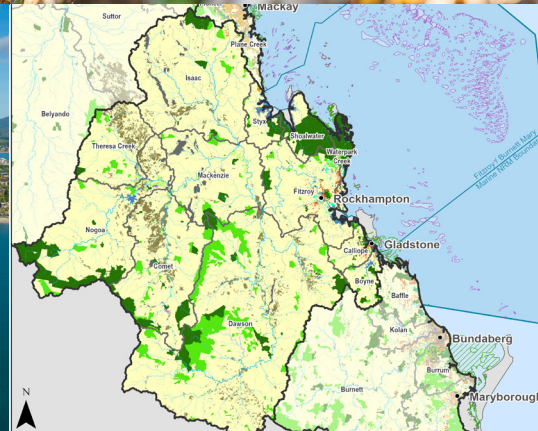




Decision support framework for management options to maintain and improve water quality in the Great Barrier Reef catchment area

Analysis of key spatial factors impacting water quality and the condition of wetlands, corals and seagrass in the Great Barrier Reef



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Note: The first version of this report (Version 1.2) was released in November 2025. Version 2.0 contains the following revisions: Adjustments to the copyright attribution to remove reference to the Queensland Government (as agreed between DCCEEW and the Queensland Government - DETSI) and associated amendments in the Reference list; corrections to Section 2.2.2 and Appendix 2 Table 8 to clarify terminology including amendment of wording from 'wetland loss' to 'wetland loss and modification', and specific reference to 'natural unmodified wetlands' when comparing current and historical extent; corrections to Section 2.2.4 and Appendix 2 Table 11 gully density figures for the Belyando catchment (and associated regional interpretation); amendments to Table 26 to improve clarity following review of associated communication products by DETSI, and ensure the need to validate the wetland hazard assessment is referred to consistently; recognition of updated pollutant load information (Catchment model V3.0) which has been incorporated into the associated Catchment Profiles; and replacement of the Catchment Profile example in Section 7.4.

Acronyms and abbreviations

ACA	Aquatic Conservation Assessment
ADOPT	Adoption and Diffusion Outcome Prediction Tool
AIMS	Australian Institute of Marine Science
ALUMC	Australian Land Use Management Classification
APVMA	Australian Pesticides and Veterinary Medicines Authority
Anth.	Anthropogenic
AquaBAMM	Aquatic Biodiversity Assessment and Mapping Method
Chl- <i>a</i>	Chlorophyll <i>a</i>
COTS	Crown-of-thorns starfish
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAF	Queensland Department of Agriculture and Fisheries
DCCEEW	Australian Government Department of Climate Change, Energy, the Environment and Water
dd	Decimal degree
DETSI	Queensland Department of the Environment, Tourism, Science and Innovation
DIN	Dissolved Inorganic Nitrogen
EEF	Enhanced Efficiency Fertiliser
EoC	End-of-Catchment
GBR	Great Barrier Reef
GBRCA	Great Barrier Reef Catchment Area
GBRCLMP	Great Barrier Reef Catchment Loads Monitoring Program
GBRF	Great Barrier Reef Foundation
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GIS	Geographic Information Systems
Ha	Hectare
HVHCV	High and/or Very High Conservation Value
IPM	Integrated Pest Management
ISP	Reef 2050 Water Quality Improvement Plan Independent Science Panel
JCU	James Cook University
Koc	Soil Absorption Coefficient
LCAT	Land Condition Assessment Tool
LUCTOR	Land Use Crop Technical coefficient generatOR
MCL	Maintain Current Loads
MERI	Monitoring, Evaluation, Reporting and Improvement
MLA	Meat and Livestock Australia
MMP	Marine Monitoring Program
Ms-PAF	multisubstance-Potentially Affected Fraction
MU	Management Unit
N	Nitrogen
NA	Not available
N/A	Not applicable
ND	No data
NESP	National Environmental Science Program
NQ	North Queensland
NRM	Natural Resource Management
NTU	Nephelometric Turbidity Unit
NUE	Nitrogen Use Efficiency
OGBRWH	Office of the Great Barrier Reef & World Heritage (Part of DETSI, Queensland Government)
P	Phosphorus
P2R	Paddock to Reef program
PAF	Potentially Affected Fraction
PAH	Polycyclic Aromatic Hydrocarbons
PFAS	Per- and Polyfluoroalkyl Substances

PN	Particulate Nitrogen
POP	Persistent Organic Pollutants
PP	Particulate Phosphorus
PRM	Pesticide Risk Metric
PSII	Photosystem II
PVPCP	Pharmaceutical, Veterinary Products and Personal Care Products
QLUMP	Queensland Land Use Mapping Program
SCS	Scientific Consensus Statement
SLATS	Queensland Statewide Landcover and Trees Study
STP	Sewage Treatment Plant
TSS	Total Suspended Sediments
TUMRA	Traditional Use of Marine Resources Agreements
UWSF	Urban Water Stewardship Framework
WQIP	Reef 2050 Water Quality Improvement Plan
WQT	Water Quality Targets

Glossary

The following definitions are adopted in the project. Where possible, these are aligned with the definitions used in the [2022 Scientific Consensus Statement \(SCS\)](#).

Basin: There are 35 basins that drain into the Great Barrier Reef. A basin can be made up of a single or multiple rivers (e.g. North and South Johnstone rivers belong to one basin, the Johnstone Basin). Basins are primarily used here when discussing the relative delivery of a pollutant to the marine system. *See table below for links between Natural Resource Management regions, Basins and Management Units.*

Coastal ecosystems: Coastal freshwater wetlands and estuarine systems connect the land and sea and have the potential to influence the health and resilience of the Great Barrier Reef. This includes the Great Barrier Reef catchment and 10% of the Reef waters seawards of the coastline (Great Barrier Reef Marine Park Authority 2012). The risk assessment in this report specifically includes floodplain wetlands (vegetated swamps and lakes), in line with the scope of the Reef 2050 Water Quality Improvement Plan.

Ecological risk assessment: The process of determining the nature and likelihood of effect of anthropogenic actions on animals, plants and the environment (SETAC 1997; US EPA 1998). It is a systematic process for estimating the likelihood of occurrence (or probability) and the severity of the consequences (or magnitude) of the effects of human actions or natural events on ecosystems of ecological value and their sustainability (modified from Hart et al. 2005).

Ecosystem health: Ecosystem health is defined here as the state or condition of an ecosystem in which its dynamic attributes are expressed within normal ranges of activity relative to its ecological stage of development.

eReefs marine model: eReefs is a platform developed by CSIRO that provides a picture of what is currently happening on the reef, and what will likely happen in the future. The eReefs regional and relocatable marine models include hydrodynamic, sediment, wave and biogeochemistry models for the Great Barrier Reef ecosystem¹.

Floodplains: Floodplains are areas of land that are subject to inundation by floods up to and including the probable maximum flood event – that is flood-prone land².

Freshwater floodplain wetlands: Palustrine and lacustrine wetlands located on floodplains and characterised by regular or intermittent inundation from a river's overbank flow and associated geomorphological features.

Groundcover: Ground cover is the vegetation (living and dead) and biological crusts that are in contact with the soil surface. Groundcover includes both green (i.e. photosynthetic vegetation) and non-green (i.e. non-photosynthetic dry vegetation and plant litter) areas³.

Hazard: A situation that poses a level of pressure or threat to ecosystem health.

Management unit: There are 48 management units in the Great Barrier Reef catchment, which incorporate the 35 basins that drain directly to the Great Barrier Reef and internal catchments or management units within the Burdekin, Fitzroy and Herbert basins. *See table below for links between Natural Resource Management regions, Basins and Management units.*

Other pollutants: As per the definition adopted in the 2022 Scientific Consensus Statement:

- Metals (and metalloids): consisting of arsenic (As), cadmium (Cd), cobalt (Co), copper (Cu), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se), antimony (Sb) and zinc (Zn). Excludes

¹ [eReefs models | CSIRO](#)

² [Flood terms and definitions | Queensland Reconstruction Authority](#)

³ [Ground cover explained | Queensland Government Statewide monitoring and mapping](#)

tributyltin (TBT) as this is not considered to be terrestrially derived. Iron is also excluded as it is not considered to be a pollutant despite concentrations being intrinsically linked to land use.

- Persistent Organic Pollutants (POPs): includes oils, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), dioxins and hexachlorobenzene (HCB). Excludes organochlorines.
- Per- and poly-fluoroalkyl substances (PFAS/PFOS) and fire retardants.
- Coal and fly ash.
- Plastics: including microplastics and fibres.
- Pharmaceuticals, veterinary products and personal health care products (PVPCPs): also includes antibiotics, veterinary products, hormones and endocrine disrupting contaminants.
- Sunscreen.

Pesticides: Herbicides, insecticides and fungicides.

Pollutants: Suspended (fine) land-derived (or terrigenous) sediments, nutrients (nitrogen, phosphorus) and pesticides are referred to as ‘pollutants’ in this report. In this situation we explicitly mean enhanced concentrations of, or exposures to, these pollutants which are (directly or indirectly) derived from human activities in the Great Barrier Reef ecosystem or adjoining systems (e.g. river catchments). Fine sediments and nutrients naturally occur in the environment; all living things in ecosystems of the Great Barrier Reef require nutrients, and many have evolved to live in or on terrigenous sediment. Pesticides do not naturally occur in the environment. The natural concentrations of sediments and nutrients in Great Barrier Reef waters and inflowing rivers can vary, at least episodically, over considerable ranges. Pollution occurs when human activities introduce pesticides or raise ambient levels of fine sediments and/or nutrients (time averages, or event-related) to concentrations that cause environmental harm and changes to the physical structure, biological communities and biological functions of the ecosystem. *[Note: This definition was adopted in the 2013 Risk Assessment and was identified by the ISP as the preferred definition for pollutants at their meeting on 12 March 2024].*

Region: There are six natural resource management (NRM) regions covering the Great Barrier Reef catchments. Each region groups and represents catchments with similar climate and bioregional settings, with boundaries extending into the adjacent marine area. The regions are Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary. *See table below for links between Natural Resource Management regions, Basins and Management Units.*

Sub-catchment: Sub-catchments are smaller areas within a catchment that also contribute to the overall flow of water within the larger system. They are typically defined by hydrological and topographical characteristics and can be used for targeting management at smaller scales.

Wetland aggregations: Wetland aggregations are defined by their connectivity. Aggregations are groups of wetlands within the landscape that are connected through hydrological, ecological, or biological processes. These connections can be permanent, like a stream or groundwater flow, or intermittent, like periodic flooding. As defined in the Paddock to Reef Wetland Condition Monitoring program.

Links between Natural Resource Management (NRM) Regions, Basins and Management units applied in this report. Listed in north to south order.

NRM Region	Basin	Management units
Cape York	Jacky Jacky	
	Olive-Pascoe	
	Lockhart	
	Stewart	
	Normanby	
	Jeannie	
	Endeavour	
Wet Tropics	Daintree	

NRM Region	Basin	Management units
	Mossman	
	Barron	
	Mulgrave-Russell	
	Johnstone	
	Tully	
	Murray	
	Herbert	Upper Herbert
		Lower Herbert
Burdekin	Black	
	Ross	
	Haughton	
	Burdekin	East Burdekin
		Burdekin Delta
		Belyando
		Suttor
		Upper Burdekin
		Bowen Bogie
		Cape Campaspe
	Don River	
Mackay Whitsunday	Proserpine	
	O'Connell	
	Pioneer	
	Plane Creek	
Fitzroy	Styx	
	Shoalwater	
	Waterpark Creek	
	Fitzroy	Lower Fitzroy
		Dawson
		Isaac
		Mackenzie
		Comet
		Nogoa
		Theresa Creek
	Calliope	
	Boyne	
Burnett Mary	Baffle	
	Kolan	
	Burnett	
	Burrum	
	Mary	

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The following Appendices are provided as a separate report:

Appendix 1: Summary of datasets used in the assessment

Appendix 2: Water quality drivers

Appendix 3: Modelled annual average pollutant loads

Appendix 4: Additional pesticide data

Appendix 5: Wetland condition

Appendix 6: Marine pollutant exposure – nutrients and sediments

Appendix 7: Marine condition

Appendix 8: Management options

Executive Summary

A spatial management prioritisation method was developed and applied to the Great Barrier Reef (GBR) to provide robust and scientifically defensible information for guiding GBR water quality management responses and to inform the review of the Reef 2050 Water Quality Improvement Plan (WQIP). The method is based on the relationship between land management and the exposure of freshwater floodplain wetlands (herein referred to as 'wetlands'), coral reefs and seagrass meadows in the GBR to fine terrigenous sediments, nutrients and pesticides.

The scope covers all 35 basins and 48 management units within the GBR catchment area. The land uses of primary interest were grazing, sugarcane, horticulture, bananas, irrigated and dryland cropping (including grains) and urban land uses. Other non-agricultural land uses including sewage treatment plants, intensive industrial land uses and roads were within scope, but there is generally less information available for the latter land uses in relation to GBR water quality.

Using a comprehensive analysis of catchment characteristics, water quality drivers, pollutant sources and loads, pollutant exposure and ecosystem condition, this project developed, presents and applies a water quality management response decision support framework to guide intervention strategies, illustrated in Figure i. The Framework combines two complementary approaches to goal setting: stressor-based goals that aim to reduce water quality pollutant pressures affecting aquatic ecosystems, and outcome-based goals that focus on maintaining or improving ecosystem condition through comprehensive interventions that address multiple pressures. This approach highlights the need to protect ecosystems currently in good condition while taking action to improve ecosystems in poor condition, in both cases proportional to the level of pollutant exposure.

		Pollutant Exposure			
		Minimal	Low	Moderate	High
Ecosystem Condition	Poor	Foundational response + Investigate	Proactive response + Investigate	Accelerated response + evaluate	Intensive response + evaluate
	Moderate	Foundational response + Investigate	Proactive response + Investigate	Accelerated response + further assessment	Intensive response + further assessment
	Good	Foundational response	Proactive response	Accelerated response + increased vigilance	Intensive response + increased vigilance
		Trust development, prepare for future developments	Small-scale intervention	Targeted intervention	Comprehensive intervention
Management approach					

Figure i. Water Quality Management Response Decision Support Framework.

The Framework identifies four levels of management response based on pollutant exposure and ecosystem condition. There are four key management response levels determined by pollutant exposure that include and build on from the Foundational management response. The **Foundational** management response should be applied across all GBR catchments as a minimum response.

