

INTERNATIONAL REVIEW OF THE GREAT BARRIER REEF CATCHMENT LOADS MONITORING PROGRAM

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Executive Summary

The aim of this international review is to discuss the strengths and limitations of the Great Barrier Reef Catchment Loads Monitoring Program (GBRCLMP) (the Program), respond to the terms of reference and to incorporate these into recommendations that will *enable a more structured development and improvement of* the Program *for the next five to ten years*. The limitations and strengths will be assessed in view of the [Reef 2050 Long-Term Sustainability Plan](#), the [Reef 2050 Water Quality Improvement Plan 2017–2022 \(Reef 2050 WQIP\)](#), [Paddock to Reef Integrated Monitoring, Modelling and Reporting Program - Program design 2018–2022](#) (Paddock to Reef) and the GBRCLMP objectives.

The International Review Panel (the Panel) consisted of Associate Professor Michael Warne (University of Queensland and Coventry University), Professor Rodger Grayson (University of Melbourne) and Dr Mark Landers (United States Geological Survey). The Panel had a broad range of expertise covering all aspects of the Program.

The nine-day review process consisted of:

- reviewing documents provided by GBRCLMP;
- a day of introductory presentations;
- three-days in the field with Program team leaders visiting representative stakeholders and water quality monitoring sites of the Program and associated networks;
- a day of technical presentations from Program staff covering key components of the Program;
- a half-day of detailed discussions with Program leadership on relationships with the larger Paddock to Reef Program and future directions of the Program;
- additional information and clarification were sought through interaction with Program staff; and
- the recommendations were presented to Senior Executive members of the Department of Environment and Science (DES), the University of Queensland and the Queensland Chief Scientist.

The overall impression of the Panel was that the Program was equal or superior to similar international programs of which the Panel are aware.

The Program is probably the largest targeted water quality monitoring program in Australia and has a major impact within the Paddock to Reef Program but has limited national and international presence and influence.

The Panel was very impressed by and strongly supports the following characteristics of the Program:

- the 'esprit de corps' amongst a motivated, talented and thoughtful Program team;
- the outward and problem-solving focus of the Program team;
- the quality of the design, construction and maintenance of the monitoring stations;
- annual training of water quality samplers and the unique multi-stakeholder involvement in collecting samples;
- automating the data processing framework;
- the planning and development of a database and data delivery, communication and interpretation products (e.g., Apps, Dashboards, Pesticide Portal and StoryMaps);
- the extensive engagement that helps deliver broader Paddock to Reef goals of changing management practice and expanding regional capabilities; and
- the innovative pesticide work and its influence on the broader Paddock to Reef Program and government policy.

The Program has experienced rapid expansion since its inception to fill an increasing range of stakeholder needs and desires. While the Program has been very agile and successfully addressed these needs it has now reached a point where a more formal articulation of its priorities and objectives is warranted. These are reflected in the following fifteen recommendations. The recommendations are intended to identify means of improving the Program without being overly prescriptive as the Panel believes it is for the Program to determine the best way to address our recommendations.

Recommendations

1. Develop a Strategic Plan that meets the needs of the Reef 2050 Water Quality Improvement Plan and the Paddock to Reef Integrated Monitoring, Modelling and Reporting (Paddock to Reef) Program and guides interactions with associated programs. This should include:
 - a. short, medium and long-term components;
 - b. the revision of Program goals and objectives to reflect current and future activities;
 - c. defining what work is in and out of scope;
 - d. research and development strategies; and
 - e. flexibility to adapt to future needs and opportunities.
2. The Strategic Plan should include a set of criteria to guide the review of current and future projects and determine if they should be continued, expanded or reduced and the decision recorded. The Plan should outline how to deal with projects that are rejected – e.g., forward to other parts of the Paddock to Reef Program or the Independent Science Panel.
3. Conduct an internal review of current and future workloads to ensure that Program objectives and quality are maintained. The outcome of this should be incorporated into the Strategic Plan.

The Panel is of the opinion that the current balance of workload to human resources is not sustainable. The preceding three recommendations are intended to provide some formal structure around the Program which is large and complex. They are intended to generate a road map for activities and the direction in the Program; not to limit the responsiveness and innovation of the Program to changing needs and opportunities. They will contribute to addressing all the Terms of Reference. The Strategic Plan should be concise and focused so that it is not overly bureaucratic. Its development is an opportunity for the Program to formally articulate its vision and pathways for its realisation.

4. Place a greater emphasis on innovation, research and development in relation to sediment and nutrients (i.e., monitoring, loads calculations, thresholds of impact and water quality targets).

The Program has led considerable innovation and change in terms of pesticides, and it is felt that a re-alignment could yield similar improvements for sediments and nutrients.

5. Ensure that Program data and calculated values are uploaded in a timely manner, publicly discoverable and easily accessible. It is essential this is delivered via a platform that is integrated with the broader data management architecture developed and managed by Water Quality and Investigations.

This will facilitate efficient data dissemination and the provision of Program expertise to stakeholders.

6. Conduct a site-network analysis of all GBRCLMP sites and associated networks. This should identify the purpose of each site, what is being monitored, who is conducting the monitoring and the minimum period needed to meet its purpose. Periodic review of the site-network analysis is required.

This will facilitate an optimal site design and guide future decisions about sites.

7. Identify and communicate with current and potential stakeholders and record their needs and desires of the Program.

This will be valuable for setting and defending Program priorities.

