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Final Case Study Report

1622 Water Quality Apps Prospective Analysis

Prepared for

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Executive Summary

The 1622 project is part of the Commonwealth Scientific and Industrial Research Organisation's (CSIRO's) Digiscape Future Science Platform (FSP). It aims to promote environmental stewardship in Australia's agricultural sector by providing farmers and land managers with decision support systems (DSSs) that increase their resource use efficiency. The project was created to help reduce nitrogen (N)-based nutrients in catchments adjacent to the Great Barrier Reef (GBR). N runoff from agricultural activities in the coastal region has been one of the greatest contributors to deteriorating water quality and subsequent decline in reef cover.

The 1622 apps provide situational awareness by giving farmers high-frequency data about water quality in nearby waterways. The DSS component shows them how their crop yields will respond to different N-based fertiliser application rates. The underlying theory is that when sugarcane farmers realise that their fertiliser use leads to an increase in water pollution, while simultaneously having the tools that enable them to reduce fertiliser use and maintain their yield levels, they will readily reduce their fertiliser use to lower their input costs and improve water quality.

1622 mostly comprises two apps—*1622WQ* (information portal) and *1622WhatIf* (DSS)—and has the potential to benefit sugarcane farmers and the Australian economy at large. Key benefits include

- reduction in water N-based pollution in coastal catchments,
- reduction in the input costs of sugarcane farming and increased profitability,
- reduction in N-oxide greenhouse gas emissions caused by N-based fertilisers,
- conservation of the GBR and the industries and ecosystems that depend on it, and
- increased scientific knowledge and human capital through innovation and peer-reviewed publications.

The project was funded by CSIRO over a 5-year period (2016/17 to 2020/21) with an investment of $2.15 million. CSIRO plans to continue partially funding the further development of the *1622WhatIf* app with $200,000 over an additional 3- to 4-year period. The development team is led by Peter Thorburn, PhD.

We conducted a quantitative cost-benefit analysis (CBA) of the project and provide these results with a qualitative discussion of impacts that could not be monetised. The *1622WQ* app is operational, but the *1622WhatIf* app is still under development. Because we expect the latter to have a more influential impact on achieving N reduction, this report presents a prospective analysis under multiple possible scenarios. The scenarios vary in both adoption and impact levels.

The summary of the economic performance measures we estimated are reported in Table ES.1. We estimate that the 1622 apps have the potential to provide between $20.4

million and $62.9 million in economic impacts (net present value terms, 2020, 7% discount rate) between 2021 and 2030. The benefit-cost ratio ranges from 11.1 to 32.1, indicating that the project produced at least $11.1 in benefits for every $1 invested in the project. The largest contributor to the benefits was cost savings from reduced fertiliser use, followed by improvement in ecosystem service values. We also estimate that the internal rate of return (IRR) of the project ranged from 43.2% to 61.1%, which is higher than the social discount rate of 7%.

We also found that the project led to several other important benefits, including trade competitiveness, management of risk and uncertainty, increased access to resources, and development of human capital through innovation and knowledge advancement.

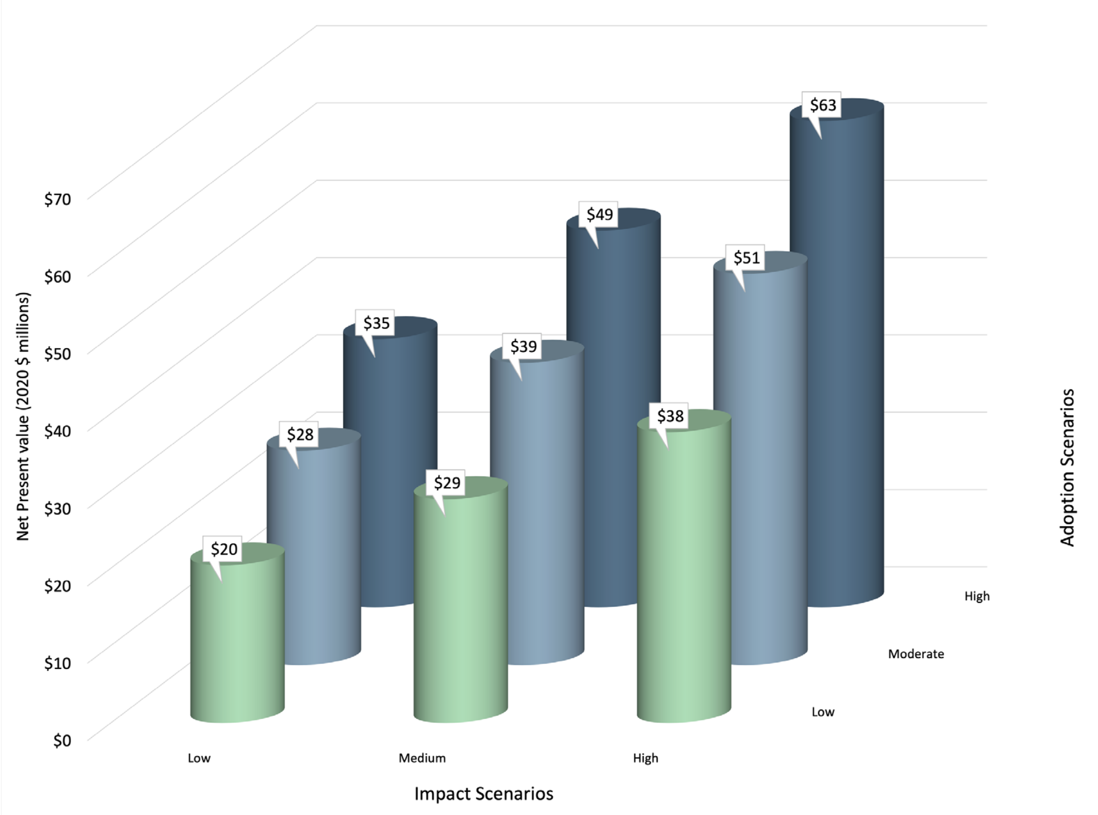
Table ES.1. Summary of Economic Performance Measures for the 1622 Water Quality Apps, 2021–2030

Impact	Adoption	NPV (2020 million $)	BCR	IRR
Low	Low	20.37	11.1	43.2%
	Moderate	27.72	14.7	47.9%
	High	34.66	18.1	51.4%
Medium	Low	28.94	15.3	48.4%
	Moderate	39.09	20.3	55.2%
	High	48.69	25.1	56.8%
High	Low	37.59	19.6	52.4%
	Moderate	50.59	26.0	57.4%
	High	62.87	32.1	61.1%

Figure ES.1 shows the net present value of benefits after deducting costs.[1]

[1] Each scenario result is the present value of future benefits from 2021 through 2030, assuming that *1622WhatIf* is deployed commercially from 2023 through 2024 and that the apps cause reductions in N usage starting in 2025. We employed a 7% real social discount rate, per the CSIRO *Impact Evaluation Guide*. The values presented represent CSIRO's share of the estimated benefits, determined by their contribution to the overall funding of the apps.

Figure ES.1. Estimated Range of Net Present Value from 1622 Apps, 2021–2030



Note: Values are in millions of 2020 dollars.

1. Introduction and Background

1622 is a suite of digital agriculture apps that aim to reduce the adverse environmental impacts caused by nitrogen (N) pollution from sugarcane farms in coastal catchments of wet tropical Queensland. Two apps were developed: one is operational (the *1622WQ* app) and another is being developed for commercial use (*1622WhatIf* app). The rationale for multiple apps was to provide sugarcane farmers with both an information source and a decision support system (DSS) to aid them in efficiently managing their crops.

The *1622WQ* app was publicly launched in January 2020[2] with the aim of providing farmers with real-time information on precipitation and water quality, such as nitrate concentrations, in nearby waterways. This information helps farmers realise the impact their farming practices and N fertiliser applications have on water quality in nearby catchments. The *1622WQ* app uses data from water quality monitoring projects in different regions of Queensland, leveraging the automatic nitrate sensors these programs already had in place. The app also displays precipitation data from rainfall gauges. Precipitation data are important because rainfall is a main driver of N pollution runoff from catchments. These data complement information on nitrate concentrations and other water quality data.

The objective of the *1622WhatIf* app is to provide a DSS that provides farmers with probabilistic information about the predicted response of sugarcane yields to changes in N application rates. This enables them to manage the uncertainty involved in choosing optimal N application rates for water quality targets while not compromising sugarcane yields. The *1622WhatIf* app relies on remote sensing data; user-provided inputs; and climate, soil, and elevation data. Using the data, predictive machine-learning models simulate and predict yields across the sugarcane value chain (e.g., cane, commercial cane sugar, sugar yields). This app is currently under development in collaboration with Farmacist, the largest group of private advisors servicing the sugarcane industry, and the Great Barrier Reef Foundation. Its development is expected to take an additional 3 to 4 years.

This report quantifies the potential impacts stemming from the 1622 project. It describes the technology; leverages learnings from the scientific and economic literatures; and describes the potential economic benefits from various use cases at varying degrees of adoption and impact. The overall goal is to provide a reasonable assessment of how this project may generate economic and social value for Australians over the 10-year period from 2021 through 2030.

1.1 Digiscape Future Science Platform

The development of the 1622 water quality apps was supported by the Future Science Platform (FSP) initiative. FSPs are investments in science that underpin innovation and have the potential to help reinvent and create new industries for Australia. FSPs are

[2] To the knowledge of the app developers, this is the first app to provide high-frequency water quality data to users on a mobile platform.

designed to grow the capability of a new generation of researchers and allow Australia to attract the best students and experts.

The Digiscape refers specifically to the digital agriculture FSP. According to CSIRO, Digiscape is about harnessing the digital revolution for Australian farmers and land managers. It endeavours to solve multiple real-life knowledge shortfalls in the land sector simultaneously by building a common big data infrastructure to support next generation decision-making and transform agricultural industries and environmental action.