- The **Foundational management response** includes all the core components of management that set the foundation of water quality management in all areas to maintain good water quality and prevent future issues. This includes those areas that have Minimal pollutant hazard / exposure and

ecosystems in Good condition. The response should build on the strengths of what is already established and available, e.g. skills, expertise, and innovations, and the networks, relationships and trust with stakeholders, Traditional Owners and communities. The scale of effort is broadscale and could be viewed as a minimum level of water quality management across the GBR catchment area. This response focuses on maintaining regulated minimum practice standards, regulatory compliance, actively maintaining ecosystem values and services, fostering Traditional Owner involvement, identifying established strengths for program delivery, design and development of fit-for-purpose engagement models for supporting adoption of sustainable land management practices with water quality benefits, strategic communications, building relationships and preparing for future developments.

- The **Proactive management response** builds on the *Foundational* management response with localised actions where pollutant exposure is Low but may be increasing. Adopting a proactive approach will ensure that emerging issues are addressed and good water quality is maintained in these areas into the future. The response may include small-scale localised interventions could include actions in specific land uses, active uptake of practices with water quality benefits, small scale system repair and landscape restoration actions, and presence of industry stewardship programs.
- The **Accelerated management response** builds on the previous management responses, with more targeted and coordinated approaches where pollutant hazard / exposure is Moderate and action to reduce pollutants needs to be stepped up. The focus shifts from 'preventing' to 'reducing' pollutant exposure and impact, and the need to manage pollutant exposure to support ecosystem recovery potential and reducing or managing disturbances (where possible) at the local or regional scale. This requires targeted and tailored management options, most likely across multiple land uses with a diversity of management options in strategically defined and targeted sub-catchment areas within the basin or management unit. Greater levels of collaboration, more intensive coordination and planning, strategic design, program development and delivery are critical to support accelerated change.
- The **Intensive management response** requires comprehensive, urgent action across multiple land uses where pollutant hazard / exposure is High and ecosystems may be under significant stress. It builds on previous management responses with increasing intensity to deliver large-scale land management, targeting all dominant pollutant sources, multiple land uses (with intensity depending on contributions) and water quality drivers. Involves integrated whole-of-system strategic design, planning and delivery of programs with implementation of a comprehensive suite of options for sustainable land management including management practices with water quality and co-benefits, engineered solutions and systems repair. Recognition of co-benefits is important to facilitate additional resourcing for areas requiring intensive management.

The current ecosystem condition also influences management actions in the Framework. Within each management response level, there are additional actions that are triggered according to the ecosystem condition. These actions vary depending on the level of exposure.

- **Good condition** ecosystems: Require routine and ongoing monitoring of ecosystem condition and water quality drivers, with reactive monitoring of large-scale disturbance events. Under Moderate and High pollutant exposure, additional responses are required for **increased vigilance** of changes in ecosystem condition to ensure condition does not decline.
- **Moderate condition** ecosystems: Under Minimal or Low pollutant exposure an **investigation** would be triggered to determine the other pressures driving the Poor condition (assuming it is not related to nutrient, sediment or pesticide impacts) and to inform relevant managers of the need to act. Under Moderate or High pollutant exposure, a Moderate condition ecosystem would trigger **further assessment** to understand additional pressures on the ecosystem, to identify trends in ecosystem condition and to understand the role of pollutant impacts on the ecosystem's state to avoid further

declines. **Tailored communications** on these ecosystems, drivers and pressure under threat should be developed and disseminated.

- **Poor condition** ecosystems: Under Minimal or Low pollutant exposure an **immediate investigation** would be triggered to determine the drivers of the condition and inform relevant managers of the need to act. Under Moderate or High pollutant exposure, a Poor condition ecosystem would trigger an **evaluation** of the ecosystem's ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Depending on the outcome of the evaluation, other intervention options may need to be considered. **Tailored communications** on these ecosystems under threat should be developed and disseminated.

The results of the water quality management response assessment are presented for freshwater floodplain wetlands and marine ecosystems in Tables i and ii. Table iii provides a more detailed summary of the results of the water quality management response assessment by basin, for each pollutant that floodplain wetlands and marine ecosystems are exposed to, and the focus areas for management.

Key findings:

- The assessment identified that 24 basins require **Intensive** management responses for at least one pollutant type: 13 individual basins for the marine-driven management response (5 nutrients, 5 sediments, 6 pesticides) and 24 individual basins for the freshwater wetland management response (20 nutrients, 21 sediments, 7 pesticides).
- Thirteen basins were assessed as requiring **Intensive** management responses across all pollutants: the Barron, Johnstone, Tully, Murray, Herbert, Haughton, Burdekin, Proserpine, O'Connell, Pioneer, Kolan, Burnett and Mary.
- Several basins consistently required *Foundational* or *Proactive* management responses for the marine-driven and wetland assessments including most basins in the Cape York region, with the notable exception of the Normanby which requires *Intensive* management of sediment and the Endeavour which requires *Accelerated* management of nutrients and sediments. This indicates areas where current water quality conditions are relatively good but require ongoing maintenance and proactive intervention to ensure future protection.
- The Wet Tropics, Burdekin and Mackay Whitsunday regions consistently require a higher response level across multiple pollutants, which is coupled with Moderate or Poor condition of freshwater wetlands, seagrass and coral ecosystems in these regions.
- The Cape York region generally requires *Foundational* management responses and has generally Good ecosystem condition (where data are available) with the exception of some seagrass habitats in the southern basins, highlighting the need for *Proactive* management and ongoing maintenance to prevent increases in pollutant exposure and protect these ecosystems.
- The Fitzroy and Burnett Mary regions show a mixed pattern, with *Intensive* management needed for sediment across most basins and management units with varying levels of response required for nutrients and pesticides. Ecosystems in these regions are generally in Moderate to Poor condition.
- The assessment results highlight the critical importance of cross-boundary management approaches, as adjacent basins often share similar management needs, particularly for sediment management in larger basins like the Burdekin and Fitzroy.
- The focus areas for *Intensive* management responses for each pollutant are:
 - **Nutrients:** Basins with large areas of intensive agricultural land uses, predominantly sugarcane, bananas and horticulture, particularly in the Wet Tropics, Burdekin and Mackay Whitsunday regions. Urban areas are also important contributors in some basins.

- **Sediments:** Basins with large areas of extensive grazing including the Normanby, Herbert, Burdekin, Fitzroy and Mary basins.
 - **Pesticides:** Basins with large areas of intensive agricultural land uses, predominantly sugarcane, particularly in the Mackay Whitsunday basins of Proserpine, O’Connell, Pioneer and Plane Creek as well as the Murray basin in the Wet Tropics region and Haughton basin in the Burdekin region.
- The framework's integration of ecosystem condition with pollutant exposure provides important context for management priorities. For marine ecosystems, coral and seagrass condition varies across the GBR, with many areas showing a decline in condition in recent years due to multiple pressures including water quality, climate change, and other disturbances. Wetland condition was presented for 27 management units that have monitored wetland aggregations. Of these, 4 were assessed as being in Good condition, 12 in Moderate condition, and 11 in Poor condition.
 - The assessment highlights that management responses need to be tailored to both pollutant levels and to ecosystem condition. For example, in areas like the Mulgrave-Russell basin where some wetlands remain in Moderate condition despite significant development, management approaches need to address both protection and restoration priorities to support wetland function for pollution load reduction.
 - The assessment highlights important information about the remaining natural unmodified freshwater floodplain wetland extent, which ranges from as little as 3% remaining in highly developed basins like the Mossman and Boyne (noting that these basins had less than 150 ha of natural unmodified wetlands to start with), to nearly 100% remaining in less developed Cape York basins. This information is crucial for contextualising the urgency and scale of wetland management responses.
 - The assessment emphasises that successful implementation will require varying levels of monitoring, evaluation and investigation, and on-ground management actions including agricultural and non-agricultural management practices, engineering solutions and systems repair and a focus on factors influencing adoption. Increasing the levels of monitoring, evaluation and investigation is recommended as pollutant exposure increases, where ecosystem condition is Poor, or where confidence in the current assessments is low.
 - Management actions vary based on the level of the management response. The *Foundational* management response requires minimum standards set through regulations to be met, enforcement of legislative requirements where needed, embedding key governance and institutional planning frameworks and oversight (including ecosystem protection planning for new developments or land use changes), and alignment with current best practices for the relevant land use/environmental protection.
 - Increasing extension capacity and capability, and collaborative approaches with stakeholder engagement in co-design processes is likely to be required in areas requiring more intervention, along with cross-boundary coordination since adjacent basins often share similar management needs.
 - Greater emphasis on designing tailored and effective delivery programs to implement management responses at appropriate scales that consider societal factors influencing adoption, will be necessary to accelerate change and create the foundations for enduring change.

While this project does not extend to identifying specific management options for each basin or management unit, it does provide a summary of the most effective water quality management options across the range of land uses considered. To illustrate the application of the assessment framework, a worked example presented as a ‘basin profile’ has been developed for the Tully basin. The profile

synthesises the collective results of the assessment and provides a practical demonstration of how the framework can inform logical decision making.

Direct comparison between this assessment and the 2017 water quality management prioritisation is challenging due to a shift in the methodology. The current approach moves beyond prioritising basins that pose the highest relative risk, to also recognising the value of ecosystems in good condition with low pollutant exposure. Despite these differences, key distinctions between the two assessments can be highlighted to support strategic alignment and inform future prioritisation efforts. Basins identified for *Intensive* management responses typically align with those previously classified as Very High or High priority in 2017. However, this assessment identifies additional priority basins including the Normanby for sediment, Burdekin (Delta) and Burnett for nutrients, and Murray, Proserpine and O'Connell for pesticides. Conversely, several previously high-priority basins now require lower management response levels, including the Mulgrave-Russell, Johnstone, Plane and Mary for nutrients and Burnett for sediments. These changes have significant implications for planning and investment priorities. For freshwater floodplain wetlands, there is high consistency between the current and 2017 assessments, with several additional areas now requiring higher management responses.

This assessment acknowledges the challenges in identifying management priorities due to complex interactions between water quality drivers, ecosystem condition, and evolving GBR management needs. Despite these limitations, advances in modelling, monitoring, and knowledge accumulation support a more precise, targeted approach to management responses. The assessment quantifies condition and exposure of GBR freshwater floodplain wetlands and marine ecosystems to land-based runoff while highlighting the need for better understanding of the severity, consequences, and cumulative impacts on these ecosystems, and their management. It does not consider the social and economic aspects of implementation, a critical factor for the Reef 2050 Water Quality Improvement Plan.

Whole-of-system, values-based approaches are key to GBR water quality initiatives and future multi-scale management. Regular updates within five years or after major disturbances are recommended to ensure relevance. The assessment provides decision-makers with spatial priorities using a flexible, evidence-based framework that balances immediate pollutant reduction with long-term resilience. Management strategies must be adaptable to local contexts while maintaining a whole-of-system perspective.

Table i. Management responses for regions and management units based on the wetlands assessment.

Nutrients	Sediment	Pesticides
Foundational		
Cape York: Jacky Jacky, Olive-Pascoe, Lockhart, Stewart, Jeannie Wet Tropics: Daintree, Mossman Fitzroy: Styx, Shoalwater, Waterpark Creek	Cape York: Olive-Pascoe, Lockhart, Stewart, Jeannie Wet Tropics: Daintree, Mossman Fitzroy: Waterpark Creek	Cape York: Jacky Jacky, Olive-Pascoe, Lockhart, Stewart, Normanby, Jeannie, Endeavour Wet Tropics: Daintree Burdekin: Belyando, Upper Burdekin, Bowen Bogie, Cape Campaspe Fitzroy: Styx, Shoalwater, Waterpark Creek, Lower Fitzroy, Calliope, Boyne
Proactive		
Cape York: Normanby Wet Tropics: Mulgrave-Russell	Cape York: Jacky Jacky Wet Tropics: Mulgrave-Russell	Burdekin: Ross, Suttor Fitzroy: Comet
Accelerated		
Cape York: Endeavour Burdekin: Ross, Belyando, Suttor, Upper Burdekin Fitzroy: Calliope	Cape York: Normanby, Endeavour Mackay Whitsunday: Plane Creek Fitzroy: Styx, Shoalwater	Wet Tropics: Upper Herbert Burdekin: Black, Don Fitzroy: Dawson, Isaac, Mackenzie, Nogoa Burnett Mary: Baffle, Burrum
Intensive		
Wet Tropics: Barron, Johnstone, Tully, Murray, Upper Herbert, Lower Herbert Burdekin: Black, Haughton, East Burdekin, Burdekin Delta, Bowen Bogie, Cape Campaspe, Don Mackay Whitsunday: Proserpine, O'Connell, Pioneer, Plane Creek Fitzroy: Lower Fitzroy, Dawson, Isaac, Mackenzie, Comet, Nogoa, Theresa Creek, Boyne Burnett Mary: Baffle, Kolan, Burnett, Burrum, Mary	Wet Tropics: Barron, Johnstone, Tully, Murray, Upper Herbert, Lower Herbert Burdekin: Black, Ross, Haughton, East Burdekin, Burdekin Delta, Belyando, Suttor, Upper Burdekin, Bowen Bogie, Cape Campaspe, Don Mackay Whitsunday: Proserpine, O'Connell, Pioneer Fitzroy: Lower Fitzroy, Dawson, Isaac, Mackenzie, Comet, Nogoa, Theresa Creek, Calliope, Boyne Burnett Mary: Baffle, Kolan, Burnett, Burrum, Mary	Wet Tropics: Mossman, Barron, Mulgrave-Russell, Johnstone, Tully, Murray, Lower Herbert Burdekin: Haughton, East Burdekin, Burdekin Delta Mackay Whitsunday: Proserpine, O'Connell, Pioneer, Plane Creek Fitzroy: Theresa Creek Burnett Mary: Kolan, Burnett, Mary

Table ii. Management responses for regions and basins based on the marine assessment.