8. Conduct formal meetings with the Paddock to Reef modellers at least annually to ensure alignment between monitoring and modelling needs and to inform future research and development.

9. Release a brief annual summary of the key measurements of the activities, successes and quality control outcomes of the Program.

This will be useful in broadly communicating successes of the Program.

10. Expand the collaboration with universities and other research and development organisations (e.g., co-supervising students and/or collaborating in the development of research funding proposals) to facilitate the analysis of Program data and to address key knowledge gaps/questions.

The Program will benefit from such interactions by accelerating innovation and will raising its profile.

11. Conduct an internal review on how to achieve national and international collaboration that enhances recognition of the Program and accelerates Program innovation. Some strategies to consider include:
 - a. collaborating with other national and international organisations;
 - b. allocating a percentage of staff time to publishing;
 - c. increasing attendance at international conferences; and
 - d. staff exchanges with appropriate Australian and International organisations (e.g., the United States Geological Survey).

The Program is world class but does not have a commensurate level of national and international collaboration and recognition.

12. Develop a prioritised list of key knowledge gaps/questions to be addressed, maintained and disseminated to potential research providers.
13. Allocate more time and effort to analysing the wealth of data generated by the Program. Two high priority issues that should be considered are:
 - a. analysing the temporal trends in suspended solids, nutrients and pesticides. This should include power analysis to indicate the minimum number of years that data sets need to be to detect changes of a certain magnitude. This information should feed back into on-going site-network analysis.
 - b. determine if there are statistically significant relationships between sample-based water quality parameters and outputs from continuous monitoring probes. Such relationships could be used to provide real-time estimates of parameters that usually require laboratory analysis.
14. Conduct concurrent point to cross-section sampling and analysis at each monitoring site where automated point or manual grab samples are collected. Determine how regularly each site should be re-assessed. Include the results as a key reportable quality control measure for each site and the Program.
15. Redefine the frequency at which quality control checks of sampling procedures are conducted and develop minimum conformance criteria (e.g., 'x'% of sites have 'y' QC samples a year and 'z'% of samples meet standards). Examine and report the results for each site and the Program annually. A method for addressing non-conformance should be developed and implemented.

The two preceding recommendations are operational in nature yet are seen to be essential to ensure Program quality.

Review Panel's Responses to the Terms of Reference

- 1. That current monitoring and sampling methods are fit for purpose (i.e., the monitoring Program provides data that meets the Program objectives) and reflect the latest monitoring techniques.***

The equipment used at all GBRCLMP sites including micro-sites is of high quality and appropriate for the conditions at the sites. There is an on-going program of replacing, standardising, and upgrading the sampling equipment.

There is a program of annual training of all people collecting water samples for the Program. For new samplers the training is over two-days and covers both theoretical and practical training. Emphasis is placed on correct procedures for sampling to minimise contamination. This level of training and partnership with stakeholder groups to undertake sampling to professional standards is impressive and possibly unique.

Sampling for the Program is edge-based grab sampling. There is the potential for water quality parameters to vary significantly both vertically and horizontally in the water bodies. The Program has information on the homogeneity/heterogeneity of water quality parameters only for two of the waterbodies sampled. It is recommended (Recommendation 14) that the Program develop a schedule for conducting point to cross section sampling and analysis for each monitoring site used to generate loads. Concurrent samples should be collected for the point (or edge) sample location and for a depth and width integrated sample. The depth and width integrated sampler should be isokinetic to ensure representative sediment size distributions. The concurrent samples should be analysed for sediment size distribution; at least for sand/silt size fractions (i.e., the 32 micron split) and preferably for full size distributions in the initial point-to-cross section sampling work. It is also necessary to determine how regularly each site should be re-assessed. If the Program is only concerned with fine sediments and the first set of point to cross section samples are homogeneous for fine sediments, then subsequent analysis could be conducted using surrogates of fine sediments such as turbidity or total suspended solids equivalents. The comparative sampling should be conducted at bankfull or higher flows if at all possible.

Continue to assess opportunities to leverage the existing monitoring network to address emerging issues. For example, adding additional sensors to existing monitoring sites (e.g., salinity and/or temperature) to add greater value and address stakeholder concerns.

The Program is pursuing innovations in monitoring technologies and methods; and this should continue. However, in the experience of the Panel, these innovations should not be expected to reduce monitoring costs so much as to increase the scope and quality of the monitoring data. The objectives of the Program are expanding and as shown throughout the review, local engagement is critical to the success of the broader objectives of affecting on-ground change. Certainly, there is an opportunity for efficiency gains and streamlining but the increasing demands and expanded scope of issues being dealt with by the Program will quickly fill any freed-up resources.

Where the Program is measuring flow rather than obtaining it from another program, non- contact

surface velocity methods (radar or photographic-based methods) should be investigated. Where GBRCLMP is obtaining flow data from other organisations, the Program should collaborate with those organisations and review their records and methods that are used to compute flow.

Maintenance of the monitoring site network requires regular visits to the regions. The potential of Government directives to minimise the carbon footprint may have implications for the Program in the longer-term. Further innovative arrangements may be required to meet a desire for a reduced carbon footprint without compromising the quality of the Program.

Relevant recommendations for this term of reference (ToR) are Recommendations 6 and 14.

2. The Program's Quality Assurance and Quality Control framework and documents comply with Queensland and/or international standards.