1.2 The Science Behind 1622

The motivation for developing the 1622 water quality apps was to address the issue of unacceptable water pollution levels in the catchments adjacent to the Great Barrier Reef (GBR), a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage–listed ecosystem. The GBR Marine Park, located off the coast of northern Australia, contains the world's largest coral reef ecosystem and is one of the most biodiverse regions in the world (Great Barrier Reef Marine Park Authority [GBRMPA], 2019; UNESCO, 2021a). The GBR provides substantial benefits to Australia (and the world), such as protecting coastlines, providing habitats for sea life, and aiding in nutrient cycling. The region also plays an important role in Australia's tourism sector. Despite its beauty and importance, the reef's health has declined because of both natural and anthropogenic causes over the last several decades. Between 1985 and 2012, nearly 50% of the coral reef cover has declined (De'ath et al., 2012).

Land-based water pollution is one of the main threats to the health of the GBR and one of the leading causes of the deterioration of its marine and coastal ecosystems. Agricultural activities have been identified as the main source of primary pollutants in the form of nutrients, fine sediments, and pesticides (State of Queensland, 2018; Waterhouse et al., 2017), leading to eutrophication (see Appendix A for details). Despite investments and measures put in place to improve management practices and reduce pollutant discharges from agriculture, progress has been slow, and the current trajectory will not meet ecological targets necessary to preserve the ecosystem health of the GBR (State of Queensland, 2018; Waterhouse et al., 2017). N-laden agricultural discharges are one of the most significant contributors to land-based water pollution in GBR-adjacent catchments (Waterhouse et al., 2017) and are directly related to the amount of N fertiliser applied to agricultural lands (Thorburn et al., 2013).

N contained in fertiliser changes to dissolved inorganic nitrogen (DIN) in soil and water, and DIN is easily used by plants and algae to grow. DIN is also easily transported into waterways through rainfall and drainage (State of Queensland, 2020). The largest contributor to DIN exported to the GBR (78%) is sugarcane farming in nearby catchments (State of Queensland, 2020).[3] Because sugarcane is a high-value crop, farmers apply high rates of N fertiliser to maximise yields. Moreover, sugarcane is a

[3] More details about the effects of N pollution on the GBR are provided in Appendix B.

dominant crop planted in coastal regions. Therefore, reducing N fertiliser application rates, while optimising N usage, has the potential to greatly reduce the exports of N into the catchments while preserving yield productivity.

However, changing farmers' management practices is challenging for the following reasons:

- their scepticism about the impact their N application rates have on local water quality,
- uncertainty about the effect of management practice changes on yields and productivity, and
- difficulty of evaluating the success of new management practices (Thorburn et al., 2012).

Therefore, the 1622 project targets N reduction in sugarcane farming in north Queensland by providing farmers with the information they need to undertake more environmentally friendly management practices. Undertaking more environmentally friendly management practices will achieve the dual target of improving water quality and marine ecosystem health and reducing costs and improving profitability for farmers.

1.3 Case Study Purpose

Case studies of the outcomes and impacts of CSIRO activities are a central component of CSIRO's evaluation and performance measurement program. They describe the rationale for CSIRO action, the investment made and research conducted toward national goals, and the resulting or expected outcomes and impacts. Cost-benefit analysis (CBA) is CSIRO's primary impact evaluation methodology and the one used in this report.

CSIRO commissioned RTI International, an independent non-profit research institute, to evaluate the potential social, environmental, and economic impacts stemming from the 1622 water quality apps project. This evaluation was an in-depth analysis of the potential impacts this project may have on the agriculture industry.

As stated above, farmers are using the *1622WQ* app, while the *1622WhatIf* app is under development in a collaboration between CSIRO, Farmacist, and the Great Barrier Reef Foundation. Both apps target behavioural changes that entail a reduction in N application rates. The project director, Dr. Thorburn, anticipates that impacts of the *1622WQ* app will be realised in about 5 years, while the impact of the *1622WhatIf* app, once developed, will be more rapid at 1 to 2 years. Our independent assessment concurs. This means that both apps are expected to cause behavioural changes around the year 2025.

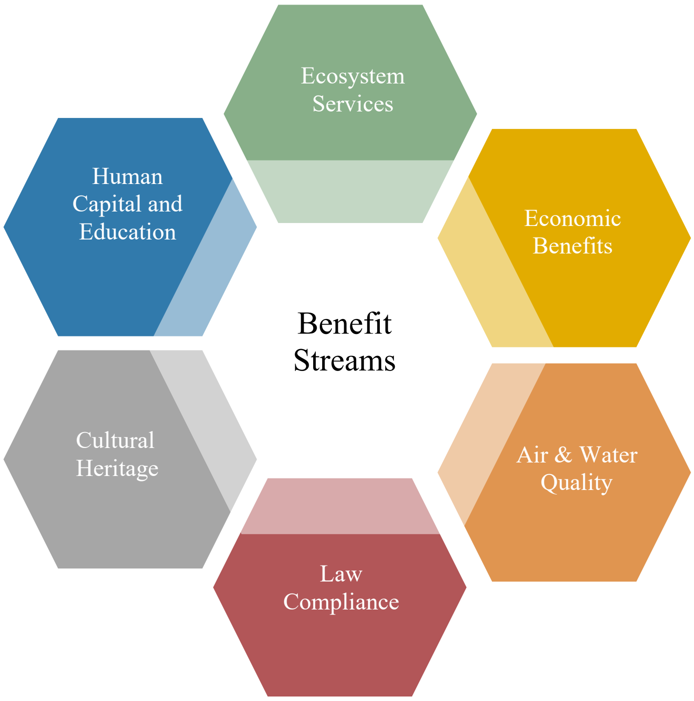
As such, this case study undertook a *prospective* CBA to quantify the net benefits arising from the development, adoption, and use of the 1622 apps over a future 10-year period with varying rates of adoption and impacts to reflect uncertainty. The findings from this study are intended to be used for the purposes of performance management, accountability, communications, and continual improvement.

2. Prospective Impacts of the 1622 Water Quality Apps

2.1 Types of Prospective Impacts

Multiple types of potential benefits can accrue from developing and adopting the 1622 apps. Figure 2.1 displays the main types of benefits provided by the apps, and Table 2.1 lists the detailed economic, social, and environmental impacts and the pathways by which they lead to these benefits. Given the damage that N runoff has been causing in the GBR region, many of the impact pathways that we considered are directly associated with the GBR and its health and protection.

Figure 2.1. Main Areas of Benefits Provided by the 1622 Apps



We monetised several of the benefits listed in Table 2.1 and analysed the rest qualitatively. The remainder of this section describes prospective qualitative impacts, grouped by their type: economic, environmental, and social. In Section 3, we describe the quantitative analysis approach, then we report the findings of the quantitative analysis in Section 4.

Table 2.1. Main Benefits of 1622 Apps and Their Pathways

Impact		Pathway
ECONOMIC	Protection of GBR-dependent industries	Tourism, recreation, scientific research, and fishing are four key industries related to the GBR and add an annual value of $6.9 billion annually to Australia. Protecting the reef's health and coral cover is an important component in protecting these industries. Reducing N runoff can help preserve the coral cover.
	Trade and competitiveness	Australia is the world's second largest exporter of raw sugar (U.S. Department of Agriculture [USDA], 2021; Department of Agriculture, Water, and the Environment [AWE], 2020). Using the *1622WhatIf* app can help farmers decide what is the optimal level of N fertiliser to apply to reach the best yield outcome, which may reduce N application without compromising profits. This process may help preserve and possibly increase Australia's competitiveness on the global market, while reducing the adverse impacts of N runoff on the GBR.
	Productivity, efficiency, and management of risk and uncertainty	At the micro level, using the *1622WhatIf* app can help manage uncertainty and risk by providing the farmers with valuable information regarding the optimal level of N application without reducing yields. The potential reduction in N use would lead to reduced costs and more efficient use of N fertilisers.
	Scientific stature and advancing knowledge through peer-reviewed papers	The work conducted by CSIRO to develop the *1622WQ* and *1622WhatIf* apps has already led to peer-reviewed journal articles. Continued work and research in this area have the potential to expand the literature on data and app usage for improved nutrient management.
	Compliance with N budget laws	In 2019, more stringent regulations on N application were enacted that resemble a cap-and-trade system. Using the *1622WhatIf* app can provide farmers with valuable guidance on fertiliser applications on high- or low-risk fields.
ENVIRONMENTAL	Preservation of coral reef cover	N runoff from agricultural production contributes to coral decline. N feeds algae and can lead to an algal bloom that reduces the amount of light and oxygen that reach the coral, slowing down its growth rate (University of Melbourne, 2019). Also, increases of N can lead to higher populations of phytoplankton, which feed predators of the GBR such as the crown of thorns starfish (World Wildlife Fund [WWF], 2015). Reducing runoff can play a role in preserving existing coral cover and decelerating its decline.
	Improving ecosystem health and integrity (natural capital)	The GBR is considered essential to Australia's natural capital stock. The area includes 14 different types of coastal ecosystems. Using the *1622WQ* and *1622WhatIf* apps can improve water quality, which will ultimately have positive impacts on ecosystem health.
	Preserving biodiversity and benefits to aquatic environments	The GBR supports biodiversity and aquatic life, so preserving the GBR will protect biodiversity (GBRMPA, 2021a). N pollution directly affects aquatic life, so reducing N runoff will contribute positively to the quality of aquatic environments.
	Improved air quality (reducing greenhouse gases [GHGs] from N)	Applying N-based fertilisers to fields releases harmful gases that contribute to the depletion of the ozone layer. The apps can inform behavioural changes that lead to reduced N application rates, leading to a reduction in the damage caused by excessive N use.