Dissolved Inorganic Nitrogen (DIN)	Fine sediment	Pesticides
Foundational		
Cape York: Jacky Jacky, Olive-Pascoe, Lockhart, Stewart, Normanby, Jeannie, Endeavour Burdekin: Black, Don Fitzroy: Styx, Shoalwater, Waterpark Creek, Fitzroy, Calliope, Boyne Burnett Mary: Baffle, Burrum	Cape York: Jacky Jacky, Olive-Pascoe, Lockhart, Stewart, Jeannie Wet Tropics: Daintree, Mossman, Murray Burdekin: Black, Ross Mackay Whitsunday: Proserpine Fitzroy: Styx, Shoalwater, Waterpark Creek, Calliope, Boyne Burnett Mary: Baffle, Kolan, Burrum	Cape York: Jacky Jacky, Olive-Pascoe, Lockhart, Stewart, Normanby, Jeannie, Endeavour Wet Tropics: Daintree, Barron Burdekin: Black, Ross Fitzroy: Styx, Shoalwater, Waterpark Creek, Calliope, Boyne Burnett Mary: Baffle
Proactive		
Burnett Mary: Kolan	Cape York: Endeavour Wet Tropics: Mulgrave-Russell Mackay Whitsunday: Plane Creek	Wet Tropics: Mossman Burdekin: Burdekin, Don Fitzroy: Fitzroy Burnett Mary: Kolan, Burnett, Mary
Accelerated		
Wet Tropics: Daintree, Mossman, Barron, Mulgrave-Russell, Johnstone, Murray Burdekin: Ross Mackay Whitsunday: Proserpine, O'Connell, Pioneer, Plane Creek Burnett Mary: Mary	Wet Tropics: Barron, Johnstone, Tully Burdekin: Haughton, Don Mackay Whitsunday: O'Connell, Pioneer Burnett Mary: Burnett	Wet Tropics: Mulgrave-Russell, Johnstone, Tully, Herbert Burnett-Mary: Burrum
Intensive		
Wet Tropics: Tully, Herbert Burdekin: Haughton, Burdekin Burnett Mary: Burnett	Cape York: Normanby Wet Tropics: Herbert Burdekin: Burdekin Fitzroy: Fitzroy Burnett Mary: Mary	Wet Tropics: Murray Burdekin: Haughton Mackay Whitsunday: Proserpine, O'Connell, Pioneer, Plane Creek

Table iii. Summary of the results by basin of the water quality management response assessment for each pollutant for freshwater floodplain wetlands and marine ecosystems, and the focus areas for management relevant to the results. For management responses, F = Foundational, P = Proactive, A = Accelerated and I = Intensive. ¹Management responses for freshwater floodplain wetlands are more targeted to areas within the basin that present a hazard to the wetlands, whereas the management responses for marine exposed areas are at the basin level, noting that management responses at the Management Unit (MU) level are only presented for freshwater floodplain wetlands. The default management response for all areas is 'Foundational', additional levels of response are featured where required for specific pollutants. The overall management and focus areas for the basin defaults to the Basin-level (marine-driven) management response. ²The dominant pollutant sources and pathways are sourced from Appendix 3 and Appendix 4. Dominant land uses for pesticides are based on those land uses within the basin with higher potential for pesticide risk and are ordered based on decreasing proportional area. Conservation sources have been excluded from the assessment to target management of anthropogenic sources and grazing was excluded for DIN. ³ The freshwater floodplain wetland nutrient hazard exposure does not distinguish particulate and dissolved nutrient forms. In these basins, the dominant nutrient influence is likely to be particulate nutrients (informed by loads by land use data), however, validation is required to distinguish dissolved and particulate sources. * Low confidence due to insufficient data or observations (requires validation or investigation).

			Management Response ¹					Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)	
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine			Wetland
Cape York	Jacky Jacky		F		F	P	F		• Broadscale foundational management across the basin for all pollutants. • Validate wetland sediment hazard assessment and where required, implement appropriate management for wetlands in sediment hazard exposed areas. • Investigate wetland and coral condition. *	Sediment & particulate nutrients: Minimal anthropogenic sources <i>Hillslope</i> Pesticides: No high-risk land uses
	Olive-Pascoe		F		F		F		• Broadscale foundational management across the basin for all pollutants. • Investigate wetland and coral condition. *	Sediment & particulate nutrients: Minimal anthropogenic sources <i>Hillslope</i> Pesticides: No high-risk land uses
	Lockhart		F		F		F		• Broadscale foundational management across the basin for all pollutants. • Investigate wetland and coral condition. *	Sediment & particulate nutrients: Minimal anthropogenic sources <i>Hillslope</i> Pesticides: No high-risk land uses
	Stewart		F		F		F		• Broadscale foundational management across the basin for all pollutants. • Investigate wetland and coral condition. *	Sediment & particulate nutrients: Minimal anthropogenic sources <i>Hillslope</i>

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									Further assessment of seagrass condition to understand additional pressures, increase confidence in status (including trends) and qualify the role of pollutant impacts.	Pesticides: No high-risk land uses
	Normanby		F	P	I	A	F		- Large-scale intensive management of sediment at the basin level. Broadscale foundational management in all other areas across the basin. - Accelerated management of sediments for wetlands in hazard exposed areas. - Validate wetland nutrient³ hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Investigate coral condition. *	Sediment & particulate nutrients: Grazing <i>Gully & Hillslope</i> Pesticides: Dryland Cropping, Bananas & Irrigated Cropping
	Jeannie		F		F		F		- Broadscale foundational management across the basin for all pollutants. - Investigate wetland and coral condition. * - Further assessment of seagrass condition to understand additional pressures, increase confidence in status (including trends) and qualify the role of pollutant impacts.	Sediment & particulate nutrients: Minimal anthropogenic sources <i>Hillslope</i> Pesticides: Dryland Cropping & Horticulture
	Endeavour		F	A	P	A	F		- Broadscale foundational management across the basin for all pollutants, with localised proactive management of sediment. Accelerated management of sediments for wetlands in hazard exposed areas. - Validate wetland nutrient³ hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Investigate wetland condition and coral condition. *	Sediment & particulate nutrients: Grazing <i>Hillslope</i> Pesticides: Dryland Cropping, Horticulture & Bananas

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									Further assessment of seagrass condition to understand additional pressures, increase confidence in status (including trends) and qualify the role of pollutant impacts.	
Wet Tropics	Daintree		A	F	F		F		- Broadscale foundational management across the basin for all pollutants, with accelerated management of nutrients in targeted sub-catchment areas. - Validate wetland pesticide hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Investigate wetland condition. *	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Streambank in various land uses & Grazing <i>Hillslope & Streambank</i> Pesticides: Sugarcane
	Mossman		A	F	F		P	I	- Accelerated management of nutrients in targeted sub-catchment areas, and localised proactive management of pesticides. Broadscale foundational management in all other areas across the basin. - Validate wetland pesticide hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Investigate wetland condition. *	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Minimal anthropogenic sources (some Sugarcane & Urban) <i>Hillslope</i> Pesticides: Sugarcane
	Barron		A	I	A	I	F	I	- Accelerated management of nutrients and sediment in targeted sub-catchment areas. Intensive management of all pollutants for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Investigate wetland condition. *	Nutrients (DIN): Urban, Sewage Treatment Plants, Sugarcane & Bananas Sediment & particulate nutrients: Streambank in various land uses & Grazing <i>Streambank & Hillslope</i> Pesticides: Sugarcane, Irrigated Cropping, Horticulture & Bananas

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
	Mulgrave-Russell		A	P	P		A	F	- Accelerated management of nutrients and pesticides across multiple land uses in targeted sub-catchment areas, and localised proactive management of sediment. Broadscale foundational management in all other areas across the basin. - Validate wetland nutrient hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. Intensive management of pesticides and localised management of sediment for wetlands in hazard exposed areas. - Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition.	Nutrients (DIN): Sugarcane, Bananas, Urban & Sewage Treatment Plants Sediment & particulate nutrients: Streambank in various land uses, Sugarcane & Grazing Hillslope & Streambank Pesticides: Sugarcane & Bananas
	Johnstone		A	I	A	I	A	I	- Accelerated management of nutrients, sediment and pesticides across multiple land uses in targeted sub-catchment areas. Intensive management of all pollutants for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Evaluate wetland ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem rehabilitation /recovery may need to be considered (based on values assessment).	Nutrients (DIN): Sugarcane, Bananas & Urban Sediment & particulate nutrients: Streambank in various land uses & Grazing Hillslope & Streambank Pesticides: Sugarcane, Bananas & Urban
	Tully		I		A	I	A	I	Multi-pollutant, strategic management required across multiple land uses, with intensive large-scale management of nutrients and accelerated management of sediment and pesticides in targeted sub-	Nutrients (DIN): Sugarcane & Bananas Sediment & particulate nutrients: Streambank in various

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									catchment areas. Intensive management of all pollutants for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. • Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition. • Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	land uses & Sugarcane <i>Hillslope & Streambank</i> Pesticides: Sugarcane & Bananas
	Murray		A	I	F	I	I		• Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of pesticides and accelerated management of nutrients in targeted areas. Intensive management of nutrients and pesticides for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. • Validate wetland sediment hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. • Evaluate wetland and seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem rehabilitation/recovery may need to be considered (based on values assessment).	Nutrients (DIN): Sugarcane & Bananas Sediment & particulate nutrients: Streambank in various land uses & Sugarcane Pesticides: Sugarcane & Bananas

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
	Herbert	Upper Herbert		I		I		A	- Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of nutrients and sediment and accelerated management of pesticides in targeted sub-catchment areas. Intensive management of all pollutants for wetlands in hazard exposed areas in the Lower Herbert MU and for sediments in the Upper Herbert MU. - Validate wetland nutrient³ and pesticide hazard assessment in the Upper Herbert MU and where required, implement appropriate management for wetlands in hazard exposed areas. - Evaluate wetland ecological, social and cultural values in the Lower Herbert, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem rehabilitation/recovery may need to be considered (based on values assessment). - Further assessment of wetland condition in the Upper Herbert MU to understand the role of pollutant impacts and actively manage other drivers of wetland. - Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Grazing, Streambank in various land uses & Sugarcane <i>Hillslope & Streambank</i> Pesticides: Sugarcane & Irrigated Cropping
		Lower Herbert		I		I		I		
		Herbert basin total	I	I	I	A	I			
Burdekin	Black		F	I	F	I	F	A	- Broadscale foundational management across the basin for all pollutants. - Validate wetland nutrient³ and sediment hazard assessment and where required,	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Grazing

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									implement appropriate management for wetlands in hazard exposed areas. Evaluate wetland ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem rehabilitation /recovery may need to be considered (based on values assessment).	<i>Hillslope</i> Pesticides: Sugarcane, Horticulture & Urban
	Ross		A		F	I	F	P	- Broadscale foundational management across the basin for all pollutants, with accelerated management of nutrients in targeted sub-catchment areas including for wetlands in hazard exposed areas. - Validate wetland sediment and pesticide hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition.	Nutrients (DIN): Sewage Treatment Plants Sediment & particulate nutrients: Grazing <i>Hillslope</i> Pesticides: Horticulture, Irrigated Cropping & Urban
	Haughton		I		A	I	I		- Multi-pollutant, strategic management required across multiple land uses, with intensive large-scale management of nutrients and pesticides and accelerated management of sediment in targeted sub-catchment areas. Intensive management of all pollutants for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Evaluate wetland and seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Grazing & Sugarcane <i>Gully & Hillslope</i> Pesticides: Sugarcane

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									repair/recovery may need to be considered (based on values assessment).	
	Burdekin	East Burdekin		I		I		I	- Multi-pollutant, strategic management required across multiple land uses at the basin level, with intensive large-scale management of nutrients and sediment (including for wetlands in hazard exposed areas). Localised, proactive management of pesticides except for wetlands in hazard exposed areas where pesticide management increases to intensive in the Burdekin Delta. Broadscale foundational management in all other areas across the basin. - Validate wetland nutrient³ hazard assessment for Belyando, Suttor, Upper Burdekin, Bowen Bogie and Cape Campaspe, and where required, implement appropriate management for wetlands in nutrient hazard exposed areas. - Validate wetland pesticide hazard assessment for East Burdekin MU, and pesticide and sediment hazard for Suttor MU. Where required, implement appropriate management for wetlands in hazard exposed areas. - Investigate wetland condition in the Belyando, Suttor and Bowen Bogie MU. - Evaluate wetland ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery in the Burdekin Delta. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Grazing <i>Gully</i> Burdekin Delta - Streambank in various land uses <i>Streambank</i> Pesticides: Dryland Cropping, Irrigated Cropping & Sugarcane
		Burdekin Delta		I		I		I		
		Belyando		A		I		F		
		Suttor		A		I		P		
		Upper Burdekin		A		I		F		
		Bowen Bogie		I		I		F		
		Cape Campaspe		I		I		F		
		Burdekin basin total	I		I		P			

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									Further assessment of wetland condition in the Upper Burdekin MU to understand the role of pollutant impacts and actively manage other drivers of wetland condition.	
	Don River		F	I	A	I	P	A	- Accelerated management of sediment in targeted sub-catchment areas and localised proactive management of pesticides. Intensive management of nutrients and sediment for wetlands in hazard exposed areas. - Validate wetland pesticide hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition.	Nutrients (DIN): Horticulture Sediment & particulate nutrients: Grazing <i>Gully</i> Pesticides: Horticulture & Irrigated Cropping
Mackay Whitsund ay	Proserpine		A	I	F	I	I		- Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of pesticides and accelerated management of nutrients in targeted sub-catchment areas. Intensive management of all pollutants in wetland hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Evaluate wetland and coral ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	Nutrients (DIN): Sugarcane & Urban Sediment & particulate nutrients: Grazing & Streambank in various land uses <i>Hillslope & Streambank</i> Pesticides: Sugarcane
	O’Connell		A	I	A	I	I		Multi-pollutant, strategic management required across multiple land uses, with	Nutrients (DIN): Sugarcane & Urban

			Management Response ¹					Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² <i>and pathways (ranked)</i>	
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine			Wetland
								large-scale intensive management of pesticides and accelerated management of nutrients and sediment in targeted sub-catchment areas. Broadscale foundational management in all other areas across the basin. • Validate wetland nutrient, sediment and pesticide hazard assessment, and where required, implement appropriate management for wetlands in hazard exposed areas. • Investigate wetland condition. * • Evaluate coral ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	Sediment & particulate nutrients: Streambank in various land uses, Grazing & Sugarcane <i>Streambank & Hillslope</i> Pesticides: Sugarcane	
	Pioneer		A	I	A	I	I	• Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of pesticides and accelerated management of nutrients and sediment in targeted sub-catchment areas. Broadscale foundational management in all other areas across the basin. • Validate wetland nutrient, sediment and pesticide hazard assessment and where required, implement appropriate management for wetlands in nutrient hazard exposed areas. • Investigate wetland condition. * • Evaluate coral ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention	Nutrients (DIN): Sugarcane & Urban Sediment & particulate nutrients: Streambank various land uses <i>Streambank & Hillslope</i> Pesticides: Sugarcane & Urban	