The Program has a comprehensive Quality Control framework that covers many of the key issues relevant to the Program and meets appropriate Queensland, Australian and International Standards. All chemical analyses conducted for the Program are conducted in NATA approved laboratories. NATA approved laboratories conform to accepted QAQC procedures and comply to ISO17025.

Quality assurance and quality control procedures are taught in the annual training of samplers for the Program. The Program has a requirement that a set of QC samples will be collected after every twenty samples. However, this requirement has never been met (*Turner pers. comm.*) and the results of the QC testing and compliance with the QC requirement are not reported. As noted in Recommendation 15 we propose that the Program review the QC requirement and develop a more realistic frequency of sampling that accounts for site-specific variation. The selected frequency should be scientifically defensible, and the justification recorded. In addition, the degree of compliance with the QC requirement should be reported annually.

The Program has a Quality Committee which meets monthly to discuss all issues related to quality. This is attended by the Program leader and Science Leader which indicates the seriousness of this issue. This is a strong component of the Program.

There has been a rapid turnover of Quality Officers with 7 Officers in the last 10 years. This poses a potential concern for continuity and enhancement of QAQC management.

The development of automated techniques for checking all data is a very good development. This is particularly important given the large volumes of data (millions of unique data points) being generated by the Program annually, particularly by the continuous monitoring component. Traditional human conducted quality control procedures would not be possible with such large volumes of data. The automated process will conduct the standard quality control checks and highlight issues for the quality control officer to investigate, saving considerable time and minimising human errors.

Key performance measures of the Program should be reported annually in a brief informatics type document (Recommendation 9).

- 3. That information management is FAIR — findable, accessible, interoperable, and reusable. Specifically, that:**
- a. The data are discoverable and being provided in a format that supports further analysis and interpretation;**

The short answer to this ToR is “not yet, but it should be soon”. At present, information management is not uniformly FAIR across the Program. Some information is easy to find and view while other requires direct contact with the team e.g., the sediment and nutrient loads. Historical loads data are even difficult for Program team members to extract from DARTS – such a situation means this data is far from FAIR.

Over the past few years, the Program has undertaken a major and fundamental reassessment of information management. This has resulted in the development of a new database architecture and suite of data access, communication, and delivery tools. These are tailored for a range of stakeholders, providing different levels of access and functionality.

It is intended that all of the Program’s data (discrete and continuous) and data products (such as calculated loads and risk metrics) will be publicly accessible and downloadable, with links to background documents and QCQA information, completely describing the data. This will include all of the concentration and load data collected by the GBRCLMP along with matching flow data. These platforms will also provide interpretation of the data and become the primary channels through which all of the Program’s output is delivered. Roll out should address criticisms of the Program that information has not always been FAIR.

Some of these tools are publicly accessible now (e.g., GBRCLMP Condition Reports and the Pesticide Reporting Portal). Others are in use by the team and selected partners. For example, the Eagle.io platform enables access to and basic visualisation of, all continuously monitored data as well as quality checked grab sampling results. Varying degrees of access and functionality are available to different stakeholders to satisfy their individual needs. There are also various dashboards under development or in Beta form, to provide more sophisticated visualisation and download capability to a wider audience.

Completion and release of all these elements will be critical to ensuing FAIRness, not only for Program stakeholders but also for a wider audience, including potential collaborators (Recommendation 10).

The basic database architecture is also designed to enable almost complete automation of data management from the field to lab to quality control and error checking, to computation of loads and risk metrics, to storage and retrieval. This will bring significant efficiencies to the Program.

Clearly this is a major undertaking, the completion of which will usher in a new era for access to and interpretation of the Program’s work. It will also provide efficiencies in data handling and QAQC. The Panel understands that the initial roll out will be completed in 2024 and will include access to and download capability of all basic GBRCLMP sediment, nutrient and pesticide concentration data, associated flow, as well as loads and risk metrics. Once this is complete, the primary data and data

products will be FAIR. Ongoing development is expected to further enhance access, communication and interpretation.

The ongoing development and maintenance of this new architecture and associated tools will require considerable resources (financial and personnel). Thoughtful assessment of these needs should be integral to the Strategic Plan development (Recommendations 1 to 3) and will be crucial for ensuring FAIRness of the Program's outputs into the future.

The Panel also notes that development of the new data management infrastructure and associated tools has the potential to be useful to other Paddock to Reef programs. There is an opportunity for all RP projects that conduct water quality monitoring to have their data included. However, there would be cost implications associated with this. It is suggested that the Program discuss means of funding the incorporation of such RP project data with the Reef Program (Chris Johnson and Scott Robinson). The requirement that all RP funded projects that include water quality monitoring include as a task the incorporation of their data and a line item in their budgets is one way that this could be achieved.

A technical issue that the Program will need to consider is the question of "provisional" vs "verified" data. This will be particularly important for access to continuously monitored data. There is some tension between making information available as soon as possible and waiting until all QAQC checks are complete (e.g., flow data collected by other agencies and used by the Program often takes several months to be verified). The Panel sees benefits in the release of well-labelled "provisional" data for reasons of transparency, timeliness and relevance that is later replaced by (again clearly labelled) "verified" information. The Panel believes that while important this is of lower importance than delivering the new architecture and associated tools.

It is important that the metadata associated with the water quality data are also FAIR and that links to the data and quality control documents are maintained in the data architecture and associated tools. These metadata can be particularly valuable for internal data review and quality control.