(continued)

Table 2.1. Main Benefits of 1622 Apps and Their Pathways (continued)

Impact		Pathway
SOCIAL	Health and wellbeing: Improved air quality	N-based fertiliser causes air pollution, which can negatively affect human health. Exposure to these pollutants increases the risk of developing certain illnesses and increases morbidity (Rojas-Rueda et al., 2021). Using the apps can inform an optimal application level that reduces human exposure to harmful air pollutants.
	Improved access to resources and information	The apps allow farmers to access various information and data sources in one convenient platform, minimizing the burden of data collection and leading to "data democratisation."
	Building human capital through innovation	Similar to other FSPs.
	Indigenous culture and heritage (Traditional Owners)	The Traditional Owners have a spiritual, cultural, and historical connection to the GBR (O'Mahoney et al., 2017). Reducing N runoff can help preserve the reef so the Traditional Owners can continue engaging in their customs and managing the reef.
	Iconic and heritage value	The GBR is an icon for Australia and is recognized worldwide as a UNESCO World Heritage site and one of the seven wonders of the natural world (UNESCO, 2021b; Seven Natural Wonders, 2021). Improving the water quality in the GBR catchment is an important step in improving reef health to preserve it for future generations.
	Quality of life	The potential reduction in input costs brought on by lower N application rates increases farm profitability and improves quality of life for farmers, their households, and their communities.

2.2 Prospective Qualitative Impacts

2.2.1 Economic Benefits

Compliance with N Budget Laws

During the 1900s, the use of N fertilisers in sugarcane production grew dramatically from 60 kg N-ha in the 1940s to a peak of 200 kg N-ha in the mid-1990s (Bell, 2014). Over the past 20 years, the application of N-based fertiliser has declined slightly, but the application is still significantly higher than it was in the mid-1900s.

Given the potential damage that can be caused from overuse of N-based fertilisers, stricter regulations were enacted in Queensland in 2019. The new regulation required that farmers follow an N and phosphorous budget (Queensland Government, 2019). The budget operates similar to a "cap-and-trade" system because the fertilisers can be shared across fields within the same farm but cannot exceed the maximum fertiliser amount permitted (Queensland Government, 2019; Thorburn et al., 2021).

1622WhatIf can be a valuable tool that can help farmers comply with the N budget laws without sacrificing their sugarcane yields. In addition to complying with laws, farmers could potentially use the apps to demonstrate compliance with the requirements of the

Reef Credit Scheme (RCS), a market-based framework devised to bring about improvements in the GBR's water quality.[4]

Trade and Competitiveness

Sugarcane production is an important contributor to the Australian economy. Australia is the second largest exporter of raw sugar globally, exporting around 80% of all sugar produced domestically (ABARES, 2020). About 95% of sugarcane produced in the country is grown in Queensland (Sugar Australia, 2018).

As mentioned above, sugarcane farmers apply N fertiliser intensively because of the crop's high value and to reduce the risk of lower yields. Thus, there is a trade-off between improving the water and air quality of the region and maintaining crop yield productivity and trade competitiveness.

The use of the 1622 apps has the potential to promote this balance by enabling farmers to temporally and spatially optimise the use of their N fertilisers to achieve the dual target of reducing N inputs while maintaining productivity and profitability. App usage thus ultimately allows Australia to reduce N pollution and preserve the air and water quality of the GBR, while maintaining trade competitiveness.

Management of Risk and Uncertainty

While trade competitiveness is an economic benefit at the national, macro level, the apps also provide micro-level benefits to farmers by allowing them to manage the risk of potential yield loss while maintaining farm-level profitability.

Scientific Stature and Knowledge Advancement

The 1622 project led to technological and scientific advancement through multiple pathways.

First, the research funded by the project led to development of an additional product, *1622WhatIf*, once user feedback made it clear there is a need for it. The code developed for the two apps may potentially be leveraged for other uses and in other contexts.

Second, multiple students worked on the project, and some of them later contributed to publications generated by the project research. The knowledge acquired by the project team members contributes to Australia's knowledge base in the relevant fields of machine learning, remote sensing, and statistics.

Finally, the project research has led so far to the publication of 12 journal papers and seven conference papers and reports, published between 2018 and 2021. For this group of publications, we performed a brief scientometric analysis by querying them in the Dimensions database (Dimensions, 2021). We found 14 publications in the Dimensions

[4] Reef credits would represent a quantifiable and tradeable unit of pollutant reduction (Reef Credit, 2021).

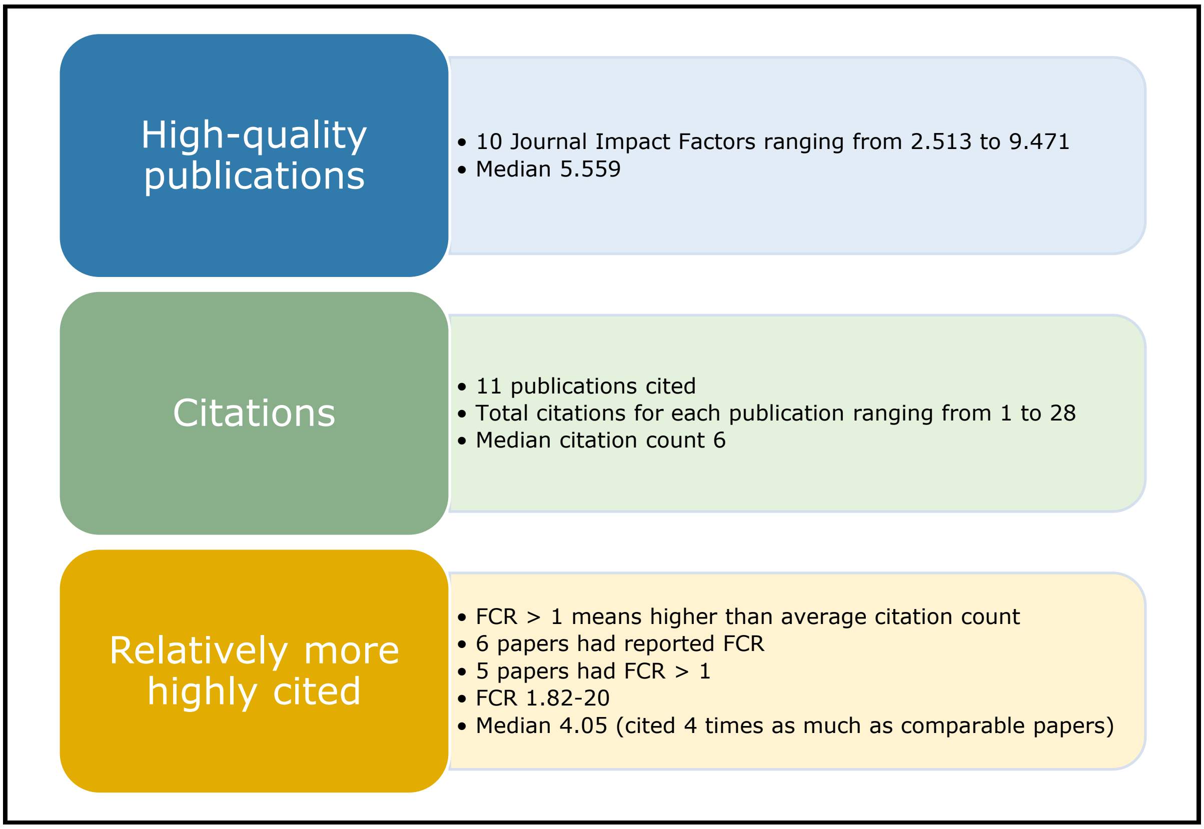
database and compiled several metrics that describe the publications' influence and impact on the scientific community:

- Journal Impact Factors (JIFs): We found JIFs for 10 publications, ranging from 2.513 to 9.471, with a median of 5.559. These are relatively high JIFs, indicating that the papers were published in high-quality journals that reach a broad audience.
- Total citation counts: Despite the vast majority of the papers being only recently published, 11 publications have already been cited, with citations ranging from 1 to 28 with a median of 6.
- Field Citation Ratio (FCR):[5] FCR is a year- and field-normalised metric, which makes it more suitable to comparing the relative citation performance between papers. Publications with an FCR over 1 are cited more than other papers in their field and year of publication. In this analysis, six papers had a reported FCR with only one paper having an FCR less than 1 and the others ranging from 1.82 to 20 with a median of 4.05. This means the median paper has been cited 4 times as much as the average paper in its field and publication year, indicating that this set of publications has been significantly more highly cited than comparable papers in the literature.

The summary of the scientometric analysis is displayed in Figure 2.2.

[5] The FCR is calculated within the Dimensions database and is described as "… a citation-based measure of scientific influence of one or more articles. It is calculated by dividing the number of citations a paper has received by the average number received by documents published in the same year and in the same Fields of Research (FoR) category.
The FCR is calculated for all publications in Dimensions which are at least 2 years old and were published in 2000 or later. Values are centered around 1.0 so that a publication with an FCR of 1.0 has received exactly the same number of citations as the average, while a paper with an FCR of 2.0 has received twice as many citations as the average for the Fields of Research code(s)" (Dimensions, 2019).

Figure 2.2. Summary of Scientometric Analysis of Project-Based Publications



2.2.2 Environmental Benefits—Meeting Water Quality Targets

Farmers using the app and achieving cost reductions may be more likely to promote its use in the farming community, leading to widespread adoption among canegrowers. Widespread adoption will accelerate reductions in N-based pollution and subsequent improvements in water quality. Adoption also helps promote higher levels of environmental awareness in coastal communities, which may motivate more segments of the population to take additional environmentally conscious measures outside the scope of sugarcane farming.