			Management Response ¹					Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)	
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine			Wetland
								options for ecosystem repair/recovery may need to be considered (based on values assessment).		
	Plane Creek		A	I	P	A	I	- Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of pesticides, accelerated management of nutrients in targeted sub-catchment areas, and localised proactive management of sediment. Intensive management of pesticides and nutrients, and accelerated management of sediment in wetland hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Evaluate wetland and coral ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	Nutrients (DIN): Sugarcane & Urban Sediment & particulate nutrients: Grazing, Streambank in various land uses & Sugarcane <i>Hillslope & Streambank</i> Pesticides: Sugarcane	
Fitzroy	Styx		F		F	A	F	- Broadscale foundational management across the basin for all pollutants. - Validate wetland sediment hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Investigate wetland condition., and immediate investigation of drivers of coral and seagrass condition. *	Sediment & particulate nutrients: Grazing <i>Gully & Hillslope</i> Pesticides: Sugarcane	
	Shoalwater		F		F	A	F	- Broadscale foundational management across the basin for all pollutants. - Validate wetland sediment hazard assessment and where required, implement appropriate management for	Sediment & particulate nutrients: Grazing <i>Hillslope & Gully</i> Pesticides: No high-risk land uses	

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									wetlands in sediment hazard exposed areas. Investigate wetland condition, and immediate investigation of drivers of coral and seagrass condition. *	
	Waterpark Creek		F		F		F		- Broadscale foundational management across the basin for all pollutants. Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition. - Immediate investigation of drivers of coral and seagrass condition. *	Sediment & particulate nutrients: Grazing <i>Hillslope</i> Pesticides: Horticulture & Dryland Cropping
	Fitzroy	Lower Fitzroy		I		I		F	- Multi-pollutant, strategic management across multiple land uses at the basin level, with intensive large-scale management of sediment (including for wetlands in hazard exposed areas), and localised proactive management of pesticides. Broadscale foundational management in all other areas across the basin. - Investigate sources of DIN marine exposure. * - Validate wetland nutrient³ and pesticide hazard assessment and where required, implement appropriate management response. - Investigate wetland condition in the Comet and Theresa Creek MU. - Evaluate wetland (in Lower Fitzroy and Nogoia MU), coral and seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem	Sediment & particulate nutrients: Grazing, Streambank in various land uses & Dryland Cropping (Isaac) <i>Gully & Streambank</i> Pesticides: Dryland Cropping, Irrigated Cropping & Urban
		Dawson		I		I		A		
		Isaac		I		I		A		
		Mackenzie		I		I		A		
		Comet		I		I		P		
		Nogoia		I		I		A		
		Theresa Creek		I		I		I		
		Fitzroy basin	F		I		P			

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									repair/recovery may need to be considered (based on values assessment). Further assessment of wetland condition in Dawson, Isaac and Mackenzie MU to understand the role of pollutant impacts and actively manage other drivers of wetland condition.	
	Calloope		F	A	F	I	F		- Broadscale foundational management across the basin for all pollutants. - Validate wetland nutrient³ and sediment hazard assessment and implement appropriate management response where required. - Investigate wetland condition, and immediate investigation of drivers of coral and seagrass condition. *	Sediment & particulate nutrients: Grazing <i>Hillslope & Gully</i> Pesticides: Horticulture, Dryland Cropping & Irrigated Cropping
	Boyne		F	I	F	I	F		- Broadscale foundational management across the basin for all pollutants. - Validate wetland nutrient³ and sediment hazard assessment and implement appropriate management response where required. - Investigate wetland condition. * - Evaluate coral ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	Sediment & particulate nutrients: Grazing <i>Hillslope & Gully</i> Pesticides: Dryland Cropping & Irrigated Cropping
Burnett Mary	Baffle		F	I	F	I	F	A	- Broadscale foundational management across the basin for all pollutants, with management increasing accelerated for pesticides, in wetland hazard exposed areas. - Validate wetland nutrient³ and sediment hazard assessment and implement	Sediment & particulate nutrients: Grazing & Urban <i>Hillslope & Gully</i> Pesticides: Horticulture, Sugarcane, & Irrigated Cropping

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									appropriate management response where required. - Investigate coral and seagrass condition. * - Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition.	
	Kolan		P	I	F	I	P	I	- Localised, proactive management for nutrients, sediment and pesticides at the basin level. - Validate wetland nutrient³, sediment and pesticide hazard assessment and where required, implement appropriate management response. - Investigate wetland and coral condition. * - Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Streambank in various land uses & Grazing <i>Hillslope & Streambank</i> Pesticides: Sugarcane, Horticulture & Urban
	Burnett		I		A	I	P	I	- Multi-pollutant, strategic management required across multiple land uses at the basin level, with intensive large-scale management of nutrients, accelerated management of sediment in targeted sub-catchment areas, and localised proactive management of pesticides at the basin level. Intensive management of all pollutants for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Investigate coral condition. * - Evaluate wetland and seagrass ecological, social and cultural values, other potential	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Streambank in various land uses & Grazing <i>Streambank</i> Pesticides: Dryland Cropping, Irrigated Cropping, Sugarcane, Horticulture & Urban

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² and pathways (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	
	Burrum		F	I	F	I	A		- Broadscale foundational management across the basin for all pollutants, with accelerated management of pesticides in targeted sub-catchment areas including for wetlands in hazard exposed areas. Intensive management of nutrients and sediment for wetlands in hazard exposed areas. - Investigate coral condition. * - Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Urban & Horticulture <i>Hillslope</i> Pesticides: Sugarcane, Horticulture & Urban
	Mary		A	I	I		P	I	- Multi-pollutant, strategic management required across multiple land uses at the basin level, with intensive large-scale management of sediment, accelerated management of nutrients in targeted sub-catchment areas, and localised proactive management of pesticides. Intensive management of all pollutants for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition.	Nutrients (DIN): Sugarcane & Urban Sediment & particulate nutrients: Streambank in various land uses, Grazing & Urban <i>Streambank & Hillslope</i> Pesticides: Sugarcane, Horticulture, Irrigated Cropping & Urban

			Management Response ¹						Overall management and focus areas	Dominant pollutant sources for targeting management (ranked) ² <i>and pathways</i> (ranked)
NRM Region	Basin	MU	Nutrient		Sediments		Pesticides			
			Marine	Wetland	Marine	Wetland	Marine	Wetland		
									Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem’s potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).	

1. Introduction

1.1 Background

The Great Barrier Reef Marine Park (GBRMP) is an iconic and highly valued marine protected area that is recognised locally, nationally and internationally for its ecological, social, economic, and culturally diverse (including Indigenous heritage) values (GBRMPA 2024). It includes one of the largest coral reef ecosystems in the world within its boundaries (348,000 km²) as well as extensive areas of soft-bottom, seagrass, and mangrove communities. These ecosystems host a range of fauna including whales, dolphins, dugongs, turtles, sharks, and large fish populations that support commercial beneficiaries like tourism, recreation and commercial fishing, and recreational beneficiaries and maintain substantial economic value (GBRMPA 2024). The adjacent GBR catchment area (424,000 km²; McCloskey et al. 2021a) includes an extensive network of freshwater ecosystems. The combination of marine and freshwater ecosystems includes the terrestrial catchment, rivers, streams, coastal floodplain wetlands, estuaries, islands, reefs and inter-reefal areas, the continental slope, and deep oceanic waters (Creighton et al. 2021). This interconnected system is critical to the continued condition and resilience of the GBR (Davis and Pearson 2024).

Exposure to land-sourced pollution has been identified as an important factor of the global decline in coral reef ecosystem condition (Pandolfi et al. 2003; Burke et al. 2011). Different parts of the GBR are exposed to different degrees of influence from land-sourced pollutants (Waterhouse et al. 2017a; Waterhouse et al. 2024a). The degree of exposure in coastal and marine ecosystems is a function of factors such as distance from the coast, the magnitude and frequency of river discharges, the distance from river mouths, wind and current directions and, the mobility of different pollutant types, and the different land uses in the 35 drainage basins of the GBR catchment area (Waterhouse et al. 2017a). For freshwater wetlands, exposure to poor water quality is driven by land use, proximity to sources of pollution, direct pollutant inputs, climate factors, land management practices and landscape disturbance factors such as lack of riparian buffer areas. This differential exposure of ecosystems to land-sourced pollutants has important implications for prioritising catchment management to reduce water quality impacts on GBR catchment freshwater floodplain wetlands and GBR marine ecosystems.

The purpose of this project is to provide an updated understanding of the relative priorities for water quality improvement in the 35 basins and where possible, the 48 management units of the GBR catchment area, an exercise last conducted in 2017 (Waterhouse et al. 2017a; 2017b). It is one of several projects that provides supporting information for the design, delivery and implementation of the Australian and Queensland Governments' Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP; Australian and Queensland governments 2018)⁴. The Reef 2050 WQIP defines objectives and targets related to water quality improvement, identifies management priorities for water quality and catchment condition (guided by this project) and describes actions for improving the quality of the water that enters the GBR from the adjacent catchment area and is underpinned by the best available information. The long-term outcome of the Reef 2050 WQIP is to achieve '*Good water quality [that] sustains the outstanding universal value of the Great Barrier Reef, builds resilience, improves ecosystem health, and benefits communities.*' There are two major groupings of management objectives associated with this goal: i) environmental – improved coral condition, seagrass condition, wetland condition and biodiversity, and ii) social and cultural – improved land management, increased culture of stewardship, maintenance of viable communities and improved governance. In the context of these objectives, it is important to understand:

- The ecosystem values that are exposed to and potentially impacted by poor water quality, and
- The (social and cultural) values linked with the management actions to improve poor water quality or maintain good water quality – that are consistent with the objectives for improving ecosystem values.

⁴ <https://www.reefplan.qld.gov.au/>

Since the 2017 prioritisation process, there has been a significant shift in the drivers that influence how the management of GBR ecosystems should be approached. Multiple mass coral bleaching events since 2017 have fundamentally changed perspectives of the best approaches for reducing the threats to the GBR, highlighting the urgent need to minimise all pressures on the GBR as climate impacts intensify (GBRMPA 2024; Waterhouse et al. 2024b). The previous spatial prioritisation approaches primarily focused on areas with high pollutant exposure, aiming to achieve the greatest reductions in pollutant loads. However, with the necessary shift in perspective of management and decision-making, the concept of ‘prioritisation’ needs to evolve to find a balance of both stressor reduction- and ecosystem protection-based goals. This is widely recognised and was highlighted in the 2022 Scientific Consensus Statement (SCS), 2024 GBR Outlook Report and by the Reef 2050 Independent Expert Panel in advice to the Federal Environment Minister in 2023. This shift acknowledges that while reducing pollutant pressures remains critical, protecting ecosystems already in good condition is equally important for preserving biodiversity and maintaining resilience.

In accordance with this logic, a revised approach has been adopted for the assessment in this project, guided by the goals and principles outlined below.

The project was funded by the Australian and Queensland Governments (Department of Climate Change, Energy, the Environment and Water [DCCEEW] and the Department of the Environment, Tourism, Science and Innovation [DETSI]), and delivered by C₂O Consulting Coasts | Climate | Oceans with significant in-kind support from DETSI. Technical advice on the methods has been sought from the Technical Advisory Group for the project reviewing the Water Quality Targets, and the scope and methods have been reviewed by the Reef Water Quality Independent Science Panel (ISP) throughout the project.

1.2 Defining goals and principles for a management response to water quality pressures

Management planning typically employs two complementary approaches to goal-setting: stressor-based goals and outcome-based goals. Each serves a distinct but interrelated purpose in environmental management (Behr et al. 2016). Stressor-based goals aim to reduce specific pressures (such as pollutants) affecting aquatic ecosystems. These goals typically prioritise cost-effective management actions that will achieve the greatest reductions in pollutant loads, with the assumption that exposed ecosystems will subsequently recover once the pressure has been reduced or removed. This approach often emphasises quantity-based targets for stressor reduction. Outcome-based goals (or ecosystem-based management) focus on maintaining or improving the condition of aquatic ecosystems through comprehensive interventions that address multiple pressures. This approach requires detailed information about ecosystem value, condition and extent, and the various threats affecting each system, requiring more holistic management strategies aimed at protecting or restoring ecosystem function and resilience. Ecosystem services and economic value are important considerations for outcome-based goals.

In the context of the Reef 2050 WQIP, both approaches are essential. Stressor-based goals are necessary because the Reef 2050 WQIP specifically addresses water quality pressures on GBR ecosystems, with clear targets for reducing pollutant loads and risk. However, the Reef 2050 WQIP exists within the broader Reef 2050 Long Term Sustainability Plan, which considers all pressures on GBR ecosystems. This broader context recognises that reducing water quality pressures helps maintain ecosystem health and resilience in the face of other challenges, particularly climate change.

Therefore, outcome-based goals taking into account the extent and value of ecosystems within each management unit must also guide water quality management planning. This is especially important when considering future scenarios of increasing climate impacts and the importance of preserving high-value ecosystems that maintain biodiversity and can serve as sources for recolonisation. Improving water quality now is critical both for the recovery and maintenance of currently affected ecosystems and for ensuring water quality does not become an additional pressure on critical habitats that still retain good condition and rich biodiversity.