Recommendation 5 addresses ToR 3a. If it is addressed suitably all GBRCLMP data will be FAIR.

b. There is effective peer-review of outputs and methods developed; and

The peer-review process is consistent with national and international practices. A short summary of the processes is provided below. All publications (internal and external) of methods or results that are authored by members of GBRCLMP must undergo the usual Department of Environment and Science internal publication review process. This requires the draft publication to be reviewed by two referees – at least one of which must be internal. The referees conduct their review as per the normal peer review process of scientific journals. In addition, the internal referee must consider potential implications for the Queensland Government. If the publication is likely to have implications on other parts of DES or the Queensland Government, then relevant representatives are to be forwarded a copy and their input sought. Articles to be published externally go through the normal review process of that organisation.

In 2016 GBRCLMP switched from publishing annual reports of their results to releasing them via

StoryMaps. All the material in the annual StoryMap undergoes the standard DES internal review process. In addition, all data generated by GBRCLMP must pass a thorough internal quality assurance and quality control process.

In ToR 3a the Panel suggests that the Program consider storing and making available data from Reef Program funded projects. To do this, consideration will be required on how this data is to be reviewed. Taking on such a task would be an additional task for the Program which is probably not desirable. An alternative would be to clearly denote the data is not generated by GBRCLMP and to provide links to appropriate QAQC documentation for each RP project.

c. Information and data are provided in accessible and credible published formats.

Prior to 2016 the results of the Program were published in peer reviewed Queensland Government Technical Reports. These reports were distributed to key stakeholders and also publicly available from the web-site of the Queensland Department of Environment and Science (DES). While the reports were readily accessible there was usually a delay of at least 18 months between sampling and release of the reports. The reports were very technical in nature and hence had a limited audience. Articles have also been published in peer-reviewed scientific journals and conference proceedings. These are the traditional formats for releasing scientific information.

As of 2016 annual results of the Program have been released electronically via Story Maps (e.g., [Modelling and monitoring | Reef 2050 Water Quality Improvement Plan \(reefplan.qld.gov.au\)](http://reefplan.qld.gov.au)) for reports and scientific publications. Also, the data goes through QAQC. As data becomes more easily available to public it is important that links to reports and QAQC documents are included to provide credibility.

4. There is active engagement with all relevant stakeholders:

We have interpreted 'all relevant stakeholders' to mean those undertaking monitoring as part of the Program, the broader Paddock to Reef Program and associated projects to whom the Program provides data. Interaction with 'all relevant stakeholders' is a major strength of the Program especially in relation to regional and industry groups. It appears that the Program has focussed its engagement in the regions. Possibly increased engagement with more senior stakeholders (i.e., "up the tree") would provide them with a greater appreciation of the strengths of the Program. Enhanced promotion of the data management and reporting architecture could lead to similar systems being adopted elsewhere.

The training of regional monitoring teams and presentations of locally relevant water quality data to wider stakeholders have been crucial to increasing stakeholder awareness, engagement and willingness to modify land management practices. Program staff have also acted as a bulwark to increase the understanding of water quality, reef science and counter criticisms of reef science.

The presentations have been a particularly effective engagement activity and should continue, although if demands on the Program continue to increase, time allocated to engagement will need to be strategically prioritised (see also Recommendation 7).

As noted in Recommendation 8, there is the opportunity for improved interaction with the Source

Catchment Modelers to deal not only with routine data needs but also current and emerging issues and future directions.

a. Data are made available in a timely manner;

The Panel understands that all data provision deadlines for delivery to relevant stakeholders, particularly the Source Catchment Modellers have been met. Currently only some of the data generated by the Program are available in a timely manner. At present data delivery is achieved by team members preparing specific data requested for stakeholders. This is only partially automated and therefore takes considerable time by the GBRCLMP team. However, the data management architecture that is being developed and should be completed by the end of 2023 with initial roll out in 2024, will greatly facilitate this. Greater detail is provided in the response to ToR 3 and 4. Recommendation 5 addresses this issue.

b. Data are available in an easily accessible format; and

Yes, this is the case, but only when people request the data from the Program. As noted under ToR 4a currently data provision is manually “personalised” so formats are suited to each stakeholder but usually take the form of Excel or CSV worksheets. Ultimately data delivery will be automated and people seeking the data can select its format from a range of formats (Neelamraju *pers. comm.*). Greater detail is provided in the response to ToR 3 and 4. Recommendation 5 addresses this issue.

c. GBRCLMP team expertise is sought and provided to all stakeholders

The expertise of the Program staff is extensively sought by regional partners and industry groups. From discussions with stakeholders it is clear that the Program is identified as the leading agency for water quality monitoring expertise within Queensland. Program staff’s expertise is regularly sought by regional stakeholders who wish to conduct water quality monitoring or wish to interpret water quality data. For example, Program staff are on the Technical Advisory Panels of several regional water quality and ecosystem health report cards and the Great Barrier Reef Foundation. Program staff regularly advise stakeholders on appropriate water quality monitoring equipment, and water quality monitoring site installation and provide advice and standard operating procedures to regional stakeholders. This is a key and highly successful component of the work undertaken by the Program. While there is extremely strong anecdotal evidence that shows the Program excels in this ToR there is no formal evidence of this. With the growth of the Program and the increasing breadth of its stakeholders, it is time for a more formal, strategic analysis of interactions with stakeholders (Recommendation 7). This should ensure alignment with the strategic directions of the Program and help optimise engagement with all stakeholders. Recommendations 7 to 9 would address this and provide evidence of the provision of expertise by the Program.