These reductions will help in achieving the water quality targets set by the Reef 2050 Water Quality Improvement Plan. The plan targets a 60% reduction in anthropogenic end-of-catchment DIN loads (State of Queensland, 2018). As we see below, we estimate that DIN loads will be reduced by 9% to 15% depending on impact scenario.[6] Therefore, with widespread adoption among farmers, app usage is expected to contribute to meeting target DIN reductions.

Higher digital literacy among the population, in addition to the knowledge base created by the FSP, may also motivate the development of additional apps that build on existing ones and lead to more expansive environmental improvements.

[6] These figures (9% to 15%) assume 100% adoption among sugarcane farmers.

2.2.3 Social Benefits

Improved Health and Wellbeing via Improved Air Quality

N-based emissions have negative impacts on human health. N fertiliser can cause ammonia (NH_3) and N oxides (NO_x) emissions, which are precursors to particulate matter (PM) (U.S. Environmental Protection Agency [EPA], 2021b; Guo et al., 2020; Gouerevitch et al., 2018, Zhao et al., 2017). Exposure to PM can contribute to a wide range of negative health outcomes such as cancer, stroke, heart disease, asthma, mortality, and depression (Rojas-Rueda et al., 2021; Wu et al., 2018). The reduction in N-based emissions with the potential reduction in N fertiliser use will improve air quality and have positive impacts on human health.

Quality of Life

One of the main objectives of the apps is reducing input costs incurred by farmers and increasing profitability and disposable income. Achieving this objective may lead to an improvement in the quality of life of these farmers, their households, and their communities.

Improved Access to Resources and Information

The apps provide farmers with a portal to multiple types of data and information that help them make decisions regarding the timing and quantity of their N fertiliser application. They also get access to rainfall and water quality data in one place instead of needing to use multiple apps.

Human Capital

This 1622 project funded research that provided learning opportunities to multiple students who either worked on the project during the summer or fulfilled course requirements. Some of them also went on to become co-authors on some of the publications generated by this research. In doing so, the project helped build human capital knowledgeable in digital agricultural applications.

Traditional Owners

The GBR is of great importance to Traditional Owners from religious, cultural, and historical perspectives. The indigenous cultural significance of the GBR spans over 70 Aboriginal and Torres Strait Islander Traditional Owner clan groups, with each group heavily associating both aesthetic and bequest value with the GBR and its ecosystem. The Aboriginal and Torres Strait Islander peoples have had a connection to the GBR as Traditional Owners for over 60,000 years (O'Mahoney et al., 2017).

Icon and Heritage Value

Australians and people across the globe value the GBR for its iconic value and inherent beauty. In 1981, UNESCO designated the GBR as a World Heritage site, recognising the reef's importance to humanity and the need to preserve it for future generations (UNESCO, 2021a, b). Similarly, the reef is also recognized as one of the seven natural wonders of the world (Seven Natural Wonders, 2021). In a survey conducted about the value of the GBR, 95% of national and international respondents agreed that the GBR is an "Iconic Australian landmark that contributes to Australia's national identity and international standing" (O'Mahoney et al., 2017). Given the importance of the reef to people across the globe, it is necessary to implement measures and management schemes that will protect the reef for future generations to enjoy. Using the *1622WQ* and *1622WhatIf* apps can play an important role in preserving the health of the reef by reducing eutrophication and promoting improved water quality.

3. Economic Analysis Methodology

Our CBA approach used historical market data, existing research on the relationship between N application rates and runoff, ecosystem service valuation of the GBR in the literature, and interviews with the 1622 team. We employ multiple complementary approaches in our analysis to capture different facets of potential benefits. For the valuation of indirect economic benefits accruing to GBR-dependent industries, we used the damage avoided method, which estimates the value of the services provided by the GBR that would be lost without adoption of the app. For ecosystem service valuation, we used a benefit transfer approach, which uses results and ideas from other studies that are topically, regionally, contextually, or methodologically relevant to the current case and transfers the information to the relevant context (Norton & Hynes, 2018; Brander & Schuyt, 2010). We also calculated input cost savings attained by farmers when potentially reducing N application. Finally, we conducted a brief scientometric analysis of the peer-reviewed publications developed under this project and a qualitative analysis of multiple additional benefits that could not be reliably monetised.

Our analysis is prospective because the technology remains in commercial development and because we did not consider confounding effects of other threats to the GBR, most notably climate change. As such, all estimates presented herein should be interpreted as probable, should adoption, impact, and use cases emerge as hypothesised. Overall, we recommend focusing interpretation on the direction and magnitude of benefits rather on than the specific quantitative value.

We developed projections of potential impacts for 2021 through 2030. We present the net present value of benefits using a 7% annual discount rate (2020 base year and in 2020 dollar terms).

3.1 Time Horizon of Benefit Streams

Although *1622WQ* is already in use, we assumed that it will not motivate behavioural changes before the year 2025 (based estimates from expert interviews). Similarly, the *1622WhatIf* app is currently under development and is expected to be operational in 2024 through 2025. We anticipate that this app will lead to behavioural changes much more rapidly, perhaps within 1 to 2 years. Consequently, we started the benefit streams in the year 2025 for both apps.

3.2 Adoption and Impact Scenarios

Given *1622WhatIf*'s pre-market status and the limited historical data on *1622WQ* usage and impact, this case study offers estimates of potential value based on ranges of estimated uptake and user benefits. We designed future scenarios that cover potential outcomes based on an overall assessment of where the 1622 apps could generate impact. Three adoption scenarios (low, medium, and high) and three impact scenarios (minimum, moderate, and maximum) were combined to present a range of potential impacts.

3.2.1 Adoption Scenarios

Adoption scenarios represent the potential uptake of 1622 apps among farmers in the area of study. This area is restricted to the sugarcane farming region in north Queensland from the central district (Mackay) to the north. These scenarios took into account usage data observed on Google Analytics for the *1622WQ* app, indicating an adoption rate as high as almost 40%.[7] However, we anticipate that the effect of the *1622WQ* app alone is likely limited and is more impactful when used in conjunction with the *1622WhatIf* app. We therefore used adoption rates more aligned with the *1622WhatIf* timeline and did not break down adoption scenarios by app. Table 3.1 displays the annual adoption rates by scenario.

Table 3.1. Projected Annual Adoption Rates for Each Adoption Scenario with Percentages Representing the Proportion of Farmers Using the App, 2021–2030

Adoption Scenario	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Low	0%	0%	5%	5%	15%	25%	35%	40%	45%	**50%**
Medium	0%	0%	7%	12%	25%	35%	45%	55%	59%	**65%**
High	0%	0%	10%	25%	35%	45%	55%	65%	75%	**80%**

3.2.2 Impact Scenarios

The impact scenarios were designed to capture the uncertainty around the potential direct and indirect impacts. As with the adoption scenarios, these were designed using historical data or previous literature and used conservative estimates when data were limited (Table 3.2). Details on the development of these scenarios are presented below.

We developed a range of scenarios assuming that when farmers use the apps they will reduce their N fertiliser application, which will reduce the DIN runoff into waterways and improve water quality. We varied the parameters guiding each of these steps, as seen in Table 3.2.

[7] According to Google analytics, almost 1,100 unique users out of over 2,883 sugarcane farmers (ABARES, 2021) in the region accessed the app.

Table 3.2. Projected Annual Impact Rates for Each Impact Scenario by Parameter

Parameter	Impact Scenario	Value	Source	Name
Reduction in N fertiliser with app usage (kg ha^{-1})	Small	15	Moderate value based on expert interview estimate and small/large are ±5	R^s
	Moderate	20		
	Large	25		
Annual improvement in coral reef cover in the absence of the crown-of-thorns starfish (COTS)	Small	0.80%	Moderate value from Australian Institute of Marine Science (AIMS) (2015), small/large are lower and higher	*AEI*
	Moderate	0.89%		
	Large	0.95%		

3.2.3 Annual Reduction in N Pollution

The basis for the derivation of benefits is the improvement in the water quality of the GBR-adjacent catchments as a result of farmers using the apps. Although the exact relationship between pollution reduction and improvement in water quality and the subsequent impact on the coral reef and marine environments is not well understood, it is accepted that a reduction in N fertiliser use will lead to improved water quality. Therefore, we made various assumptions in the analysis to deduce impact, but as mentioned above, we recommend focusing interpretation on the direction and magnitude of benefits rather than the specific quantitative value.

As a proxy for improvement in water quality, we used the reduction in DIN amounts after app usage as a percentage of current DIN amounts in catchments:

$$P^s = \left(\sum_j A_j * R^s * DIN\right) / \left(\sum_j A_j N_j * DIN\right) \quad (1)$$

where a superscript of *s* denotes a parameter that is delineated by impact scenario

P = the reduction in DIN pollution (%)

A_j = the number of hectares in district j

R = reduction in N fertiliser application (kg/ha)

N = N fertiliser application in district j (kg/ha)

DIN = the percentage of N fertiliser that discharges into waterways as DIN (20%)

Computing Eq. 1, the estimated impact values corresponding to 15/20/25 kg/ha reduction in N application are displayed in Table 3.3.

Table 3.3. Projected Annual Improvement in Water Quality due to Reduction in N Pollution in GBR Catchments

Impact Scenario	Low	Medium	High
Value	8.9%	11.9%	14.9%

3.2.4 Additional Parameter Assumptions

For additional parameters influencing the impact evaluation, we conducted a literature review to better understand how N runoff affects the GBR and discover potential benefits from reducing pollution. We collected a range of journal articles, government website information, and data that informed our analysis (Table 3.4).

Computing Eq. 1 while varying the parameters that are delineated by scenario led to a range of values, depicting low-, medium-, and high-impact scenarios. The values are presented in Table 3.4 and represent percentage improvement in water quality.