This assessment integrates both of these approaches, with the objective of achieving good water quality now and maintaining it into the future, to support the health of, and reduce pollutant impact on, the GBR’s freshwater floodplain wetlands, coral and seagrass ecosystems. To articulate the logic for the assessment, a

management response framework has been defined that recognises that water quality is one of several drivers of the current condition of GBR ecosystems. It is guided by several key principles and considerations:

1. **Protection as well as recovery:** The framework recognises the importance of both protecting ecosystems in good condition and improving ecosystems in poor condition, acknowledging the complex relationship between pollutant exposure and ecosystem health.
 - a. Prioritising the protection of ‘good’ condition ecosystems – There is strong scientific evidence for protecting ecosystems in good condition as a primary management strategy. These ecosystems generally possess higher ecological resilience, greater biodiversity, and provide essential ecological services compared to degraded systems (Thompson et al. 2023; Fabricius et al. 2024; McKenzie et al. 2024a). Protection is typically more cost-effective than restoration, and many degraded ecosystems may never fully recover to their original state, even after pollutant pressures are removed. This approach is especially critical to preserve ecosystems with high biodiversity that are potential reservoirs for recolonisation of disturbed areas. These critical ecosystems will become increasingly important to conserve as climate change impacts become more frequent and widespread.
 - b. Addressing ‘poor’ condition ecosystems – Reducing pollutant pressures on ecosystems in poor condition remains a high priority for several reasons. First, many degraded ecosystems can naturally recover if they have not crossed ecological thresholds into alternative stable states. Tropical ecosystems in particular have evolved recovery mechanisms in response to extreme natural disturbances like cyclones and flooding, but these recovery processes can depend on favourable water quality conditions. Additionally, areas in poor condition can become sources of secondary stressors that affect connected areas—for example, by harbouring disease organisms, or supporting pest species that can spread. Therefore, improving water quality delivers benefits beyond the immediately affected areas (e.g. Davis and Pearson 2024). The extent of ecosystems within a region that are in a degraded state may also continue to expand if pollutant pressures are not reduced. This is particularly important in the context of climate change with the prediction of a higher frequency of intensive weather events, and the need to minimise multiple pressures as much as possible (Fabricius et al. 2024; Uthicke et al. 2024). While the scope of the management responses for this assessment is focused on water quality pressures and stressors, the framework recognises the need to inform relevant authorities when other drivers of ecosystem decline are identified through monitoring and assessment (e.g. pests and disease).
 - c. Understanding complex exposure-condition responses – The relationship between pollutant exposure and ecosystem condition may involve response time lags and the cumulative impacts of multiple pressures (e.g. Collier et al. 2024; Diaz-Pulido et al. 2024). An ecosystem currently in good condition despite high pollutant exposure should not be assumed to be resilient—it may instead be in a pre-decline state where impacts are accumulating but not yet measurable. Ecosystems often demonstrate initial resistance to stressors before exhibiting observable changes, making early intervention crucial even when condition appears stable. In addition, the GBR’s wetland and marine ecosystems face numerous pressures beyond water quality (e.g. GBRMPA 2024; McKenzie et al. 2024a).
2. **Consider future developments:** The framework recognises the need to prepare for future developments that could create new pressures on the ecosystems. By implementing appropriate management responses now, ecosystems can remain in good condition as landscapes and land uses change. This preventative approach is essential for long-term ecological resilience.
3. **Build on existing foundations:** Substantial investments and efforts have already been made to develop and implement management solutions to reduce water quality pressures on the GBR’s critical ecosystems. Many programs and relationships are well-established and play important roles in the GBR catchment area. The framework builds upon and strengthens these existing foundations rather than replacing them.
4. **Accelerating management uptake:** It is widely acknowledged that current levels and rates in the uptake of management actions may not be sufficient to achieve the pollutant reductions required

for ecosystem protection. Enabling actions, such as developing trust and collaborative approaches, are critical to accelerate uptake (e.g. Murray-Prior et al. 2024). Additionally, other actions beyond minimum standards including priority practices that directly improve water quality outcomes, and system repair and landscape restoration actions including engineering solutions will be necessary to meet pollutant reduction targets.

5. **Flexibility and adaptability:** Water quality management in the GBR is a complex challenge, extending across landscapes and jurisdictions, involving many actors and stakeholders, with no one-size-fits-all solution. Therefore, a solution is required that supports flexibility and adaptability that would allow management responses to be tailored to specific contexts and pressures across different catchments and ecosystems.

Collectively, these principles have informed the development of a **Water Quality Management Response Decision Support Framework** for this assessment (Section 7). The approach focuses on informing decision-makers about management needs in terms of the scale, intensity and comprehensiveness required for each basin and/or management unit. By doing so, it offers decision-makers the required flexibility to develop a strategic portfolio of actions that might include:

- Lower-cost proactive solutions in some areas that deliver strategic long-term ecological benefits;
- Targeted medium-cost management solutions in other areas that can achieve more rapid improvements for specific ecosystems; and
- Large-scale, comprehensive interventions across multiple land uses in areas requiring substantial pollutant reductions for ecosystem recovery (with correspondingly higher levels of investment).

It is important to note that the assessment is not intended as an exhaustive "recipe" detailing every action needed to achieve pollutant reductions. The actions and enabling factors required to achieve meaningful water quality improvements are diverse and context-specific, and not all have been captured here. The next stage of designing appropriate context-specific programs of work will need to draw upon both local expertise and knowledge and social and behavioural research and data to optimise engagement, adoption and outcomes.

1.3 Scope and outputs

The major components of the assessment are illustrated in Figure 1. The assessment follows a systematic sequence of interconnected steps. It begins with characterising the 35 basins across the GBR catchment area, establishing context through key metrics including area, climate and rainfall patterns, river discharge, and dominant land uses (Section 2.1). It then evaluates critical water quality influences through spatial analysis of historical and recent vegetation clearing (including riparian zones), floodplain wetland loss and modification, groundcover assessment, and gully density mapping (Section 2.2). Next, pollutant load distribution across the GBR catchment area is examined, identifying primary pollutant sources and their pathways into GBR waterways (Section 3).

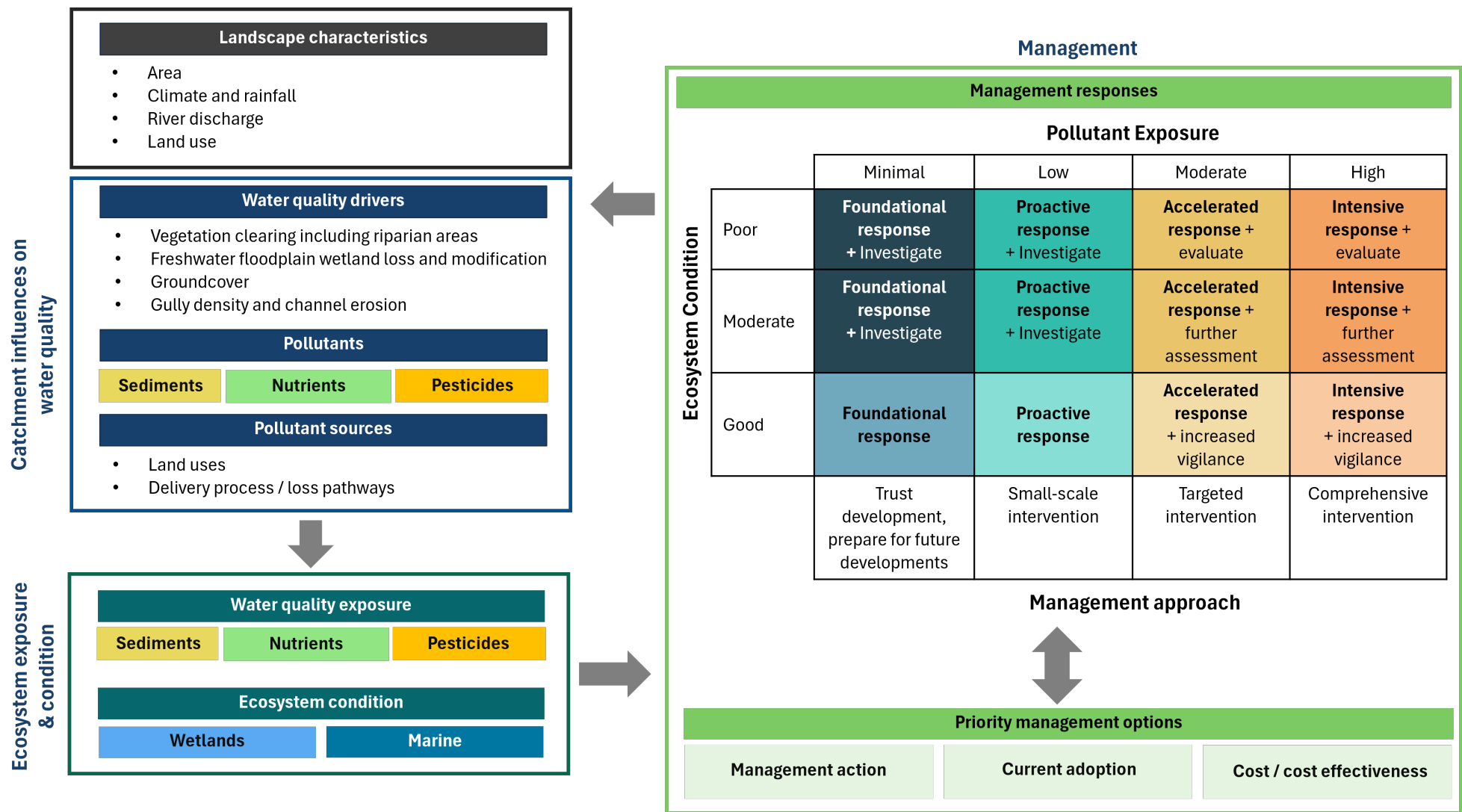


Figure 1. Representation of the major components of the GBR water quality spatial management prioritisation.

The assessment then determines pollutant hazard, exposure and/or risk to three key ecosystems—freshwater floodplain wetlands, seagrass meadows, and coral reefs (Section 4). Section 5 evaluates current ecosystem condition, acknowledging that water quality represents one of multiple influencing factors. A range of potential management options is identified (Section 6), before assessing pollutant exposure and ecosystem condition to identify appropriate management responses (introduced in Section 1.2) and corresponding actions for each pollutant-ecosystem interaction across individual basins (and management units where appropriate) (Section 7).

The assessment follows an adaptive management cycle, where implementing priority management responses drives improvements in water quality factors, subsequently reducing pollutant loads entering GBR waterways, thereby creating a continuous cycle of improvement.

The structure of the report follows the major steps illustrated in Figure 1, in addition to presentation of the summary and conclusions (Section 8). Section 8 summarises the key findings, identifies limitations and knowledge gaps. The report is supported by a separate comprehensive set of appendices (Appendices 1 to 8).

The scope of the assessment in terms of ecosystems, geographic boundaries and time periods is closely aligned with that of the Paddock to Reef Integrated Monitoring, Modelling and Reporting program (P2R program) and summarised in Table 1. A list of definitions relevant to the assessment is provided in the Glossary.

Within the GBR catchment area the assessment includes the 35 main GBR river basins, and where relevant, the 48 management units which break down the Herbert, Burdekin and Fitzroy basins into smaller catchment areas (Figure 2).

The ecosystem values in the Reef 2050 WQIP framework (corals, seagrass, wetlands and their biodiversity) are broad and encompass more habitats, organisms and species than what is within scope for this assessment. The freshwater ecosystems included in the assessment are floodplain palustrine (vegetated swamp) and lacustrine (lake) wetlands throughout the GBR catchment area. Floodplains and their wetlands have hydrological and ecological connections with GBR coastal waters and ecosystems. Specifically, the freshwater wetland aggregations defined in the P2R Wetland Condition Monitoring program (Tilden and Vandergragt 2022; Wetland Condition Science Team 2024) are used as the basis for assessment of wetland condition (Figure 5). The monitored floodplain wetland aggregations contain ~ 70% of all GBR catchment area freshwater floodplain wetlands. These aggregations form meta ecosystems hydrologically connected to GBR inshore waters. Many are located along coastal areas, with exceptions such as in the Fitzroy basin where aggregations also occur further inland. Concentrations of multiple wetlands provide focus areas for integrated, large scale, aggregation-specific management programs. Riverine and estuarine wetlands (e.g. freshwater rivers and streams, saltmarsh and mangrove communities) are out of scope, and although it is well recognised these systems can play an important role in material processing between the catchment and reef (e.g. Davis and Pearson 2024), there is limited quantification of these processes (Burford et al. 2024); and this is an area for further research and monitoring in the GBR.

The marine ecosystems included in the assessment are coral reefs and seagrass meadows (Figure 4). There is insufficient data to inform the assessment of pollutant exposure to other marine ecosystems and species such as mangroves, soft bottom communities, most plankton communities and fish. However, these systems are still recognised as important to the health of the GBR and are incorporated in the discussion of marine ecosystem condition where possible. Further detail of the source of these spatial layers is included in Appendix 1.

Within the catchment, the land uses considered in terms of management are those within the scope of the P2R program: grazing, sugarcane, horticulture, bananas, dryland cropping and urban. However, all land uses are presented in the discussion of pollutant sources. The primary pollutants of concern are sediments, including fine terrigenous sediments where specified, nutrients, including dissolved inorganic nitrogen (DIN), particulate nitrogen (PN), particulate phosphorus (PP) where specified and pesticides including PSII inhibiting herbicides, other herbicides and insecticides. The specific forms of nutrients vary between the wetland and

marine assessment due to data availability. In marine ecosystems, nitrogen (N) is considered to be the limiting nutrient and has therefore been the focus of studies in the marine environment. There is limited information about the direct impacts of phosphorus (P) on GBR freshwater and marine ecosystems, and information about P management is also limited. The complex nutrient transformation processes that occur between catchment and marine ecosystems make it challenging to understand the role of particulate nutrients (N and P) in the GBR, and since particulate nutrients are typically bound to fine sediment in transport, they are typically grouped with fine sediments in the context of management responses. Although particulate nutrients are not considered individually in this assessment, current estimates of pollutant loads are provided as pollutant load reduction targets are defined for both PN and PP.

Additional assessment areas have been defined for the condition and exposure assessments including 'wetland aggregations', 'river footprints' and 'marine waterbodies', described in Table 1.

Table 1. Summary of the ecosystem scope and spatial boundaries used in the assessment. Further detail of the sources of these datasets is provided in Appendix 1. Note: Land uses shown in bold are reported as part of the P2R program.

Element	Feature	Scope	Source (see Appendix 1 for details)
GBR catchment area	35 major drainage basins	There are 35 basins that drain into the GBR. A basin can be made up of a single or multiple rivers (e.g. North and South Johnstone rivers belong to one basin, the Johnstone Basin). Basins are primarily used here when discussing the relative delivery of a pollutant to the marine system.	Paddock to Reef Program data (Figure 2)
	48 management units	There are three large basins in the GBR catchment area that are divided into smaller catchments - the Burdekin, Fitzroy and Herbert basins. The resulting boundaries are referred to as Management Units.	Paddock to Reef Program data (Figure 2)
Land use	48 management units	¹ Grazing, sugarcane, horticulture, bananas, dryland cropping , irrigated cropping, dairy, urban . Management options only considered for land uses in bold.	Department of Environment and Science (2023b) (Figure 3)
Ecosystems	Marine	Coral reefs Seagrass meadows (compilation of surveyed extent and modelled deepwater seagrass)	GBRMPA (2024); Hillyer and Moss (2024) Coles et al. (2009); Carter et al. (2016); Waterhouse et al. (2016); McKenzie et al. (2022); Rasheed et al. (2023) (Figure 4)
	Wetland	Floodplain palustrine (vegetated swamp) and lacustrine (lake) wetlands (freshwater floodplain wetlands)	Queensland Wetland Data Version 6. Department of Environment and Science (2023a) (Figure 4)
Pollutants	48 management units	Sediments, including fine sediments where specified. Nutrients, including dissolved inorganic nitrogen, particulate nitrogen, and particulate phosphorus, where specified.	Paddock to Reef Program data
	29 major drainage basins (end-of-catchment)	Pesticides - a standard set of 22 pesticides that includes 9 PSII inhibiting herbicides, 10 other herbicides and 3 insecticides.	Paddock to Reef Program data
Additional assessment areas	Wetland aggregations	Areas with relatively high concentrations of natural and semi-natural, freshwater floodplain wetlands in the GBR catchment area.	As defined in the Paddock to Reef Wetland Condition Monitoring program (Figure 5)

Element	Feature	Scope	Source (see Appendix 1 for details)
	River footprints	A river footprint is modelled for each basin in the eReefs marine model (1 January 2011 to 30 October 2022) and is defined as the area where more than 1% of river water is present.	eReefs GBR4 model output
	Marine waterbodies	Cross-shelf marine boundaries including: Inshore (including Enclosed [Macro-tidal Enclosed Coastal and Enclosed Coastal waterbodies combined] and Open Coastal [Macro-tidal Open Coastal and Open Coastal waterbodies combined]; Midshelf; Offshore	Defined in the Great Barrier Reef Water Quality Guideline Values (GBRMPA 2010)

In addition to the supporting information described above, there are several specific outputs of the project that are relevant to a range of audiences, including:

- The Water Quality Management Response Decision Support Framework and associated explanations (Figure 56, Table 24).
- A summary table of the results of the freshwater floodplain wetland and marine ecosystem exposure and condition assessments, underpinning the identification of water quality management responses for each of the 48 management units (Table 26).
- A summary table showing the water quality management response for each management unit, the management focus, and dominant land uses relevant to management (Table i).

