on a crop and then we got eight inches of rain overnight and she spiked that machine something severe… Then he came around and said 'oh, that was my doing'. He said, 'I fertilised the day before yesterday before the rain came down'. I said 'well, it certainly spiked the machine, the monitor'. He said 'yeah, I'll have to change my ways'. It hasn't happened since. So, there's one neighbour that's sort of put himself into gear." (Canegrower not involved in Project 25, 2020)*
>
> *"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." (Project 25 Steering Committee canegrower, 2020)*

The regular and ongoing character of engagement at shed and industry organization meetings between researcher/s and leading farmers in the community was an important factor in allowing grower confidence and influence to build-up over the course of Project 25. One farmer explains this process and states that if the Project (and/or others like it) is to continue then there is a shared responsibility for passing this knowledge on to other members of the farming community, as advocates and educators:

> *"So even though you're not [a water quality expert], but you are slowly educating yourself what it all means, I think, which is a good thing… The ones within Project 25, they talk about it. They're really wrapped in it… The other blokes, it's just early days. We've got to educate them more, but we'll - that's the next step forward, too. We've got to look at that and educate them in it… The thing is, how much [value] do you put on education?" (Project 25 Steering Committee canegrower, 2020)*

The communication and media landscape of Great Barrier Reef water quality science is often emotive, imprecise, with considerable confusion in messaging across all catchment stakeholders. Growers in the Russell-Mulgrave catchment have, for example, been directly implicated by either media or government communications for significant losses of pollutants such as sediment and phosphorus to the Great Barrier Reef marine environment (Hamman and Deane, 2018). A key industry consideration in Project 25 design involved 'upstream and downstream' collection of samples from major urban centers in the catchment. Results identified consistently elevated filterable reactive phosphorus (FRP; 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. These results and expressed sentiments had considerable value in clarifying the specific local water quality issues the farming 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. Locally generated data provided actual evidence for the industry to respond to, and to counteract future external claims about local water quality issues, but also made industry stakeholders more amenable and comfortable discussing their own land-use and water quality challenges:

> "*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". (Project 25 Steering Committee canegrower, 2020)*
>
> *"So this project, like I say, initially was to validate the modelling. We have found some flaws in some results that were getting attributed to us* [the previously mentioned phosphorus losses]. *We have found those flaws, and I'm willing to talk about that later in my presentation. Do we as growers have an impact on the environment? I'm not getting into the Barrier Reef. I'm not a scientist. I'm just looking at our streams. We've got monitors there. Yes, we do—the same as everyone sitting around this table, which everyone forgets. Everyone has an impact on the environment. So the whole idea is: how do we minimise it?" (Project 25 Steering Committee canegrower to Rural and Regional Affairs and Transport References Committee Senate committee Inquiry; Hansard transcript, July 2020).*

3.3 Evidence of change over time

In the second round of interviews there was growing evidence that Project 25 contributed (directly and in concert with other interventions) to (i) *on-farm* change and practice experiments. By early 2020, several of the farmers interviewed identified specific practice change over the course of the preceding 18 months. Some of these quotes follow, regarding fertilizer management practice:

> *"Since then [interview in late 2018], I've gone away from granular onto liquid fertiliser which has got molasses in it and organic carbon. I very much focus on that, and on pour rate control. It is proper GPS rate controlled and everything, so I'm getting precision application. Every block, I can put on exactly what I want… you can see [in] that first flush… I did a lot of research… so it ticked a box like a slow-release fertiliser for me, and focussed with the surges that I know with the first flush data, well, it's a way around the fact - to keep my stuff on my land and help the environment, because I'm not at the end of the chain… So, as well as efficiencies that come….and productivity and profitability, there was also an element of environmental stewardship and it ticked that box as well, so I'd say it [Project 25] did have a part in that… I'm about 500 hectares, [another Farmer] went to it as well… they've got 1500 hectares of the catchment… that is fertilised that way. We're the two biggest growers in the area." (Project 25 Steering Committee canegrower, 2020)*

Regarding application of fertilizer as early as feasible:

> *"I would rather turn around in two weeks and fertilise it [sugarcane] in October, late October, than fertilise it in December [now]. You've got less chance of that big rainfall event. If we have the rainfall event going… what comes out of the soil goes into the creeks." (Canegrower not involved in Project 25, 2020)*

Regarding following best management practice:

> *"Well, we do our Six Easy Steps… I've been Smartcane BMP [best management practice] accredited [in the last 18 months], so I've been following that, with their recommendations, yeah… some neighbours are adhering to it, some people aren't. Some people are doing their own thing. Some people try and, well, they're basically like me, they've tried it and then they've got to wait for your result of what comes of it next year." (Canegrower not involved in Project 25, 2020)*