Table 3.4. Additional Parameter Assumptions

Parameter	Units	Value	Source	Name
DIN as a percentage of N fertiliser	%	20	Expert interview estimate	*DIN*
Cost of N fertiliser	$/kg	1.52	CANEGROWERS (2020)	P_N
Emission factor (Gg N_2O-N/Gg N)		0.0199	Commonwealth of Australia (2017)	*EF*
N_2O global warming potential (GWP)		298	Intergovernmental Panel on Climate Change (2007)	*GWP*
Australia’s share in global GDP	%	1.7	Australian Trade and Investment Commission (2021)	*GDP%*
Decline in coral cover attributable to COTS between 1985 and 2012	%	42	AIMS (2015)	Used in estimating *COTS* below
Decline in reef cover between 1985 and 2012	%	50	AIMS (2015)	Used in estimating *COTS* below
Estimate of annual decline in reef cover	%	1.85	Estimated	Used in estimating *COTS* below
Approximate annual decline in reef cover attributable to COTS	%	0.78	Estimated	*COTS*
Area of GBR that will witness improvement in water quality	%	50	Conservative estimate	*Area*
Price of carbon	$/tonne	16	Conservative estimate	
Value of ecosystem services of corral reefs[a, b]	$/ha/yr	$380,117	Calculated based on estimate from Costanza et al. (2014)	Used in *GEV*
Value of ecosystem services of seagrass/algal beds[a, b]	$/ha/yr	$41,079	Calculated based on estimate from Costanza et al. (2014)	Used in *GEV*

[a] These numbers were adjusted for inflation using Australia’s CPI and converted using the exchange rate from USD to AUD.

[b] Costanza et al. (2014) reported total *global* benefits for each hectare per year, so we only assumed benefits are equal to 1.7% of the total ecosystem service value (i.e., the Australian share of global GDP) (Australian Trade and Investment Commission, 2021).

3.2.5 Attribution to CSIRO and Relative Contribution of the Apps

CSIRO funded the *1622WQ* app at 100% and the *1622WhatIf* app at 71.6%.[8] Therefore, the attribution of benefits to CSIRO is based on these percentages. However, without CSIRO's initial funding of the *1622WhatIf* app, the app would never have been developed in the first place.

As to the relative contribution of the two apps, developing an accurate estimate of benefits is difficult. We hypothesised that the launch of the *1622WQ* app and its adoption by farmers will lead to higher digital literacy among them and pave the way to the rapid adoption of the *1622WhatIf* app when it is developed. Consequently, we assumed that the benefits realised will be, to a large extent, attributable to both apps jointly. However, because *1622WhatIf* is expected to cause larger behavioural changes, we attributed benefits to *1622WQ* and *1622WhatIf* at percentages of 25% and 75%, respectively.

Combining CSIRO's funding share in each app with the relative contribution of the apps, we estimated that CSIRO was responsible for 78.6% of the aggregate benefits achieved by the apps.

3.3 Quantification Approach

In this section, we discuss the quantification of the benefits that are amenable to monetisation. All monetary figures were adjusted for inflation using Australia's consumer price index (CPI) from the year 2015 through 2020.

3.3.1 Baseline Scenario (Counterfactual)

We estimated the impact of the 1622 project by comparing the different impact and adoption scenarios (described below) against the counterfactual, which depicts a business-as-usual (BAU) scenario. In the BAU scenario, the N fertiliser usage continues at historically observed rates, as does the amount of N-based pollutants that are leaked into the catchments adjacent to the GBR and released into the air. Consequently, the BAU also assumes water quality deterioration and coral decline occurring at historically observed rates.

3.3.2 Economic Benefits

Productivity and Efficiency

The direct monetary benefits accruing from the app usage will mostly be cost savings farmers achieve with the potential reduction of their N fertiliser inputs. The value of these annual cost savings was computed as:

$$CostSavings = (P_N * R^S) * (Adopt) \quad (2)$$

where:

[8] CSIRO funded 100% of previous work on the development of *1622WhatIf* but is only estimated to contribute around 50% of funding to its future development efforts. We estimated CSIRO's contribution based on its share of the total amount of funding, both historical and projected.

P_N = price of N fertiliser ($/kg)

R^s = total estimated N reduction (kg)

Adopt = percentage of sugarcane farmers in Queensland using the apps

GBR-Dependent Industries and Coral Cover

The GBR and the industries located around the reef are an important part of Australia's economy, and we expect that the app usage will have indirect benefits on these industries.

The region contributes to the economy through four major industries: tourism, recreation, fishing, and scientific research. A report conducted on behalf of the Great Barrier Reef Foundation estimated the potential economic contributions of these industries in fiscal year (FY) 2015–2016 (O'Mahoney et al., 2017). The industry that sees the highest impacts from the GBR is tourism, which is estimated to add a value of $6.2 billion annually to the economy and provides nearly 58,980 direct and indirect jobs.

Various studies have shown that a decline in coral cover could lead to a decline in people's desire to visit the reef, thus negatively affecting the sector (Kragt et al., 2009; Prideaux et al., 2009; Pendleton, 1994). We expect that reef health continuing to decline could negatively affect the other key industries. However, the use of *1622WQ* and *1622WhatIf* can both lead to a healthier GBR ecosystem.

For this analysis, we assumed that preserving the health and quality of the GBR can help maintain and potentially grow the four major industries.[9] Table 3.5 reports the estimated annual economic contributions of these industries.

Table 3.5. The Annual Economic Contributions of the GBR-Dependent Industries

	Tourism	Recreation	Fishing	Scientific Research	Total
Value added to the economy (2020$ millions)[a]	$6,179.6	$368.6	$172.6	$193.9	**$6,914.8**
Employment (FTE)	58,980	3,281	814	970	**64,045**

[a] These numbers were adjusted for inflation using Australia's CPI from the years 2015 through 2020.

To quantify the value of the apps, we followed a "damages avoided" approach that involved estimating the percentage of the value added of the aforementioned industries that would have been lost with the decline in reef cover in the absence of the apps. To do this, we assumed that the improvement in water quality leads to an equal decline in

[9] We decided not to project an estimated growth in the value added or jobs created because COVID-19 is an external factor that is negatively affecting the economy. It is too soon to see how this externality will affect potential growth.

the adverse impact of COTS on reef cover. Consequently, we estimated the annual damages avoided from the GBR-dependent industries that is attributable to the apps as:

$$DA = (VA * P^s * COTS) * (Adopt) \quad (3)$$

where:

DA = annual damages avoided ($)

VA = annual value added from the four industries (2020 $)

P^s is defined in Eq. 1

COTS = estimated reduction in adverse COTS impacts on the reef

Adopt = percentage of sugarcane farmers in Queensland using the apps

3.3.3 Environmental Benefits

Ecosystem Services and Biodiversity

Stretching across 2,300 km and containing more than 2,900 individual reefs, the GBR is the world's largest coral reef, consisting of 14 unique ecosystems including coral reef, seagrass, estuaries, islands, rainforests, and many others (GBRMPA, 2021a, b; De Valck & Rolfe, 2019; Richards & Day, 2018). The GBR is known for its biodiversity, housing a range of marine life, including micro-organisms, fish, plants, and other animals.[10] The whole region provides valuable ecosystem services such as providing food and habitat, cycling nutrients, protecting the coastline, and fixing carbon (Queensland Museum, n.d.; GBRMPA, 2021b).

For this analysis, we estimated the value of potential improvements in water quality resulting from using the *1622WQ* and *1622WhatIf* apps in terms of the value of the ecosystem services provided by the GBR.[11] We focused on the coral reef and seagrass ecosystems, both of which have been negatively affected by N runoff and used the benefit transfer method based on Constanza et al. (2014), who estimated the global value of ecosystem services. We used Australia's share of global gross domestic product (GDP) (1.7%) to apportion how much of the value of services could be attributed to Australia directly. To be conservative, we also assumed that only 50% of the GBR area will witness improvement from reducing N pollution in catchments.

The annual value of ecosystem services provided due to improvements in water quality was estimated as:

$$ES = (GEV * GDP\% * AEI * P^s * Area) * (Adopt) \quad (4)$$

where:

[10] Biodiversity refers to the range of unique species and the amount of genetic variation. The GBR contains six of the world's seven species of sea turtles, 2,000 species of sponge, 500 species of marine algae, and more than 1,600 species of fish (Queensland Museum, n.d.; GBRMPA, 2021b).
[11] The ecosystem services we included are climate regulation, erosion control, nutrient cycling, habitat/refugia, food production, raw materials, and genetic resources.

ES = value of ecosystem services provided as a result of water quality improvement ($)

GEV = global value of ecosystem services for seagrass and coral in Costanza et al. (2014)

GDP% = Australia's portion of global GDP (1.7%)

AEI = annual rate of the ecosystem improved by the reduction in N runoff and COTS

P^s is defined in Eq. 1

Area = percentage of GBR area that receives improvement (50%)

Adopt = percentage of sugarcane farmers in Queensland using the apps

Reduction in GHG Emissions

The use of N fertiliser, coupled with the warm, wet climate, increases the release of harmful GHGs such as nitrous oxide (N_2O) (Thorburn et al., 2010). Fertilised soil produces more N_2O emissions than unfertilised soil, and roughly 66% of global N_2O emissions come from croplands (Takeda et al., 2021; Denmead, et al., 2010). N_2O has an estimated GWP that is 298 times the potential from CO_2 over a 100-year time frame, which can profoundly affect global warming over the next century (EPA, 2020). Reductions in N fertiliser will, therefore, reduce N_2O emissions and contribute to slowing the catastrophic impacts of climate change.