It is recognised that this report captures a comprehensive yet lengthy presentation of the logic, methods and results for the assessment. Therefore, to ensure that the outputs are accessible to a wide audience, a series of 'basin profiles' are proposed to communicate the results in a concise and graphically illustrated output for each of the 35 GBR basins. These profiles will be particularly beneficial for supporting the review of the Reef 2050 WQIP and the development of Reef Regional Water Quality Strategies over the next six months. A worked example of a basin profile for the Tully basin is presented in Section 7.4.

1.4 Links to other projects, programs and initiatives

The project integrates diverse information sources and builds on several major projects and initiatives. In particular, it draws on evidence from the 2022 Scientific Consensus Statement (SCS)⁵ and uses many of the same datasets as the review of the GBR water quality targets (Waterhouse et al. 2025). Accordingly, additional review of the alignment between these information sources has been a critical component in the final stages of the project. It also draws heavily on information and frameworks from several major programs including the P2R program⁶ and all of its components, and the Queensland Wetlands Program⁷ including the supporting information portal, *WetlandInfo*⁸.

The approach to the assessment fits well within the Queensland Wetlands Program's Whole-of-System Values-Based Framework which recognises the importance of the diversity of values and their beneficiaries in decision making. It adopts a systematic, whole-of-system approach to defining management objectives taking into account system processes and components, a range of management interventions and factors affecting those including biophysical, social and economic drivers. While the process is more comprehensive than can be addressed in this assessment, it has many shared principles. The current assessment could inform several steps of the work needed to deliver the Whole-of-System, Values-Based Framework at the GBR-wide scale including analysis of water quality drivers, objectives and management interventions.

⁵ www.reefwqconsensus.com.au

⁶ <https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef>

⁷ <https://www.dcceew.gov.au/water/wetlands/programs/queensland-wetlands-program>

⁸ <https://wetlandinfo.des.qld.gov.au/wetlands/>

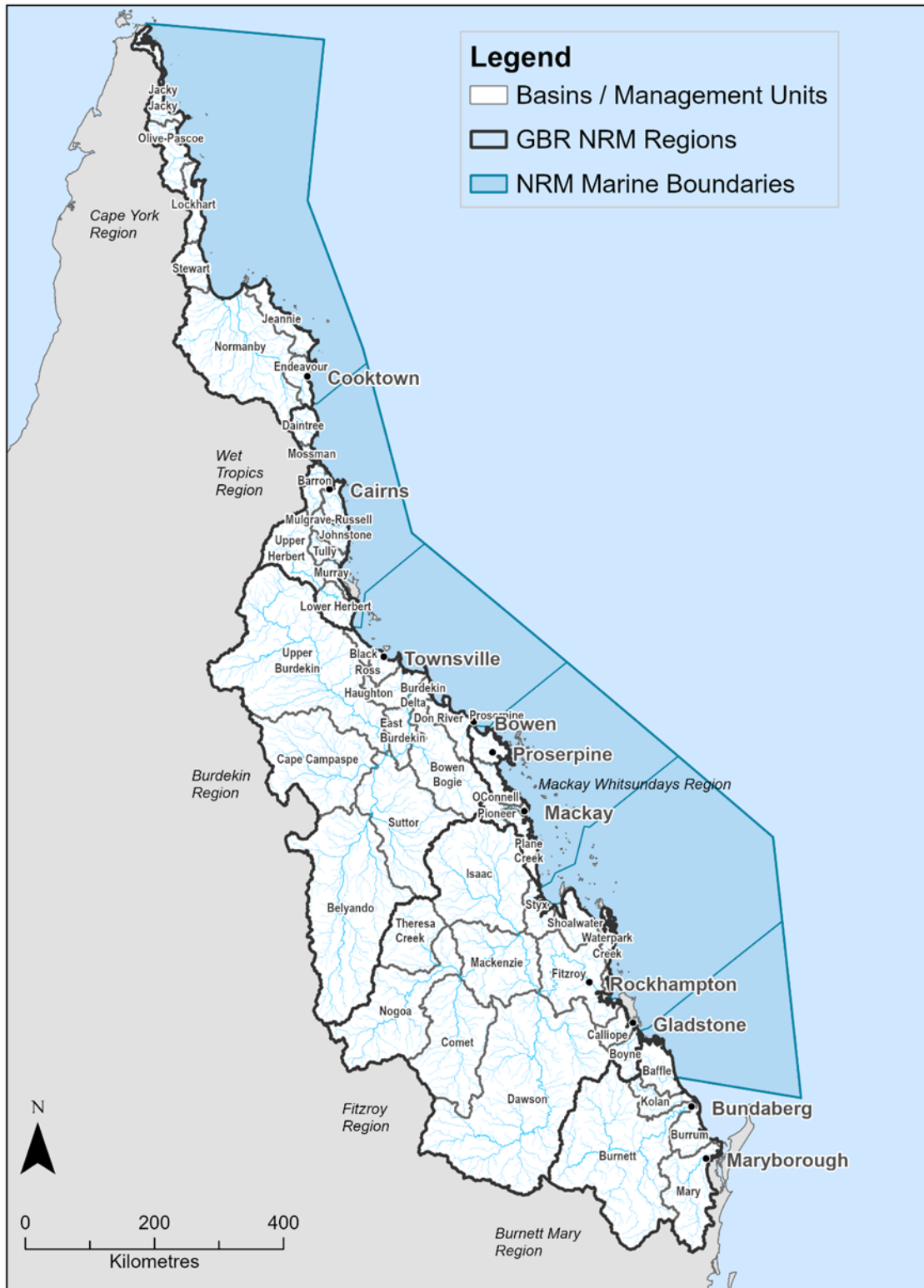


Figure 2. The GBR catchment area, 35 basins and 48 management units.

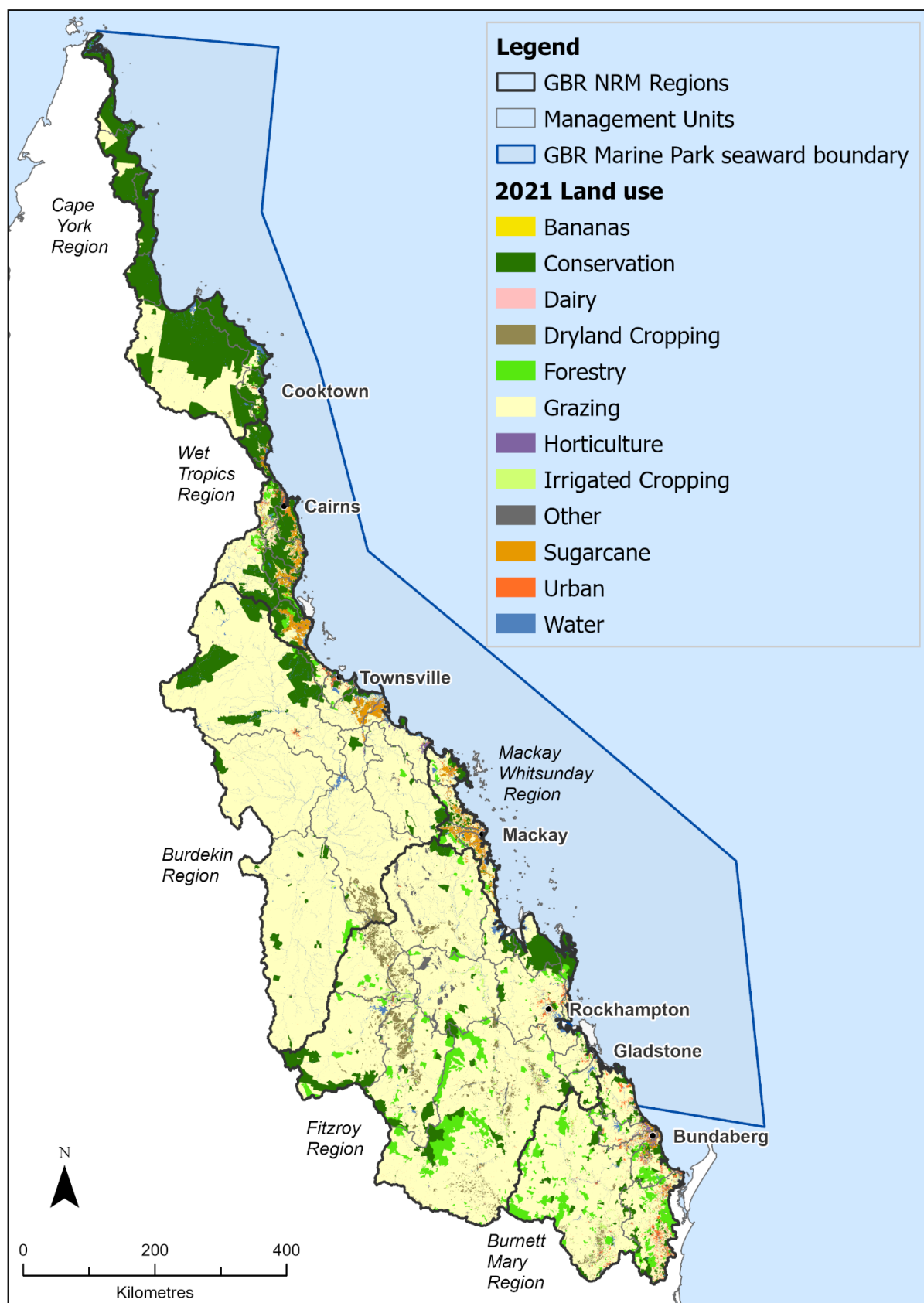


Figure 3. Major land uses in the GBR catchment area, 35 basins and 48 management units (labelled in Figure 4). Note that the management unit boundaries are equivalent to the basins except in the Herbert (Upper and Lower Herbert management units), Burdekin (East Burdekin, Burdekin Delta, Belyando, Suttor, Upper Burdekin, Bowen Bogie and Cape Campaspe management units) and Fitzroy (Lower Fitzroy, Dawson, Isaac, Mackenzie, Comet, Nogoa, and Theresa Creek management units) basins. Source: Land use data Queensland Land Use Mapping Program (2021).

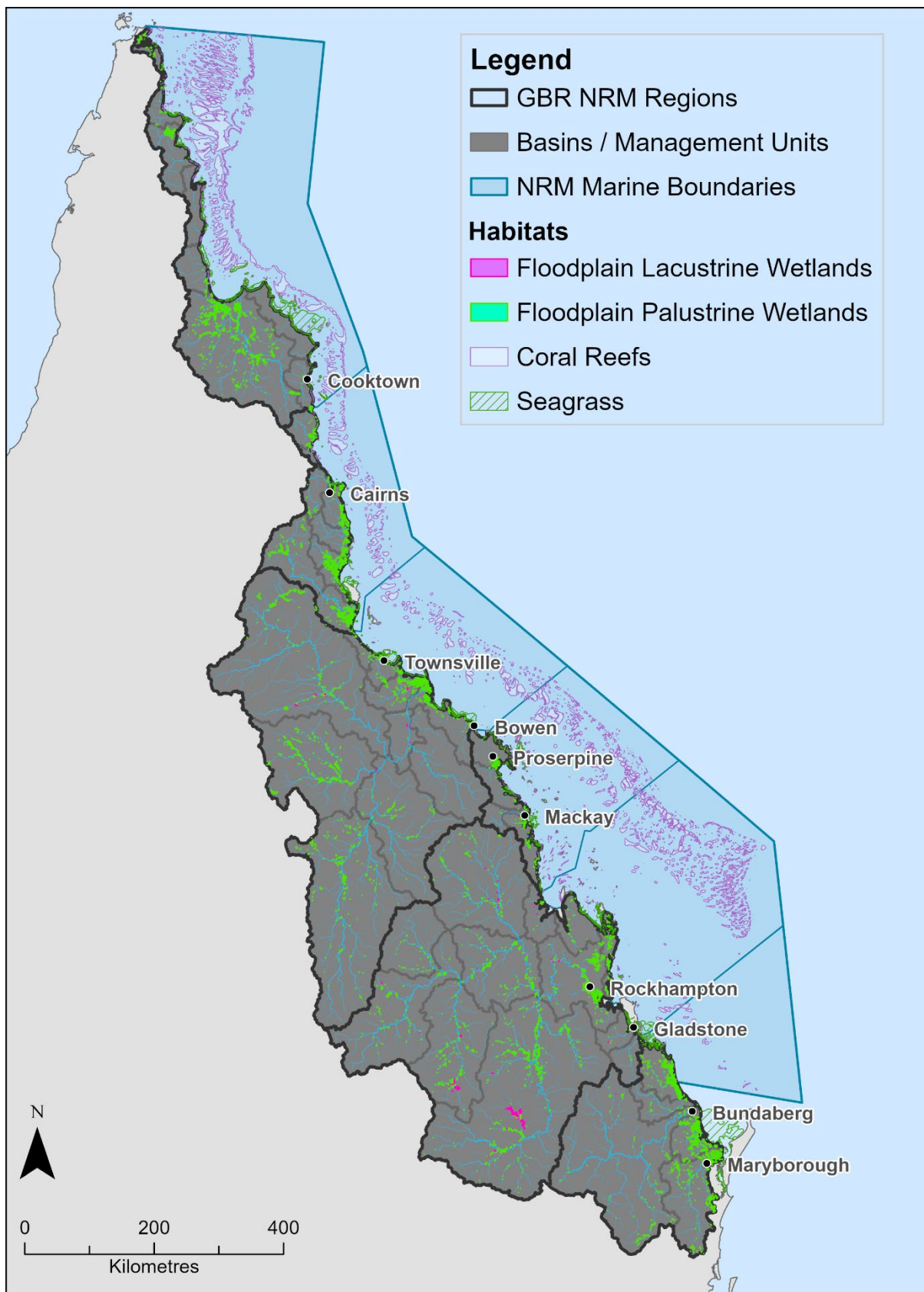


Figure 4. Ecosystems included in the assessment and associated boundaries. Data sources: Coral reefs - GBRMPA (2024), DETSI (2024); Seagrass - Coles et al. (2009), Carter et al. (2016), Waterhouse et al. (2016), McKenzie et al. (2022), Rasheed et al. (2023); Freshwater (palustrine and lacustrine) floodplain wetlands - Queensland Wetland Data Version 6. Department of Environment and Science (2023a). Refer to WetlandInfo Wetland Maps to view the wetlands at a higher resolution. Freshwater wetland polygons are displayed with a 1 pt outline, which may make them appear slightly larger than their actual size.