There was also evidence from farmers that benefits or new knowledge from the project were contributing as one of a broader complement of changes or improvements in nitrogen efficiency, soil health and related goals on the farm. For example, one farmer highlighted the importance of soil health in general and associated practice change that will help achieve increased N use efficiency:

> *"There's a lot - there's starting to be a move toward wider rows for compaction, which it's not - that's what I've got to try to explain them. Compaction isn't about growing the cane or whatever. It's about soil health. That's what you're after, so that in time, you should get a trade-off… It's going to take about two cycles, [about 10] years, but if you can get your soil health right with the legumes or with compaction, less compaction, all that, well then you should have a better soil structure that then you will reap benefits of better nitrogen use efficiency." (Project 25 Steering Committee canegrower, 2020)*

Farmers also reported changes in their (ii) *individual* perspectives about N use that Project 25 had influenced in a positive way. For example, farmers now made clear links between available data and the central hypothesis that the first large rainfall event of the season (flush) and the application of N fertilizer on top of the ground, too close to this event, caused spikes in dissolved inorganic nitrogen in the waterways:

> *"But one of the things that does stand out with what we've learnt through this, with the water quality, is that certainly the first flush is probably the biggest contributor to the nitrate and the spike in the*

> *nitrate. I know that we probably thought that that might have been the case before, but the evidence is pretty strong. So if we want to look back at best practises it was only a few years ago that most of the agronomists and SRA and that were saying 'oh you need to leave the cane get to about 12 weeks before you fertilise it'. Now the consensus is that once it gets closer to the end of the season, as soon as you can put it on, the better. So already there's been that sort of - maybe not even practice change in a sense, a lot of farmers were probably doing that to a certain degree, they were putting it on whenever they could, as soon as they could, but the whole industry now is looking at yes that is probably best practice, is to get it on as quick as you can or as soon as you can to give it the amount of time, even if the cane is small." (Project 25 Steering Committee canegrower, 2020)*

Moreover, one farmer reported the direct role the project has had in helping to shift broader farming norms and expectations described above:

> *"It's [Project 25 data] telling farmers that are putting their fertiliser on top of the ground just before a rain event that they cause the problem." (Canegrower not involved in Project 25, 2020)*

Local CANEGROWERS extension was also targeted specifically in sub-catchments identified in water quality monitoring results by the Project steering committee as 'hotspot' sub-catchments for nitrate losses. This particularly involved increasing extension effort and support for the industry-owned CANEGROWERS Smartcane BMP program, focussing on improved nutrient management use and planning and plant nutrition. Accordingly, it is possible to document and track the results of this targeted extension effort through the life of Project 25, in areas receiving increased Project 25 and CANEGROWERS extension effort, and areas outside the primary footprint of the project. Rates of BMP accreditation in terms of grower numbers, increased at faster rates within sub-catchment areas receiving Project 25 water quality monitoring and presentation back to industry, compared to grower numbers and land area outside Project 25 focus (Davis et al., 2020).

3.4 Farmer confidence in scientific literacy increases

The role of Project 25 to change perspectives of farmers was also evident in data collected as part of a short set of Likert scaled questions administered after the semi-structured questions at the end of each interview. Farmers involved with Project 25 reported on average a higher increase in 'knowledge about water quality on their farm' between 2018 and 2020 compared with those farmers not involved directly in the project, who reported on average a slight decrease in knowledge (Figure 3). Similarly, those farmers involved with Project 25 also felt the 'water quality leaving farms in the district' and their 'ability to be part of the water quality debate' increased between the two rounds of interview (Figure 3). The involved farmers were also more likely to think 'Project 25 would work elsewhere', in other regions, and 'industry wide' than those not involved in the project. These results, while indicative only and not statistically significant, do suggest a pattern of farmers participating in Project 25 identifying strongly with the benefits of the project and with the possible benefits from wider application of the project model to other districts.