5. That the GBRCLMP team prioritises future activities to address identified gaps and improvements.

a. future directions and priorities are appropriate and achievable;

It was evident from the interactions between the Program and the Panel that while individual members of the Program had particular pieces of work or projects in their mind to be undertaken in the future there was no overall or formal approach or documentation. For example, a list of key knowledge gaps or research questions was not provided despite the Panel requesting a presentation on these issues. The presentation did not provide sufficient detail to allow the Panel to address this ToR, so the Panel requested further information. A list of future projects was then quickly created by the Program. The Panel had to work backwards from the list of future work to identify the knowledge gaps/research questions. The supplied list of research and development projects seemed appropriate, but it is unlikely that it can all be conducted by the Program alone. Rather, collaboration with other organisations (Recommendation 10) will be required. However, the list of research and development projects did not let the Panel match the knowledge gaps with future projects, nor did it allow the Panel to consider how comprehensive the knowledge gaps and research question analysis had been. The list of future work also did not indicate priorities, timeframes or resource needs. Conducting a knowledge gaps analysis and subsequently developing and maintaining a list of desirable research and development projects is essential and should be included in the Strategic Plan (Recommendation 1).

The lack of a knowledge gaps and research questions analysis may have contributed to the imbalance in development activities related to pesticides compared to sediment and nutrients. Conducting the knowledge gaps analysis and developing a list of potential research and technical projects would assist in achieving Recommendation 4 about rebalancing the program. The Panel supports the previous and proposed research to quantify certain components of measurement and calculation uncertainty.

Addressing Recommendations 1 to 6 and 10 to 13 would all help address this ToR.

6. Where appropriate, the GBRCLMP team provides advice to stakeholders (e.g., the Reef Independent Science Panel) on the following:

- a. emerging methods not currently being used;**
- b. the adequacy of available resources.**

Both part 'a' and 'b' of this ToR will be addressed in the following text. Here we consider 'stakeholders' to be professionals investigating and addressing the goals of the Program at large; rather than the growers and associated organizations in the regions. The Program has an excellent relationship with the Independent Science Panel with regular two-way exchanges of ideas, opportunities, and scientific limitations in the ongoing monitoring and research and development work undertaken. The Program is pursuing innovations in monitoring technologies and methods; and this should continue.

It was not clear to the Panel that the Program proactively provides advice on emerging methods or on the adequacy of available resources. Rather, they do it on an 'as required' basis. The Panel believes that having an explicit list of opportunities and research and development needs would be

advantageous in stakeholder exchanges. This 'living' document will encourage stakeholders to: a) exchange greater information with the Program; (b) identify new monitoring or information needs; (c) contribute to or partner with the Program in prioritising and advancing opportunities and emerging methods; and (d) quantify the resources and timeframes that will be needed to pursue those needs.

This explicit list could be seen as an innovation plan for the Program or as a section of the larger Paddock to Reef research, development and innovation plan. It could address, for example, needs for monitoring related to constituent transport to the sea grass or reef ecosystem, or alternate time scales for monitoring, or new sensors to provide continuous (real time) indicators of constituents of concern, or more detailed information on specific sediment size fraction data.

Each area of research and development should include a description of methods, goals, cost, and staff resources. It should describe the personnel and expertise likely to be needed and whether the staff and expertise is currently available in the Program. It should describe the current availability and status of instrumentation or methods, and characterise where the opportunity lies on the path from research to operation. This will be a valuable improvement to advance the purposes of the Program and the objectives of the greater GBR programs.

It was clear to the Panel that the Program is very aware of their available financial and human resources. This was evident by the fact that while the Program has taken opportunities presented to it to expand they have not done this without putting in appropriate requests for money and staff to permit the work to be successfully undertaken. Examples, of this include the large expansion of the finances and staffing of the Program following the Queensland Auditors review, the Great Barrier Reef Water Science Taskforce and seeking funding for an Enhanced Pesticide Monitoring Program. Employing additional staff for expansions has been problematic due to the Queensland Public Service's cap on staff numbers, but the Program has developed innovative ways to overcome this.

Recommendations that are relevant to this ToR are 1 to 3 and 7.

7. The quality of the GBRCLMP compared to other national / international programs undertaking similar work;

The overall quality of the Program is very high. The water quality monitoring and quality assurance and quality control procedures, with the exception of the lack of point to cross section analysis (which is addressed by Recommendation 14) is very good and comparable to similar programs that the Panel are aware of in the USA and Canada. The quality of the water quality monitoring site installations is excellent and on par with the United States Geological Survey. The Program has some truly innovative components such as: its relationships with the multiple stakeholders (organisations and individuals) that collect high quality data; the annual training of sample collectors; engagement with regional stakeholders including a number of traditional owner groups; and the developments relating to pesticides (i.e., the change of the pesticide reduction target from loads, to toxic loads to percent of species protected, and the development of the method for estimating and predicting the toxicity of mixtures of pesticides). Access to the Program's data has not been good, it requires stakeholders

making a request to the Program staff, but the Program is well underway in developing and implementing a data management system. Based on presentations of the data management system it is expected that the data accessibility will be world class by the end of 2024. The Panel strongly supports the development and implementation of this data management system (Recommendation 5).

The Program has expanded dramatically over ten years in a very organic manner, modifying itself to take advantage of opportunities and to address gaps in the overall Paddock to Reef program. It has done this very successfully but given its size, the Panel feels that a more structured approach would have numerous benefits that will further enhance the success of the Program. Recommendations 1 to 3 and 6 provide guidance on how to achieve this.