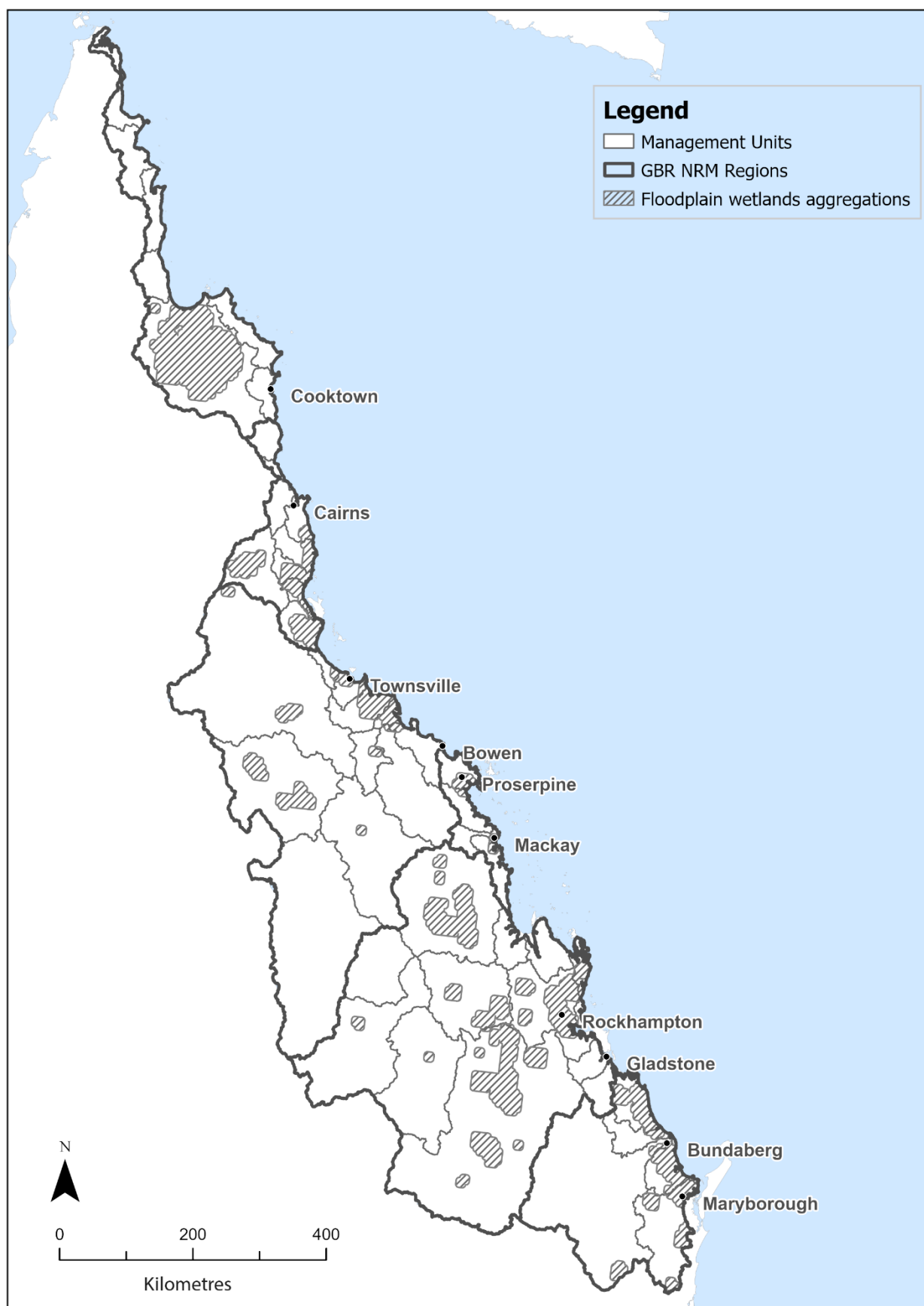


Figure 5. Freshwater floodplain wetland aggregations incorporated within the Paddock to Reef Wetland Condition Monitoring program.

2. Catchment influences on water quality

The framework for the assessment is underpinned by a substantial body of evidence linking GBR catchment influences to wetland, waterway and GBR water quality. This evidence is detailed in the 2022 SCS with comprehensive syntheses of 30 specific questions and summary information. Rather than repeat the evidence in detail here, this report contains relevant summary information sourced directly from the 2022 SCS to support the approach and assist in the interpretation of data.

This assessment takes a whole-of-system approach to managing water quality in the GBR and its catchment area, starting with an examination of the catchment characteristics and drivers of water quality conditions.

2.1 Landscape characteristics

The GBR catchment area encompasses approximately 424,000 km² across six Natural Resource Management (NRM) regions and has 35 basins with diverse landscape characteristics. The regions are Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary. Each NRM region groups and represents catchments with similar climate and bioregional setting, with boundaries extending into the adjacent marine area. These variations in landscape characteristics and land use patterns can affect the type and amount of pollutant generation and, in conjunction with water quality drivers, can influence the transport and delivery of pollutants to the GBR wetland and marine ecosystems. For this assessment, catchment area, climate, rainfall, river discharge and land use are considered the main landscape characteristics that can influence water quality. These characteristics are summarised in Table 2.

There are significant variations in basin size, with the Fitzroy (14.2 million ha) and Burdekin (13.1 million ha) basins being the largest, collectively accounting for about 65% of the total GBR catchment area. In contrast, the Mossman basin is the smallest at just 47,678 hectares. Rainfall patterns show pronounced geographic variability, with the highest annual averages occurring in the Wet Tropics region, particularly in the Mulgrave-Russell (3,239 mm) and Johnstone (3,152 mm) basins. The lowest annual average rainfall occurs in the Burdekin basin (633 mm) particularly to the west. Most catchments experience strongly seasonal rainfall patterns with the wettest periods occurring in summer months, typically between November and March but varies depending on the year. Rainfall events are often accompanied by extreme weather including cyclones and monsoonal troughs that contribute to annual flooding in many basins.

River discharge varies considerably between basins (Table 2), as highlighted in Figure 6 which shows the mean annual discharge (1990/91 to 2019/20) and standard deviation for each basin. It shows a general north-south gradient with the wettest catchments in the Cape York and Wet Tropics NRM regions (south to the Herbert River). These northern rivers, and the Wet Tropics rivers in particular, tend to have more consistent flows between seasons and contribute a much greater discharge per unit area than the rivers of the dry tropics (Puignou-Lopez et al. 2025). The Wet Tropics basins cover around 5% of the GBR catchment area (McCloskey et al. 2021a) but contribute around 32% of the mean total annual flow that reaches the GBR. In contrast, the larger dry tropics Burdekin and Fitzroy basins tend to deliver larger flows every 3 to 10 years (Furnas 2003; Lough et al. 2015). While these basins cover 68% of the total GBR catchment area, they only contribute 21% of total freshwater discharge. Rainfall in these basins is influenced by the El Niño Southern Oscillation with the largest flows generated by major events such as rain depressions, the northern Australian monsoon and tropical cyclones.

Land use across the GBR catchment area is dominated by grazing (71% of total area), followed by conservation (17%) and forestry (4.8%). Land use patterns vary considerably between basins. Northern catchments in the Cape York region such as the Stewart, Lockhart, and Jeannie are dominated by conservation areas (>85% of their catchment areas), while grazing dominates in other regions including many of the Burdekin and Fitzroy catchments (e.g. 88% of the area in the Burdekin basin is grazing land). Sugarcane production accounts for a larger proportion of land use in the Wet Tropics and Mackay Whitsunday regions. Urban areas comprise 0.8% of the total GBR catchment but reach higher proportions in specific basins like the Ross (8.0%) and Barron (6.1%). Other land uses such as mining and industrial areas can also be important in some basins including the Fitzroy and Boyne, but the areas are relatively small.

Table 2. Summary of landscape characteristics in the 35 GBR basins relevant to water quality. Sources: Area – Queensland Land Use Mapping Program (2021); Climate and annual average rainfall – Australian & Queensland Government 2019⁹; Long-term mean river discharge (Puignou-Lopez et al. 2025); dominant land uses – QLUMP (2021).

NRM Region	Basin	Area (ha)	Climate	Annual average rainfall (mm)	Long-term mean river discharge (ML) (1990/91 to 2019/20)	Dominant land uses
Cape York	Jacky Jacky	299,036	The catchments usually experience annual wet and dry seasons, with most of the annual rainfall typically falling in the summer months. The catchments also experience extreme weather events such as cyclones and monsoonal troughs during the wet season. These high volume rainfall events typically bring annual flooding.	1,703	2,740,000	Conservation (82%), Water (9.6%), Grazing (8.7%)
	Olive Pascoe	417,245		1,668	3,860,000	Conservation (79%), Grazing (21%), Water (0.3%)
	Lockhart	278,605		1,589	1,870,000	Conservation (92%), Water (5.3%), Grazing (2.7%)
	Stewart	283,542		1,216	1,050,000	Conservation (94%), Water (4.1%), Grazing (2.3%)
	Normanby	2,440,153		1,104	4,260,000	Conservation (52%), Grazing (47%), Water (0.9%), Dryland Cropping (0.1%)
	Jeannie	363,721		1,345	1,430,000	Conservation (85%), Grazing (7.3%), Water (6.9%), Forestry (0.6%), Other (0.1%)
	Endeavour	218,616		1,747	1,590,000	Conservation (72%), Grazing (24%), Urban (1.5%), Water (1.4%), Forestry (0.9%), Other (0.3%), Dryland Cropping (0.1%)
Wet Tropics	Daintree	210,527	Although rainfall totals are typically concentrated in the summer months, these catchments receive regular rainfall throughout the year. The region also experiences occasional cyclones.	2,521	2,300,000	Conservation (86%), Grazing (8.0%), Water (2.6%), Sugarcane (1.8%), Urban (1.1%), Other (0.1%), Horticulture (0.1%)
	Mossman	47,678		2,109	648,000	Conservation (73%), Sugarcane (9.3%), Grazing (5.5%), Urban (5.3%), Water (4.8%), Other (2.2%), Forestry (0.1%), Horticulture (0.1%)

⁹ <https://www.reefplan.qld.gov.au/reef-regions>

NRM Region	Basin	Area (ha)	Climate	Annual average rainfall (mm)	Long-term mean river discharge (ML) (1990/91 to 2019/20)	Dominant land uses
	Barron	218,825		1,442	865,000	Conservation (35%), Grazing (31%), Forestry (11%), Urban (6.1%), Sugarcane (3.9%), Water (3.7%), Irrigated Cropping (3.4%), Horticulture (3.0%), Other (1.7%), Bananas (1.1%), Dairy (0.4%), Dryland Cropping (0.1%)
	Mulgrave-Russell	197,473	The Mulgrave-Russell has the highest annual average rainfall in the Wet Tropics region as well as the whole GBR catchment area. The majority of this rainfall occurs in the summer months. The region also experiences occasional cyclones.	3,239	4,120,000	Conservation (71%), Sugarcane (12%), Grazing (5.6%), Water (5.0%), Urban (3.5%), Other (1.5%), Bananas (0.5%), Forestry (0.3%), Dryland Cropping (0.2%), Horticulture (0.2%), Irrigated Cropping (0.1%)
	Johnstone	231,650	The Johnstone catchment has one of the highest annual average rainfalls in the Wet Tropics as well as the whole GBR catchment area. Rainfall is strongly seasonal, with 80% occurring during the summer months. The region also experiences occasional cyclones.	3,152	4,720,000	Conservation (56%), Grazing (23%), Sugarcane (11%), Urban (2.9%), Water (2.4%), Bananas (2.2%), Dairy (1.9%), Other (0.7%), Horticulture (0.5%), Dryland Cropping (0.3%), Irrigated Cropping (0.2%), Forestry (0.1%)
	Tully	166,845	Although rainfall totals are typically concentrated in the summer months, these catchments receive regular rainfall throughout the year. The region also experiences occasional cyclones.	2,763	3,330,000	Conservation (73%), Sugarcane (12%), Grazing (6.8%), Water (2.6%), Bananas (2.4%), Forestry (1.7%), Urban (1.2%), Other (0.3%), Horticulture (0.2%), Dryland Cropping (0.1%)
	Murray	112,503		2,164	1,510,000	Conservation (62%), Sugarcane (17%), Forestry (9.1%), Grazing (6.5%), Water (2.8%), Urban (1.1%), Other (0.6%), Bananas (0.4%),