In this analysis, we estimated the potential emissions reduction from reducing N-based fertiliser application based on impact scenarios described in Table 3.2 and converted the emissions to CO_{2e} using the GWP. The annual reduction in N_2O emissions from using the apps was estimated as follows:

$$N_2O = (Ha * R^s * EF * GWP) * (Adopt) \quad (5)$$

where:

N_2O = reduction in N_2O in kg CO_2 equivalence

Ha = total hectares of sugarcane production

R^s= reduction in N fertiliser application (kg/ha)

EF = emission factor (0.0199)

GWP = global warming potential (298)

Adopt = percentage of sugarcane farmers in Queensland using the apps

3.3.4 Costs

The development of the *1622WQ* app began in FY 2016–2017. After realising the need for a decision and management tool, CSIRO began developing the *1622WhatIf* app in mid-2018 with user testing beginning during 2019. About 50% of the total direct costs went to developing the *1622WQ* app and 15% to *1622WhatIf*. The remaining portion was focused on yield prediction studies. In the next 3 to 4 years, CSIRO plans to invest $200,000 in the development of *1622WhatIf*. Additionally, we estimated that each app will require $5,000 for operation and maintenance every year. The final real, discounted costs attributed to the development and maintenance of both apps at the end of the period of study is **$1.9 million**. This figure is lower than the overall project funding amount (2.15 million) because the proportion of funding that went into developing the *1622WQ* and 1*622WhatIf* apps was 50% and 15% of overall funding, respectively.

4. Prospective Quantitative Impacts

In this section, we report the quantification results of the benefit streams described in the previous section. Unless otherwise stated, the displayed values are for the moderate adoption–medium impact scenario. Results of other scenarios are presented in Appendix B. Note that the values displayed are those that can be attributed to CSIRO's funding of the apps, which is 78.6% of the total values.

4.1 Value of Monetised Benefits

Table 4.1 displays the real, undiscounted values of the project costs and projected benefits during the period 2021–2030 in 2020 dollars. Table 4.2 displays the discounted aggregation of all benefits broken down by benefit streams and scenarios in millions of 2020 dollars. The results indicate that the estimated annual benefits attributed to the 1622 apps are on the order of millions of dollars. Figure 4.1 displays the breakdown of benefits. The cost savings from reduced N fertiliser application contribute the most to aggregate benefits over scenarios and time, followed by ecosystem service values and GBR-dependent industries.

Table 4.1. Undiscounted Project Costs and Benefits at the Moderate Adoption–Medium Impact Scenario, 2021–2030

Year	Costs (2020 $)	Benefits (2020 $)
2021	55,000	
2022	55,000	
2023	55,000	
2024	55,000	
2025	10,000	7,486,571
2026	10,000	9,626,945
2027	10,000	11,813,268
2028	10,000	12,669,552
2029	10,000	13,906,943
2030	10,000	13,907,266
Total	**1,721,854**	**69,410,545**

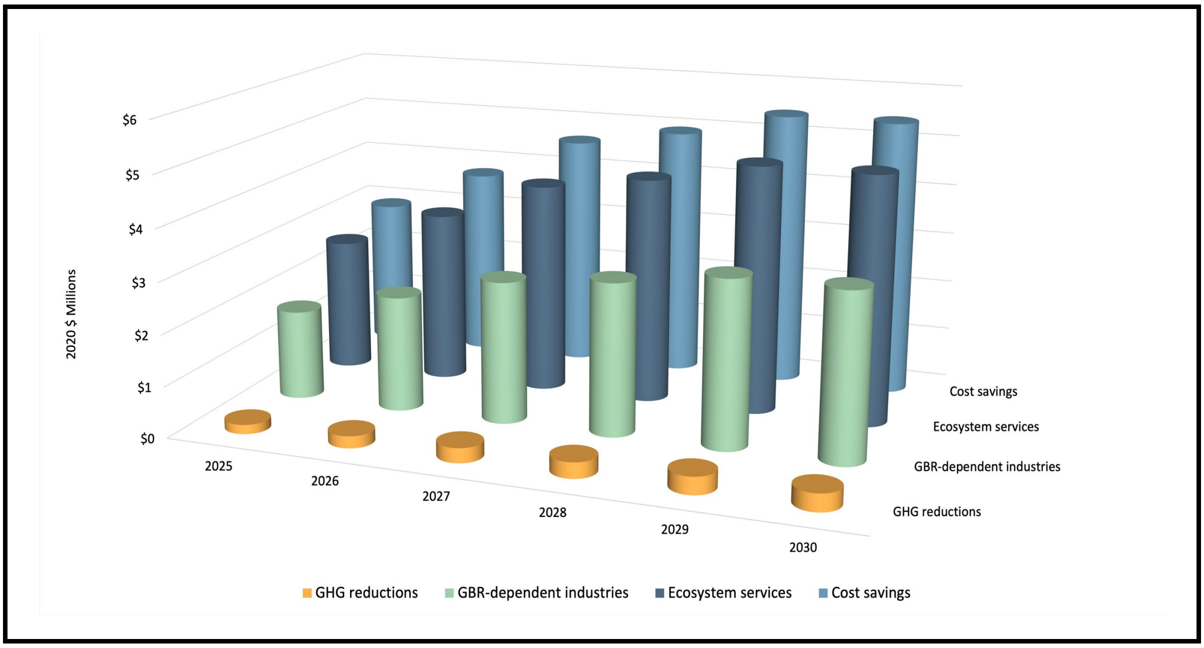
To put the N fertiliser reductions in perspective, we assumed reductions of 15/20/25 kg per ha depending on the impact scenario. N application rates in different parts of Queensland vary depending on whether the crop is a plant or ratoon and on climate and soil conditions, for instance, but they are 160 kg/ha on average, if farmers follow the recommended application rates (State of Queensland, 2016).[12] Using these rates, we estimate that the apps could reduce N application rates by as much as 9% to 16%, with an equal decrease in fertiliser input costs. Given that fertiliser cash costs represent an average of 16% of the total cash costs in sugarcane farms (calculated from ABARES [2018]), this reduced N use is expected to have a positive impact on farm incomes.

Table 4.2. Present Value of Monetised Benefits, 2021–2030 (2020 million $)

Impact	Low Impact			Medium Impact			High Impact		
Adoption	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Fertiliser cost savings	9.1	12.0	14.9	12.1	16.1	19.8	15.1	20.1	24.8
GBR-dependent industries	5.5	7.2	8.9	7.3	9.7	11.9	9.1	12.1	14.9
Ecosystem service values	7.3	9.7	12.0	10.8	14.4	17.8	14.5	19.2	23.7
GHG reductions	0.6	0.8	0.9	0.8	1.0	1.2	0.9	1.3	1.5
Total	22.4	29.7	36.7	31.0	41.1	50.7	39.6	52.6	64.9

NPV was computed using a 7% discount rate in millions of 2020 dollars with a 2020 base year.

Figure 4.1. Breakdown of Real, Undiscounted Benefits by Benefit Stream Over Time, 2025–2030 (2020 million $)



4.2 Marginal Benefits of Impact versus Adoption

Higher impact levels and higher adoption levels both naturally lead to higher aggregate benefits, as shown in Table 4.2 and Table 4.3; therefore, efforts should be made to increase both. To understand the relative importance of each, we plotted the annual, real

[12] Recommended rates are determined by the *Six Easy Steps* Program, which has been developed by Sugar Research Australia and is the current industry standard (State of Queensland, 2016).

aggregate benefits of the low adoption–low impact scenario (baseline) against the moderate adoption–low impact and low adoption–medium impact scenarios to assess whether higher impact or higher adoption leads to more marginal benefits compared with the baseline. We also then used the moderate adoption–medium impact as the baseline and plotted it against the high adoption or high impact to see if the relative importance depends on the baseline level of adoption or impact. The results are displayed in Figure 4.2. Regardless of the starting point, we found that impact has a slightly higher marginal effect on annual benefits compared with adoption. Moreover, the difference in marginal benefits is similar at higher levels of impact.