The Program should review stream flow records used in loads calculations including issues such as are the providers of flow data complying with appropriate QAQC; and ensuring flow data complies with appropriate national and international standards (e.g., a verifiable rating curve).

Integration and interaction with other Australian and International monitoring networks is very limited and the Program would benefit from greater interaction. Such interaction and sharing of the expertise of the Program staff could also be of great benefit to other jurisdictions – particularly those in the tropics with reefs. The focus of the Program is protecting the Great Barrier Reef and its ecosystems. It is therefore not surprising that the Program is very Reef centric and colloquial. Recommendations 10 to 12 address these issues.

8. The GBRCLMP's international relevance / standing / reputation

It is difficult for the Panel to answer this definitively, but it is our sense that the national and international standing and reputation of the Program is not where it should be given its size, scope and duration. Related to this, the number of publications is not extensive for a program of its size and has tended to focus on Queensland Government technical reports (grey literature). This may reflect a focus on meeting internal stakeholder needs, the rapid development and expansion of the Program and the extensive communication, interpretation, and engagement work that the Program has undertaken. It appears to the Panel that publishing and external promotion has not been an important component of the Program. The Panel has recommended that a review be conducted to determine how to increase the national and international profile of the Program (Recommendation 11). Other recommendations made by the Panel (i.e., Recommendations 9 and 10) could potentially increase the national and international reputation of the Program. Greater national and international recognition will strengthen the ability of the Program to meet its aims by encouraging research and developing partnerships that will add value to the information collected, accelerate innovation and resolve knowledge gaps.

9. The adequacy and suitability of local / national / international interactions.

The Program has very extensive and frequent interactions at the local and regional scale (i.e., within the Great Barrier Reef Catchment Area). This is illustrated by the GBRCLMP engagement with the

Major Integrated Projects (MIPs), agronomists such as Farmacist and the Herbert Cane Productivity Service Limited (HCPSL), industry groups including Tully Sugar Mill, Cane Growers and the Australian Banana Growers Council, the numerous stakeholders (e.g., individuals, NRM, NGO and Traditional Owner groups) who collect water samples for the Program and research organisations including the University of Queensland (UQ), James Cook University (JCU), the Queensland University of Technology (QUT), Australian National University (ANU) and CSIRO.

Interaction at the national or international level is limited. The lack of national interaction reflects the general paucity of long-term and/or large-scale water quality monitoring being undertaken in Australia. The GBRCLMP is working with CSIRO and the Australian Department of Agriculture, Water and Environment to derive water quality guidelines for toxicants (i.e., pesticides used in Queensland agriculture and detected in Queensland waterways). It has also commenced discussions with the New South Wales Environment Protection Authority on water quality monitoring and implementing the pesticide risk metric.

International interactions are very limited. This consists of Program members attending the semi-annual International Land Use and Water Quality conference held in Europe, international conferences of the Society of Environmental Toxicology and Chemistry and the International Rivers Symposium. It has also included using international scientists as referees for Program publications. This International Review may be a catalyst for expanding international collaboration. Recommendations 10 and 11 are directly relevant to this ToR and when addressed should improve interaction at the national and international level, while Recommendation 7 should facilitate local interaction.

Program Responses to the Recommendations

Recommendations 1 to 3 – Develop a Strategic Plan that meets the needs of the Reef 2050 Water Quality Improvement Plan and the Paddock to Reef Integrated Monitoring, Modelling and Reporting (Paddock to Reef) Program and guides interactions with associated programs.

We agree with these recommendations.

The GBRCLMP has evolved over many years, and the size and scope (See Appendix) of the Program has increased dramatically since the Reef Water Quality Taskforce recommended expansion in 2016. As a consequence of this increase in scope, the workload of the GBRCLMP, and Water Quality & Investigations more broadly, is more diverse than the original work unit could manage effectively. Since June 2023, the GBRCLMP has established a collaborative model for shared delivery of the GBRCLMP through a Consortium* of organisations. A strategic directions workshop to be held by the Consortium in April 2024 will define the requirements of a Strategic Plan for the GBRCLMP. It is envisaged that the Strategic Plan will be completed by July 2024 and will be made publicly available shortly thereafter. The GBRCLMP strategic plan will be incorporated into the Paddock to Reef program design as part of a review in 2024-2025.

Recommendation 4 – Place a greater emphasis on innovation, research and development in relation to sediment and nutrients.

We agree with this recommendation.

The Program acknowledges that some of the momentum characteristic of the Program's pesticide risk reporting, has not been replicated in the nutrient/sediment reporting. Building on recent innovations in the collection and curation of near real-time water quality data, and the collaborative research capacity at the University of Queensland and James Cook University, the Program will investigate methods to evaluate and communicate environmental risk associated with sediments and nitrates. Priorities and time frames will be established during a strategic workshop to be held in April 2024.

Recommendation 5 – Ensure that Program data and calculated values are uploaded in a timely manner, publicly discoverable and easily accessible.

We agree with this recommendation.

Considerable progress has been made in responding to this recommendation. A Microsoft Azure-based data management platform has been developed for the needs of the GBRCLMP and several custom-built applications for the dissemination of those data are currently under development. These will be completed before the end of 2024. When these developments are completed, all the data generated by the Program, including raw concentration data, calculated loads and Pesticide Risk Metric data, will be freely available and easily accessible. Importantly, these developments will satisfy:

- The Queensland Government commitment to an Open Data Policy; and
- The Queensland Government commitment to address Recommendation 2 of the Senate Inquiry - Identification of leading practices in ensuring evidence-based regulation of farm practices that impact water quality outcomes in the Great Barrier Reef. Specifically, the inquiry recommended that 'the Australian and Queensland governments improve consultation, information, accessibility and transparency of data used to inform the findings of the Paddock to the Reef Integrated Monitoring, Modelling and Reporting Program'.