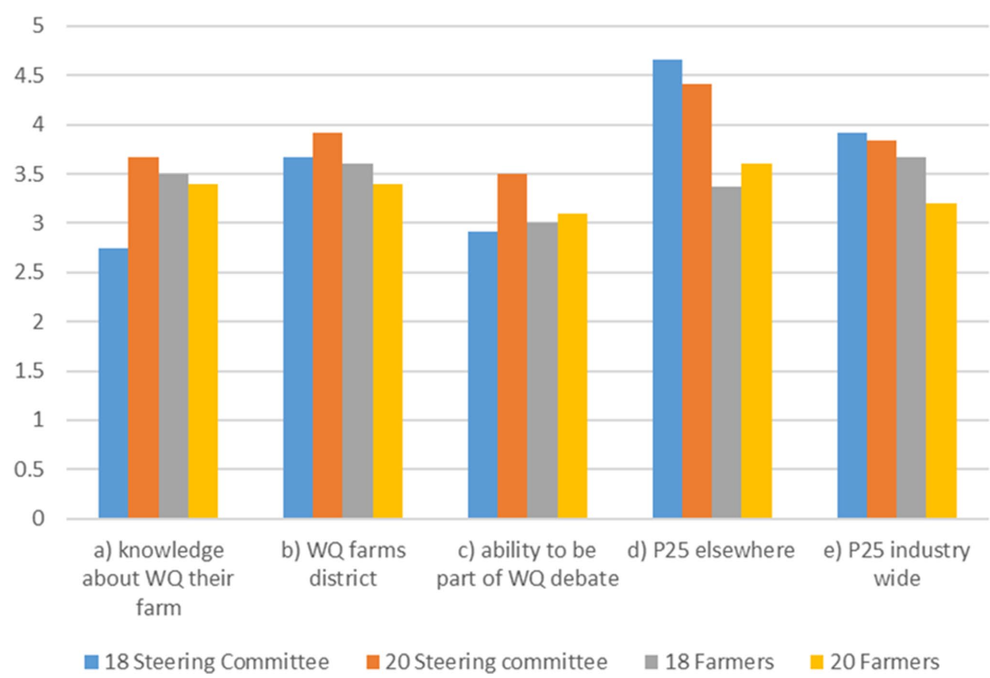

FIGURE 3
Mean scores for project 25 Steering committee farmers (2018 n = 6, 2020 n = 6) and not involved farmers (2018 n = 5, 2020 n = 5).

4 Discussion

4.1 Practical implications

Awareness of the environmental consequences of fertilizer over-application has consistently emerged, at a global scale, as a consistent gap in farmer's knowledge of the impacts of farming operations on the environment. This suggests that the concept of "awareness of consequences" needs to be further developed for on-farm nitrogen management (Floress et al., 2017). Project 25 specifically addresses these types of knowledge gaps within key stakeholder demographics. Demonstration of locally specific farm-scale impacts on the environment, loss of nutrients and capacity for active management can provide powerful landholder motivations for practice change.

The social research of Project 25 highlighted the importance of investing to build trust, maintain research practice and data transparency, and the critical role of informal learning and training as essential components to achieve impact-based research outcomes. These findings are not trivial and contribute to growing calls to recognize the input of various stakeholders and forms of research integration within processes of research and development (Polk, 2015). Social research emphasized the need for social capital, trust frameworks and co-production of knowledge, and an ongoing investment in engagement to maximize impact (Fielke et al., 2022).

4.2 Scalability of project concept

In relation to the question of scalability of the project model, both from the interviews and from observations made during the project, two considerations arise that could be influential – digital literacy and accessibility; and the role of social capital. One of the strengths of the project model is its flexibility in incorporating new technologies and partners to complement the core water quality sampling and Steering Committee components of the project design, particularly the smartphone application and supporting data analytics capability [1,622™WQ] to enhance the visualization of the relationship between water quality and rainfall event data (see Vilas et al., 2020). While this tool was generally well received by the growers in a researcher-supported setting, the exercise revealed considerable variation in digital literacy and accessibility among growers. If such a tool was to be part of a future scaling strategy for the project model, these capacity issues would need to be carefully assessed and considered (see Fielke et al., 2022).

The role of different forms of social capital in supporting or hindering collaboration in local catchment management has been studied for some time [see for instance Lubell (2004)]. The 'tight group' of growers and advisors described above reflects the 'bonded' form of social capital that often exists within local or peer-based farming communities or groups [see also King et al. (2019)]. These strong social ties, shared beliefs and norms can be helpful if an intervention is using peer-led strategies to encourage changes in behavior or establishing new norms within the group. It can mean, however, that in the absence of 'bridging' social capital (relationships that connect individuals to outside groups, skills and world views) that these tight bonds can make the introduction of new ideas or ways of doing things difficult to begin with, requiring long periods of relationship development and trust building in the early phase of projects. The resourcing implications of having dedicated scientific staff available and responsive within that initial time period across multiple smaller groups of growers, over several target catchment areas, would need to be considered in any scaling strategy.

While the Project 25 co-design template and governance arrangement could easily be broadened, elements of the target catchment itself warrant recognition in terms of transferability. Relatively simple and discrete catchment land use mosaics (rainforested, pristine upper catchments and developed floodplains) made water quality changes relatively easy and quick to quantify and present to stakeholders (in fact a reason for selection of the target catchment). The specific social and ecological conditions of the catchment may limit the application of findings to other regions or agricultural systems.