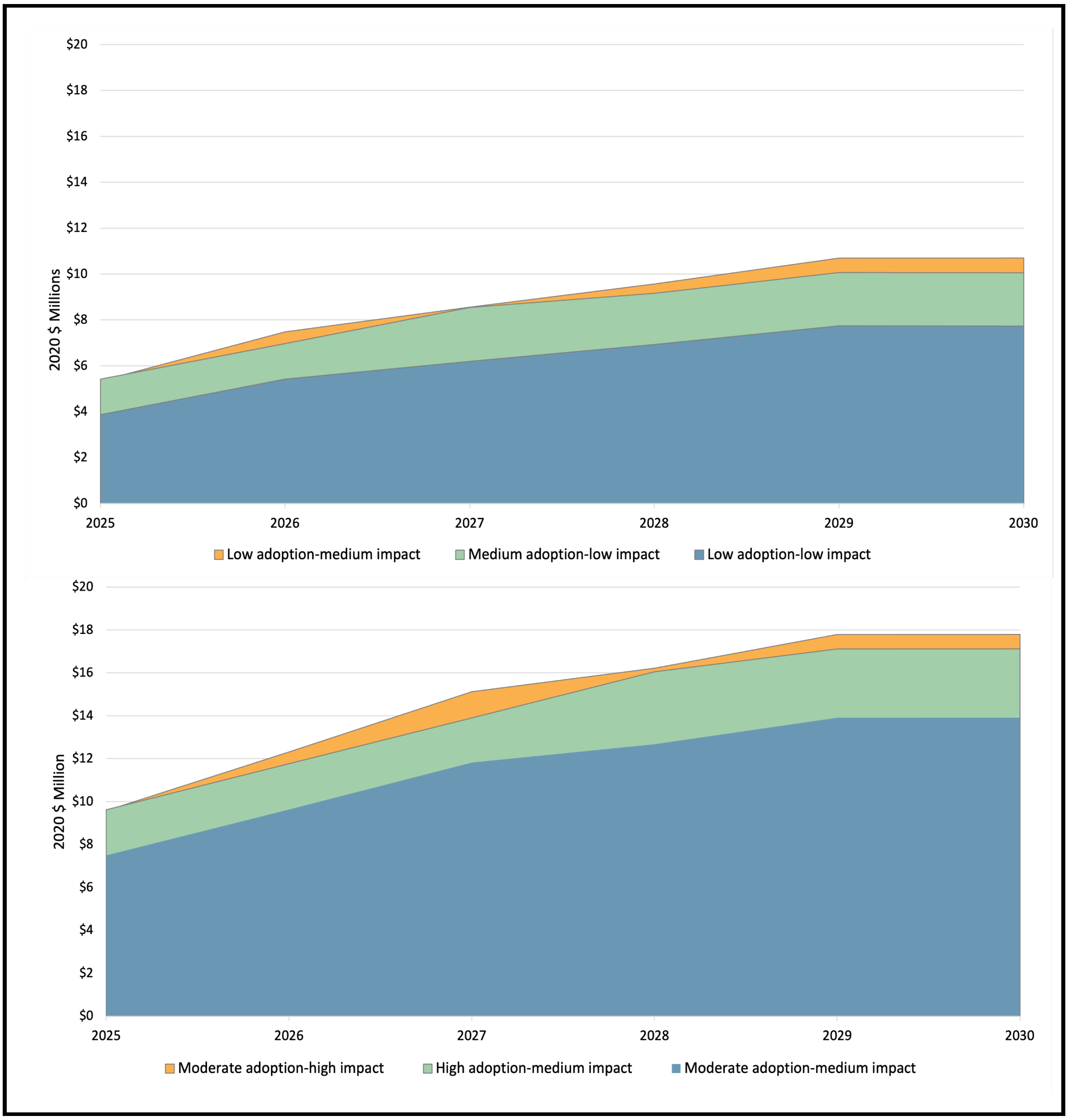
Table 4.3. Reduction in GHG Emissions (2021–2030, kilotons of CO_2 equivalence)

Adoption–Impact	Low	Medium	High
Low	59.9	79.4	97.8
Moderate	79.8	105.8	130.4
High	99.8	132.3	163.1

The defining assumption that differentiates our impact scenarios is the reduction level in N application rates. This differentiating factor thus highlights the significance of maximising impact through higher N efficiency use (NUE), a point stressed by Thorburn et al. (2017) in their study analysing the driving factors of NUE. The authors found that the most influential determinant of NUE was the N fertiliser application rate and that NUE was consistently lower at higher levels of N. Given that farmers often apply more than the recommended values of N fertiliser to avoid the risk of lower yields for a high-value crop like sugarcane, reductions in N caused by the apps may have compounding effects on reducing N pollution through increased NUE at the lower N levels.

As Figure 4.2 shows, increasing adoption levels is also important in achieving higher benefits. Marketing efforts to encourage widespread adoption by promoting the profitability benefits of the apps and potentially integrating the apps as tools for demonstrating N reduction compliance could play a significant role in maximising social benefits.

Figure 4.2. Marginal Benefits of Increased Adoption versus Higher Impact at Low and Moderate Levels of Adoption



4.3 Emissions Reductions

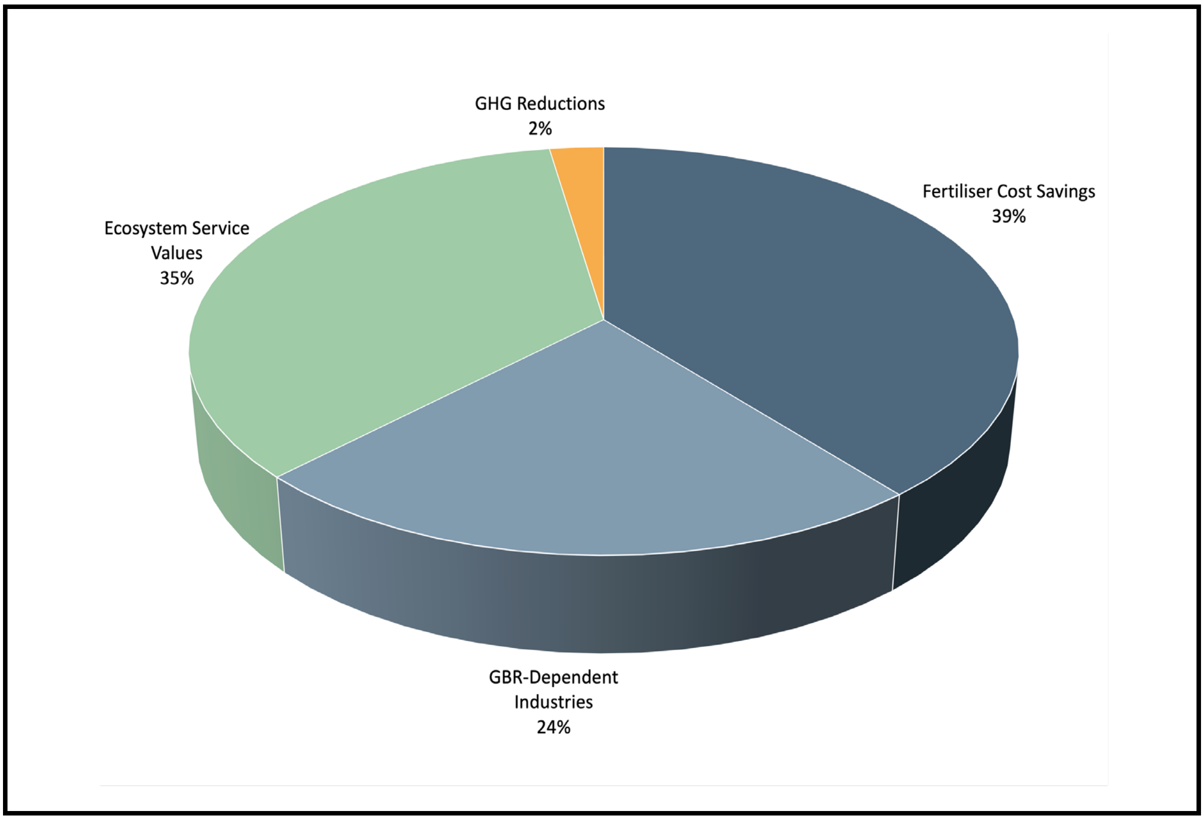
The monetised value of emissions reductions is included in the aggregate benefits values displayed in Table 4.1 and Table 4.2. The reduction amounts of N_2O that underlie these values are displayed in Table 4.3.

Based on the moderate adoption–medium impact scenario, we estimate that use of the apps will remove almost 106 kilotons of CO_2 from the atmosphere over 10 years. This is equivalent to the amount of GHG emissions from 23,000 passenger cars driven for 1 year or approximately 12 million gallons of gasoline consumed (EPA, 2021a).

4.4 Aggregation of Quantitative Benefits

Between 2021 and 2030, the value of total potential discounted benefits ranges from $22.4 to $64.9 million depending on the selection of adoption and impact scenarios. A large portion of the benefits stems from the financial savings that farmers achieve from reducing their N-based fertiliser application, followed closely by the increased value of ecosystem services. Figure 4.3 displays the relative share of the monetised benefit streams in the aggregated discounted benefits between 2021 and 2030 for the moderate adoption–medium impact scenario. We see that fertiliser cost savings account for 39% of all benefits, followed by the value of ecosystem services provided by improved reef cover (35%), the contribution of GBR-dependent industries (24%), and lastly GHG emissions reductions (2%). These aggregate benefits are likely underrepresenting the total potential benefits that can be realised, as we report in the Discussion Section.

Figure 4.3. Share of Different Benefit Streams in Discounted Benefits in the Moderate Adoption–Medium Impact Scenario



4.5 Measures of Economic Return

We quantified three economic performance measures to evaluate the potential return on investment: NPV, BCR, and internal rate of return (IRR). We adjusted all values for inflation using the CPI with a base year of FY 2020–2021. We calculated the present value (PV) using a 7% social discount rate, which represents the minimum rate of return that a public program or investment is expected to generate to be considered an effective use of public funds.

4.5.1 Net Present Value

The NPV is the difference between the PV of benefits and the PV of costs. If the calculation has a positive result, then investing in the project yields a positive social benefit when using a 7% social discount rate.

$$\text{Net Present Value} = \text{PV}(Benefits_{t+1}) - \text{PV}(Costs_t) \quad (6)$$

We calculated a positive NPV ranging from $20.4 to $62.9 million across adoption and impact scenarios and equal to $39.1 million at the moderate adoption–medium impact scenario (Table 4.4).

4.5.2 Benefit-Cost Ratio

To calculate the BCR, we calculated the ratio of the PV of benefits to the PV of costs. Generally, ratios larger than 1 imply that the investment has led to social benefit or gain, as shown in Eq. 7.

$$BCR = PV(Benefits_{t+1}) - PV(Costs_t) \quad (7)$$

For this analysis, we found a BCR ranging from 11.1 to 32.1 across adoption and impact scenarios and equal to 20.3 for the moderate–medium scenario (Table 4.4). One way to interpret the results is by using dollar terms. In other words, for every $1 invested, $20.3 in benefits accrued.

4.5.3 Internal Rate of Return

The IRR is the discount rate at which the PV of benefits is equal to the PV of costs. The return from the investment offsets the opportunity cost of investing when the IRR is larger than the social discount rate (7%). For this analysis, we found an IRR ranging from 43.2% to 61.1% (Table 4.4), all of which are above 7%, meaning that the investment achieved social value.