Recommendation 6 – Conduct a site-network analysis of all GBRCLMP sites and associated networks.

We agree with this recommendation.

Currently there are more than 100 water quality monitoring sites in the Program. The Program will document and make publicly available the location, driver(s) and intended lifespans of each site. This will involve consultation with relevant stakeholders. Priorities and time frames for this will be established during a strategic directions workshop to be held in April 2024.

Recommendation 7 – Identify and communicate with current and potential stakeholders and record their needs and desires of the Program.

We agree with this recommendation.

This recommendation will be completed as part of the development of Strategic Plan encompassed by recommendations 1 to 3. In anticipation of the need to better understand or stakeholders' data-needs, representatives of various Government and non-Government agencies were asked in early 2023 to complete a survey to gain a better understanding of their needs and expectations of the Program. The results of that survey will be documented in 2024 and form part of the response to this recommendation.

Recommendation 8 – Conduct formal meetings with the Paddock to Reef modellers at least annually to ensure alignment between monitoring and modelling needs and to inform future research and development.

We agree with this recommendation.

Both the modelling and monitoring programs of Paddock to Reef would benefit from an increased formal communication. The first of these meetings occurred in February 2023. At that meeting there was agreement that regular meetings should occur at a regional level (i.e., with modellers responsible for individual regions) and less frequent meetings (i.e., biennially) would include all modellers and Water Quality & Investigations. Following this advice, we will establish a timetable for consultative engagement that will be included in the Strategic Plan (see our response to recommendations 1 to 3). The role of the universities that are part of the Consortium* in these meetings will be explored in the strategic workshop to be held in April 2024.

Recommendation 9 – Release a brief annual summary of the key measurements of the activities, successes and quality control outcomes of the Program.

We agree with this recommendation.

It is anticipated that the data required to generate an annual report on the activities of the program will be housed within the Microsoft Azure data management platform. Exactly how these data can be communicated to stakeholders, and the timeframes in which it can be achieved, will be explored as part of a strategic directions workshop to be held in April 2024.

Recommendations 10 and 11:

- Expand the collaboration with universities and other research and development organisations to facilitate the analysis of Program data and to address key knowledge gaps/questions.
- Conduct an internal review on how to achieve national and international collaboration that enhances recognition of the Program and accelerates Program innovation.

We agree with these recommendations.

The Program recognises the value of collaborations with universities and other research organisations. In responding to this review Water Quality & Investigations has established a Consortium* with two universities for the joint delivery of the program. This will facilitate the conduct of priority research and enhance the recognition of the program. A strategic directions workshop to be held in April 2024 will explore ways to capitalise on the research potential of the universities and other research organisations to explore key knowledge gaps/questions (see recommendation 12) and increase the Program's interactions with the National and International scientific community.

Recommendation 12 – Develop a prioritised list of key knowledge gaps/questions to be addressed, maintained and disseminated to potential research providers.

We agree with this recommendation.

In conjunction with university partners (i.e., the Consortium*), the Program will collate and prioritise a list of key knowledge gaps/questions that will be addressed. This is likely to be an ongoing process reflecting changes in scientific knowledge. An initial prioritised list of key knowledge gaps that can be feasibly explored by the Consortium* before July 2026 will be documented in 2024.

Recommendation 13 – Allocate more time and effort to analysing the wealth of data generated by the Program.

We agree with this recommendation.

The two priority research areas fall within the scope of existing university collaborations (i.e. the Consortium*). The first of these activities, an analysis of temporal trends, is currently listed as an objective of the program. Some research on temporal trends has already been conducted and published:

- Warne MStJ, Turner RDR, Davis AM, Smith R, Huang A. (2022) Temporal variation of imidacloprid concentration and risk in waterways discharging to the Great Barrier Reef and potential causes. *Sci Total Environ.* 1;823:153556. doi: 10.1016/j.scitotenv.2022.153556.
- Taucare G, Bignert A, Kaserzon S, Thai P, Mann RM, Gallen C, Mueller J. (2022) Detecting long temporal trends of photosystem II herbicides (PSII) in the Great Barrier Reef lagoon. *Mar Pollut Bull.* 177:113490. doi: 10.1016/j.marpolbul.2022.113490.

In 2023, an honours student working with Dr Michael Warne and Dr Ryan Turner in 2023 further examined temporal trends in imidacloprid concentrations and diuron concentrations. In addition exploration of hyperspectral analysis of in situ measurements were also investigated.

- Are Pesticides Concentrations Increasing or Decreasing in Waterways that Discharge to the Great Barrier Reef Lagoon? (Heinrich Rass, 2023) Supervised by Associate Professor Michael Warne, Dr. Ryan Turner, and Dr. Alan Huang.

The second research area (determine if there are statistically significant relationships between sample-based water quality parameters and outputs from continuous monitoring probes) has also commenced with an honours student in 2023. This was very promising and further research is warranted. Both these recommended activities will be explored further as part of the strategic directions workshop to be held in April 2024, and included in the prioritised list of key knowledge gaps (recommendation 12).