4.3 Present and future applications

Farming industry trust in the Project 25 model saw considerable industry advocacy for future expansion of the concepts, with similar models subsequently rolled out in neighboring catchments using Federal funding. While yet to be meaningfully researched in the specific context of Project 25, development of robust trust frameworks, could well provide a foundation for facilitating future stakeholder-driven efforts across a range of local NRM issues. 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 overall interest in conservation planning (Storey et al., 2016). In somewhat organic extension to the Project 25 model, local stakeholders are driving science-based, integrated responses to water quality improvement, but also other natural resource management issues. These include on- and off-farm interventions (Figures 4A,B) to address 'first-flush' losses to the environment, and broader, whole-of-catchment initiatives such as riparian and wetland rehabilitation, ecosystem connectivity and invasive pests. These efforts in the Russell-Mulgrave include recent expansion to broader stakeholder collectives (cattle graziers, statutory Drainage Boards and indigenous Traditional Owners). Project 25 canefarmers have acted as key and trusted local 'brokers' in enabling dialogues and relationships, kick-starting major on-ground works such as wetland and water quality rehabilitation actions by local traditional owners now allowed access on freehold grazing properties (Figure 4A).

5 Conclusions and limitations

There were limitations in this study. The social analysis sample size was small, and participants were not randomly selected, with many industry leaders already interested in contributing to the monitoring/sharing/output process, which may affect the generalizability of the results. The project team was also responsible for data collection and evaluation, a dual role introducing the possibility of confirmation bias. But it should be noted that the research team had distinct expertise in social science, water quality monitoring and farming systems responsible for the different components of the project to minimize bias across the team. The role of external confounders that may have influenced outcomes, including roles of media, other programs, and policy shifts, should also be acknowledged. Project outputs cannot be assumed to be completely attributable to observed changes in perception/action, but

FIGURE 4
Madjaybana ranger traditional owners (Madjandji Aboriginal Corporation) undertaking wetland rehabilitation project on freehold grazing property **(A)**; and cane farmer-installed 'first flush' capture drainage intervention, retaining paddock runoff following an early wet season rainfall event **(B)** (image supplied by *P. Rossi*).

rather had some form of influence on certain actors over the period of the project. Similarly, the project did not attempt to identify any significant differences in attitudes, practices, or outcomes between farmers who receive incentives for adopting best agricultural practices from those who did not, distinction could significantly impact the assessment of the model's effectiveness and generalizability. There were no financial incentives involved with the Project, but a significant proportion of Russell-Mulgrave sugarcane farmers, including those in Project 25, have received some form of incentives from other programs that we are not privy to, which may also affect their views and actions.

While evidence of attitudinal and practice change was apparent at individual levels, there was also no demonstration of catchment water quality improvements, an outcome often shared with nutrient control measures and agri-environment schemes elsewhere (Worrall et al., 2009; Osmond et al., 2012; Kay et al., 2012; Jones et al., 2017). The limited evidence for catchment-scale water quality improvement reflects, in part, the difficulty of isolating and quantifying causation and the cumulative benefits of field- and farm-scale pollution mitigation activities against often significant natural climatic variation, or lag times in water quality responses to changes in land management practices that can take years or even decades to manifest (Meals et al., 2010; Sharpley et al., 2013). Longer-term monitoring will be required to evaluate the impact of behavioral change on environmental water quality indicators. Despite the lack of empirical evidence of catchment scale water quality improvements, the agency of the sugarcane industry to understand and contribute to the science of local water quality monitoring (mediated through technology) was an important step in catalyzing farming stakeholder ownership and responses to local environmental issues.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by CSIRO Social Science Human Research Ethics Committee (106/17). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AD: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. AW: Conceptualization, Investigation, Methodology, Writing – original draft. SF: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. LB: Data curation, Formal analysis, Methodology, Writing – review & editing. SM: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing – review & editing. RA: Data curation, Investigation, Project administration, Validation, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This project was supported with funding from the Australian Government's National Environmental Science Program and the partnership between the Australian Government's Reef Trust and the Great Barrier Reef Foundation. The 1622WQ and Social Dimensions projects were funded by CSIRO Digiscape Future Science Platform.

Acknowledgments

We also thank colleagues who contributed significantly to this work: Bruce Taylor; Peter Thorburn; Emma Jakku; and CANEGROWERS Queensland and Cairns Region. We acknowledge gratefully the interviewees for their input. Two reviewers also provided very constructive feedback on an earlier version of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

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