Table 4.4 Summary of Economic Performance Measures, 2021–2030

Impact	Adoption	NPV (2020 million $)	BCR	IRR
Low	Low	20.37	11.1	43.2%
	Moderate	27.72	14.7	47.9%
	High	34.66	18.1	51.4%
Medium	Low	28.94	15.3	48.4%
	Moderate	39.09	20.3	55.2%
	High	48.69	25.1	56.8%
High	Low	37.59	19.6	52.4%
	Moderate	50.59	26.0	57.4%
	High	62.87	32.1	61.1%

Note: NPV values were computed using a 7% discount rate.

5. Concluding Remarks

Our analysis found that CSIRO’s investment in developing the 1622 water quality apps is projected to have positive net social benefits, as illustrated by the economic performance measures in Table 5.1.

Table 5.1. Summary of Economic Performance Measures for the 1622 Water Quality Apps, 2021–2030

Impact	Adoption	NPV (2020 million $)	BCR	IRR
Low	Low	20.37	11.1	43.2%
	Moderate	27.72	14.7	47.9%
	High	34.66	18.1	51.4%
Medium	Low	28.94	15.3	48.4%
	Moderate	39.09	20.3	55.2%
	High	48.69	25.1	56.8%
High	Low	37.59	19.6	52.4%
	Moderate	50.59	26.0	57.4%
	High	62.87	32.1	61.1%

Our results suggest that higher levels of both impact and adoption increase aggregate benefits, though higher levels of impact have slightly larger marginal benefits than higher adoption scenarios. The main driver of impact scenario differences in our analysis was the reduction in N application due to the app. Therefore, increasing impact levels will depend on the degree to which farmers reduce their N application rates and the adoption of management practices that increase NUE. According to Thorburn et al. (2017), NUE depends on multiple factors and interactions between climate, soil, and crops that vary temporally and spatially. This fact highlights the importance of DSS in guiding farmers to management practices that increase NUE and reinforces the potential value provided by *1622WhatIf*.

As we saw in Section 4, the largest benefits from the apps are in the form of fertiliser cost savings that accrue to farmers. The importance of this result is that when farmers increase their profitability by using the apps, it may incentivise higher adoption levels among growers who had not yet used the apps. Because profitability concerns are often a source of friction between regulators and farmers, using the 1622 apps may reduce this tension and help strike the balance between environmental and social wellbeing on one hand and private profits on the other. Cost savings due to app usage may also demonstrate to a wide sector of workers in the agricultural sector that environmental improvements do not need to come at the expense of reduced profitability.

In addition to the quantitative benefits caused by app usage, we also found multiple qualitative benefits of the project that were not among its main targets but can potentially add significant economic, environmental, and social value.

There is one source of potential overestimation in our analysis for the impact of app usage and multiple reasons for potential underestimation. Overestimation of impacts may arise because we have assumed that a percentage decrease in DIN results is an equal percentage improvement in water quality. As mentioned previously, DIN is one of the main sources of pollution that is adversely affecting the GBR. However, other nutrients, such as phosphorous, and other pollutants, such as fine sediment and pesticides, also contribute to water quality degradation, so the resulting improvement in water quality may be less than that of the percentage decrease in DIN. However, for multiple reasons, our estimates may underestimate the true value of benefits:

- We did not assume any benefits start before 2025, despite the fact that the *1622WQ* app is already in use and may have some impact on motivating reduced N fertiliser use.
- We quantified the ecosystem services of coral reefs and seagrass-algal beds only and not the rest of the GBR ecosystems because these two ecosystems have the highest value services. However, improved water quality may positively affect other ecosystems such as estuaries, and these impacts were not captured in our analysis.
- We assumed that only 50% of the GBR area will benefit from improved water quality and the subsequent increase in ecosystem service values. Because water quality affects the entire coastline, 50% of the area is likely a conservative estimate of the extent to which improved water quality will affect the GBR and its ecosystems.
- Use of the 1622 apps will likely raise digital literacy, which may increase adoption rates beyond our estimates. App usage may also raise environmental awareness in the coastal community, inducing higher levels of N fertiliser reductions, as well as other conservation efforts beyond sugarcane farming. We did not consider either of these potential impacts in our analysis.
- We did not include potential revenue streams that may accrue to CSIRO from commercial use by private advisors and fertiliser retailers in the future. Private advisors, the largest of which is Farmacist, may integrate the *1622WhatIf* app into their IT platforms and potentially pay a fee, albeit small. Fertiliser retailers also provide advising services to farmers and are in increasing need of measurement tools to justify deviations of fertiliser use from recommended levels. *1622WhatIf* is one of the only tools that can provide the objective, quantitative evidence needed under new regulations. Although these revenue streams are not expected to be large, they will nonetheless contribute to covering any operational costs of maintaining the app and would improve our estimated economic performance measures.

Our view is that sources of potential underestimations far outweigh those of potential overestimation. We, therefore, consider our estimates to be a lower bound of the project benefits, and potential benefits are likely much higher in reality.

Currently, the Australian Government, as well as the private sector, is implementing or considering multiple plans and strategies to protect the GBR. One such program is the RCS, which is a market-based solution designed by natural resource management organisations in collaboration with research institutions, industry groups, and regional communities and financially supported by the Queensland Government. This scheme targets water quality improvement by allowing land managers to generate a "reef credit," a tradeable unit of pollutant (nutrient, sediment, pesticides) reduction (Reef Credit, 2021).

The RCS requires robust monitoring and measurement tools to ensure that credited pollution reductions are "real, additional and permanent." Thus, the 1622 apps would be well suited as a tool for demonstrating improved water quality in response to management practices at the farm level. Promoting the tool in this context may lead to having it be listed as an acceptable form of demonstrating compliance with the program rules and showing the required nutrient reductions. This outcome would potentially lead, in turn, to commercial buy-in by advisor and farmer groups that wish to participate in the program. Other programs that require measurement and monitoring are also potential vehicles through which more widespread adoption of the 1622 apps could take place.

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Appendix A: Impacts of Nitrogen Runoff on Coral Reef

One way that increased N runoff directly affects the GBR is through eutrophication. The increase in nutrients can lead to an increase in phytoplankton and algae. An overgrowth of algae can turn into a harmful algal bloom, which can be toxic to humans, animals, and marine organisms (National Oceanic and Atmospheric Administration, n.d.; Hallegraeff et al., 2021). Furthermore, algal blooms can limit the amount of sunlight and oxygen in the water, which slows the growth of the coral (University of Melbourne, 2019). Similarly, an increase in phytoplankton and algae can provide food to marine species that are predators of the coral reef, such as the COTS. N runoff, particularly DIN, into the GBR catchment is one reason that the COTS population ballooned (Fraser et al., 2017). Plankton and algae feed the COTS during their larval stage, leading to a higher percentage of COTS surviving into adulthood (WWF, 2015; Babcock et al., 2016; Queensland Government, 2021; Brodie et al., 2017) (Figure A.1).

The COTS are known for their destruction of the reef. About 42% of the coral reef death has been attributed to COTS (AIMS, 2015) because they feed on the reef. In areas along the reef that are particularly weak (like after coral bleaching), the presence of these starfish prevents coral from healing and expanding. Even though COTS are part of the natural ecosystem, they cause problems when there is an outbreak or overpopulation of them in a section of the reef (Westcott et al., 2020; GBR Foundation, 2021).

Figure A.1. The Relationship Between COTS Outbreaks and N Runoff (WWF, 2015)

Source: Adapted from the WWF (2015) report.

Reducing N runoff from farms will thus help reduce COTS outbreaks before they even start. One of the main goals of the *1622WQ* and 1622*WhatIf* apps is to allow farmers to reduce their N fertiliser inputs and to learn more about their farms' impact on nutrient increases in the GBR. These outcomes can lead to informed management and a reduction in N runoff. Reducing N eutrophication can preserve the GBR's coral cover, leading to a healthier reef ecosystem than what has been occurring in the current situation.

Appendix B: Time Series Adjustment Factors

Table B.1. Inflation Factors

	December Inflation	Inflation Factors
2016	110	1.065
2017	112.1	1.045
2018	114.1	1.027
2019	116.2	1.009
2020	117.2	1.000

Table B.2. Discount Factors

		Benefits		Costs	
	Discount Rate	Discount Period	Discount Factor	Discount Period	Discount Factor
2016	7%			(5)	1.40
2017	7%		1.23	(4)	1.31
2018	7%		1.14	(3)	1.23
2019	7%		1.07	(2)	1.14
2020	7%	0	1.00	(1)	1.07
2021	7%	1	0.93	0	1.00
2022	7%	2	0.87	1	0.93
2023	7%	3	0.82	2	0.87
2024	7%	4	0.76	3	0.82
2025	7%	5	0.71	4	0.76
2026	7%	6	0.67	5	0.71
2027	7%	7	0.62	6	0.67
2028	7%	8	0.58	7	0.62
2029	7%	9	0.54	8	0.58
2030	7%	10	0.51	9	0.54

Table B.3. Real, Undiscounted Project Costs and Benefits at the Lowest and Highest Levels of Adoption and Impact (2021–2030, 2020$ million)

Year	Costs	Benefits* (low adoption–low impact)	Benefits* (high adoption–high impact)
2016	119,681		
2017	430,535		
2018	437,844		
2019	422,924		
2020	30,870		
2021	55,000		
2022	55,000		
2023	55,000		
2024	55,000		
2025	10,000	3,868,682	12,315,951
2026	10,000	5,416,540	15,056,368
2027	10,000	6,190,508	17,794,821
2028	10,000	6,925,555	20,533,559
2029	10,000	7,738,350	21,903,608
2030	10,000	7,738,466	21,904,181
Total	**1,721,854**	**37,878,101**	**109,508,488**

* Benefits indicate CSIRO’s share of the overall benefits of the apps (78.6%).