- Using hyperspectral data to predict pollutants in GBR catchments (Water Fingerprinting) (Cheuk Yat NG, 2023) Supervised by Dr Ryan Turner, Assoc. Prof. Michael Warne, Dr Daniel Livsey and Dr Alan Huang.

Recommendation 14 – Conduct concurrent point to cross-section sampling and analysis at each monitoring site where automated point or manual grab samples are collected. Determine how regularly each site should be re-assessed. Include the results as a key reportable quality control measure for each site and the Program.

We agree in-principle with this recommendation.

This is currently an acknowledged limitation of the Program. Ideally the program would conduct cross sectional sampling at different flow regimes at each site to determine any required adjustment. Enacting this recommendation is constrained by resourcing and safety considerations.

As an alternate approach, work has begun on validating the use of Acoustic Doppler Current Profilers (ADCP's) to capture the required cross-sectional data. This method utilises one of the secondary outputs of the ADCPs (acoustic back-scatter), in combination with vertical turbidity profiles. This allows the computation of the ratio between mean cross sectional TSS and point based TSS concentrations. The data required for this method can be collected via a remotely operated vessel, removing the risk of staff conducting boat work during high flows, and greatly reducing the operational requirements of the task. Once the method has been finalised, it is expected that the application of it would still be a significant body of work, both initially and in an ongoing capacity, to ensure the currency of the computed ratios. The program's capacity to complete this work will be explored as part of the strategic directions workshop to be held in April 2024.

Recommendations 15 – Redefine the frequency at which quality control checks of sampling procedures are conducted and develop minimum conformance criteria (e.g., 'x'% of sites have 'y' QC samples a year and 'z'% of samples meet standards). Examine and report the results for each site and the Program annually. A method for addressing non-conformance should be developed and implemented.

We agree in-principle with this recommendation.

The Program is committed to a re-assessment of the QA/QC requirements of the Program in order to determine what is achievable and necessary, and to adjust the requirement set out in the Quality Management System. How best to address this recommendation will be discussed as part of the strategic directions workshop to be held in April 2024.

* The Consortium currently includes Water Quality & Investigations in the Department of Environment, Science & Innovation, the Reef Catchment Science Partnership in the University of Queensland and TropWater in James Cook University.

Appendix - Increase in Program scope since 2015

1. Rapid expansion in the number of nutrient and sediment loads validation sites;
2. Development of pesticide risk assessment sciences
 - a. Derivation of pesticide guidelines for ecosystem protection,
 - b. Development of the Pesticide Risk Metric,
 - c. Development of the Pesticide Risk Baseline,
 - d. Implementation of Pesticide Risk Metric on behalf of external organisation (i.e. GBRMPA Marine Monitoring Program, Wet Tropics Regional Report Card and Mackay Whitsunday Regional Report card) and Reef Water Quality Report Card.
3. Rapid expansion in the number of pesticide sampling sites for the calculation of Pesticide Risk Metric (PRM)
 - a. Expansion into banana catchments,
 - b. Expansion into mixed horticulture catchments,
 - c. Expansion to create PRM calibration sites.
4. Introduction of, and rapid expansion in, the number of sites reporting near real-time nitrate and TSS_{eq} data using Trios nitrate probes.
5. Proof of Concept deployment of ADCP to estimate particle size distributions in waterways.
6. Commitment to Reef Water Quality Program projects, including
 - a. RP144C - Sub-catchment Water Quality Monitoring for Pesticides in the Plane Basin (Sandy Creek),
 - b. RP167C - Sandy Creek – on-farm change for water quality improvement,
 - c. RP232 Fine scale water quality monitoring in high priority catchments,
 - d. RP246 Cape York Water Quality Monitoring project.
7. Greater involvement in external programs
 - a. Technical Working Group for Major Integrated Projects,
 - b. Technical Working Group for two regional report cards,
 - c. Collaboration with Farmacist – e.g. Project Bluewater,
 - d. CSIRO eDNA project,
 - e. Ongoing involvement with Sandy Creek Project – e.g. assist with pesticide analyses and dissemination of data, information and knowledge.
8. Development of an integrated data management system to better manage larger quantities of data
 - a. Development of an Azure data platform to ingest and disseminate all water quality and calculated data,
 - b. Development of a Microsoft Power Apps field App and associated office App to eliminate paper records and risks of transcription errors ,
 - c. Development of a loads calculation tool (ReLo),
 - d. Development of a publicly accessible data portal (Tahbil).
9. Development of monitoring-site management systems using Eagle IO.
10. Development of information sharing platforms
 - a. Annual Condition Report – Story Maps,
 - b. Pesticide Reporting Portal,
 - c. Pesticide Risk Metric Dashboard,
 - d. Sediment and Nutrient Loads Dashboard (in development),
 - e. Real-time nitrate dashboard (in development).
11. Increased collaboration with external organisations:
 - a. Collaboration with CSIRO to develop the 1622 real-time data platform,
 - b. Collaboration with CSIRO eDNA citizen science project,
 - c. Collaboration with QUT in Australian Research Linkage Grant to develop anomaly detection algorithms in real-time data,
 - d. Collaboration with ANU to explore uncertainty in loads calculations ,
 - e. Collaboration with the BOM in the development of flow models for ungauged catchments,
 - f. Collaboration with various external organisations in the development of new real-time sensing equipment,
 - g. Increased participation in Reef Science Forums,
 - h. Increased participation in various science communication forums – usually at the request of external organisations and often occurring in regional locations.