NRM Region	Basin	Area (ha)	Climate	Annual average rainfall (mm)	Long-term mean river discharge (ML) (1990/91 to 2019/20)	Dominant land uses
						Horticulture (0.3%), Dryland Cropping (0.1%)
	Herbert	985,181	The catchment consists of wet and dry regions with the rainfall increasing towards the coastline. Heavy rainfall on the coastal floodplains during summer months is common. The region also experiences occasional cyclones.	1,222	4,440,000	Grazing (50%), Conservation (32%), Sugarcane (7.8%), Forestry (4.6%), Water (4.0%), Urban (0.7%), Irrigated Cropping (0.4%), Other (0.2%), Dryland Cropping (0.1%)
Burdekin	Black	104,052	These catchments usually experience annual wet and dry seasons, with 80% of the area's rainfall during the summer months.	1,523	514,000	Grazing (43%), Conservation (39%), Forestry (7.6%), Urban (3.8%), Water (2.7%), Other (2.0%), Sugarcane (1.0%), Horticulture (0.8%), Irrigated Cropping (0.1%)
	Ross	164,711		1,124	583,000	Grazing (48%), Conservation (27%), Urban (8.0%), Water (7.9%), Other (5.8%), Forestry (2.8%), Horticulture (0.6%), Irrigated Cropping (0.1%)
	Haughton	384,007	The area experiences highly variable rainfall predominantly in summer months, and mostly in coastal areas. The area experiences occasional cyclones and flooding.	953	1,020,000	Grazing (59%), Sugarcane (16%), Conservation (16%), Water (5.8%), Forestry (0.8%), Horticulture (0.7%), Urban (0.7%), Other (0.7%), Irrigated Cropping (0.3%)
	Burdekin	13,060,829	The Burdekin area has a pronounced wet and dry season, with most rain falling in the summer months. The coastal areas have higher rainfall, which gets progressively lower and more variable towards the west.	633	9,000,000	Grazing (88%), Conservation (8.0%), Water (2.1%), Dryland Cropping (1.0%), Forestry (0.6%), Sugarcane (0.3%), Other (0.2%), Irrigated Cropping (0.1%), Urban (0.1%)
	Don	346,632	The area experiences a dry tropical climate with approximately 75% of the rainfall occurring during the summer months. Flooding also occurs, which is often attributed to cyclones.	871	844,000	Grazing (82%), Water (6.9%), Conservation (5.6%), Horticulture (3.3%), Urban (0.9%), Other (0.7%), Irrigated Cropping (0.5%), Sugarcane (0.2%)

NRM Region	Basin	Area (ha)	Climate	Annual average rainfall (mm)	Long-term mean river discharge (ML) (1990/91 to 2019/20)	Dominant land uses
Mackay Whitsunday	Proserpine	251,283	These catchments receive high to very high rainfall, predominantly in the summer months. The area experiences occasional cyclones, including Severe Tropical Cyclone Debbie in March 2017.	1,474	1,420,000	Grazing (50%), Conservation (23%), Sugarcane (9.8%), Water (7.3%), Forestry (5.4%), Urban (2.8%), Other (0.9%), Horticulture (0.3%)
	O'Connell	230,522		1,705	1,380,000	Grazing (50%), Conservation (20%), Sugarcane (13%), Water (7.1%), Forestry (6.7%), Urban (2.2%), Other (0.7%), Horticulture (0.1%), Irrigated Cropping (0.1%)
	Pioneer	166,431		1,578	825,000	Grazing (31%), Conservation (21%), Sugarcane (19%), Forestry (18%), Water (4.9%), Urban (3.9%), Other (2.3%), Dryland Cropping (0.1%)
	Plane	254,680		1,526	1,460,000	Grazing (38%), Sugarcane (26%), Conservation (15%), Water (10%), Forestry (5.9%), Urban (3.9%), Other (1.3%), Irrigated Cropping (0.3%), Horticulture (0.1%)
Fitzroy	Styx	299,512	Rainfall is highly seasonal with the wettest periods occurring in summer months. As coastal catchments, annual rainfall is generally higher compared with the western parts of the Fitzroy region. This area also experiences occasional cyclones.	835	801,000	Grazing (68%), Conservation (15%), Water (13%), Forestry (1.7%), Sugarcane (0.8%), Other (0.5%), Dryland Cropping (0.1%), Urban (0.1%)
	Shoalwater	361,610		864	927,000	Conservation (63%), Grazing (29%), Water (7.8%), Forestry (0.3%), Other (0.3%), Urban (0.1%)
	Waterpark	184,786	Waterpark catchment has the highest annual average rainfall in the Fitzroy region. Rainfall is highly seasonal with the wettest periods occurring in summer months. This area also experiences occasional cyclones.	1,245	556,000	Conservation (51%), Water (17%), Grazing (16%), Forestry (10%), Urban (4.0%), Other (0.7%), Horticulture (0.3%)

NRM Region	Basin	Area (ha)	Climate	Annual average rainfall (mm)	Long-term mean river discharge (ML) (1990/91 to 2019/20)	Dominant land uses
	Fitzroy	14,238,704	The Fitzroy catchment has a subtropical, semi-arid climate characterised by prolonged dry periods often followed by floods. Rainfall is highly seasonal and variable across the catchment, with higher rainfall towards the coast and in the summer months. This area also experiences occasional cyclones.	646	5,600,000	Grazing (79%), Forestry (6.9%), Conservation (6.2%), Dryland Cropping (3.9%), Other (1.5%), Water (1.4%), Irrigated Cropping (0.7%), Urban (0.4%)
	Calliope	217,716	Rainfall is highly seasonal with the wettest periods occurring in summer months. As coastal catchments, annual rainfall is generally higher compared with the western parts of the Fitzroy region. This area also experiences occasional cyclones.	837	388,000	Grazing (78%), Conservation (6.4%), Forestry (5.2%), Urban (3.8%), Other (3.1%), Water (2.9%), Horticulture (0.1%), Irrigated Cropping (0.1%)
	Boyne	249,748		894	324,000	Grazing (75%), Conservation (14%), Forestry (5.4%), Water (4.2%), Other (1.1%), Urban (1.0%), Dryland Cropping (0.2%), Irrigated Cropping (0.1%)
Burnett Mary	Baffle	410,114	The Baffle basin has a moderate, subtropical climate with summer dominated rainfall.	1,045	718,000	Grazing (65%), Conservation (20%), Urban (5.1%), Water (5.1%), Forestry (3.0%), Other (0.8%), Horticulture (0.5%), Sugarcane (0.3%), Irrigated Cropping (0.1%)
	Kolan	289,066	The Kolan basin has a moderate, subtropical climate with summer dominated rainfall. Rainfall varies across the catchment from high rainfall closer to the coast, to lower annual average rainfall in the west.	901	316,000	Grazing (69%), Conservation (8.2%), Forestry (7.8%), Water (4.2%), Urban (3.9%), Sugarcane (3.2%), Horticulture (2.6%), Other (0.6%), Dryland Cropping (0.1%), Irrigated Cropping (0.1%)
	Burnett	3,327,364	The climate is subtropical with the wettest periods occurring in summer months. The majority of the catchment has a lower annual average rainfall than the other coastal catchments in the region.	688	955,000	Grazing (77%), Forestry (13%), Conservation (4.4%), Dryland Cropping (1.8%), Irrigated Cropping (1.0%), Urban (1.0%), Water (0.8%),

NRM Region	Basin	Area (ha)	Climate	Annual average rainfall (mm)	Long-term mean river discharge (ML) (1990/91 to 2019/20)	Dominant land uses
						Other (0.5%), Horticulture (0.4%), Sugarcane (0.4%)
	Burrum	334,559	These basins have a moderate, subtropical climate with the wettest periods occurring in summer months.	902	318,000	Grazing (40%), Forestry (23%), Conservation (18%), Sugarcane (6.1%), Urban (5.5%), Horticulture (4.1%), Water (2.0%), Other (1.5%), Irrigated Cropping (0.2%)
	Mary	941,985		1,084	1,800,000	Grazing (55%), Forestry (20%), Conservation (13%), Urban (6.6%), Sugarcane (1.5%), Water (1.2%), Other (1.1%), Horticulture (0.7%), Dairy (0.5%), Irrigated Cropping (0.3%), Dryland Cropping (0.1%)
	GBR-wide TOTAL	42,289,911			68,500,000	Grazing (71%), Conservation (17%), Forestry (4.8%), Water (2.3%), Dryland Cropping (1.8%), Sugarcane (1.2%), Other (0.8%), Urban (0.8%), Irrigated Cropping (0.4%), Horticulture (0.2%)

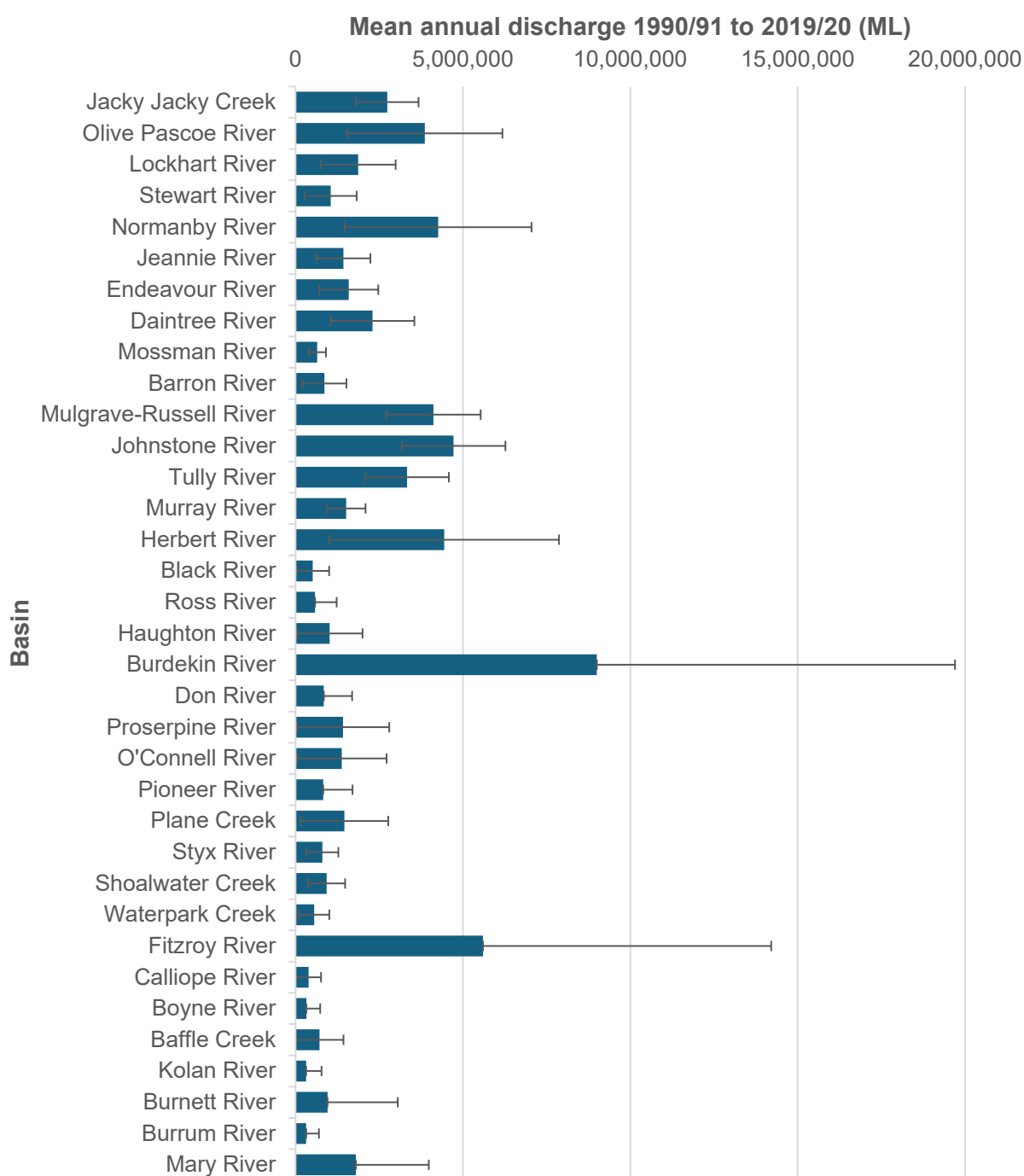


Figure 6. Mean annual discharge (ML, 1990/91 to 2019/20), with 1σ standard deviation for the 35 basins in the GBR catchment. Data source: Puignou Lopez et al. (2025).

2.2 Water quality drivers

The GBR catchment area has undergone substantial modification since European settlement, with significant changes to land use and landscape characteristics that have altered natural ecosystem processes. These modifications have profound implications for water quality in the GBR, with evidence showing that pollutant loads from the catchment area have increased substantially from pre-development levels. Fine sediment

loads have increased by 1.4 to 5 times and dissolved inorganic nitrogen by 1.5 to 3 times, depending on the basin (Waterhouse et al. 2024a).

There are several important drivers of land-based runoff in the GBR catchment area that can influence the quantity and type of pollutants entering GBR waterways. For the purpose of this assessment, the focus is on four main aspects of catchment condition that influence water quality: vegetation extent and clearing including of riparian areas, floodplain wetland loss and modification, groundcover condition, and gully density. Management drivers are also critical and are considered in Section 6. The drivers presented here influence the generation, mobilisation, and transport of pollutants through various pathways including hillslope, gully and streambank erosion, subsurface movement, and direct discharge. Modification of hydrologic connectivity through the construction of dams, weirs and other water storages is important for GBR ecosystems (e.g. see Waterhouse et al. 2023) but is not within the scope of this assessment.

These drivers operate across multiple spatial and temporal scales, often interacting with each other and with climatic factors to influence pollutant transport into GBR catchment waterways. These interactions can lead to pulse events where pollutants are mobilised and transported downstream, particularly during intense rainfall events, and especially after drought periods. Understanding the distribution, extent and impact of these drivers is essential for effective water quality management in the GBR catchment area, allowing for targeted interventions that address the root causes of degraded water quality.

The information presented in this section will be used to provide context for the priority management options for each management unit, presented in Sections 7 and 8.

2.2.1 Vegetation clearing

Vegetation clearing is one of the most significant drivers affecting land-based runoff to the GBR's waterways. Historical and ongoing clearing of native vegetation has substantially modified catchment hydrology, resulting in increased runoff volumes and velocities while simultaneously reducing the landscape's natural capacity to trap and filter pollutants.

Research has demonstrated that the clearing and removal of vegetation alters surface water runoff patterns. For instance, a long-term study examining the impacts of extensive clearing of brigalow woodland in the Fitzroy Basin (93% cleared between 1962 and 1999) for conversion to grazing lands, showed that the resultant clearing has led to a twofold increase in runoff compared to virgin brigalow woodland (Thornton and Elledge 2022). This increased runoff has been accompanied by higher peak flow rates which accelerate erosion processes and pollutant transport.

The removal of vegetation cover fundamentally changes infiltration processes in the landscape. Plot-scale trials have consistently shown that clearing and subsequent soil compaction results in less infiltration and greater surface runoff (McIvor et al. 1995; Roth 2004). In the Upper Burdekin catchment, Peña-Arancibia et al. (2012) observed that vegetation clearing was associated with a decrease in river base flow and an increase in discharge during large rainfall events, though mean annual discharge remained relatively stable. The combined effects of reduced infiltration and increased surface runoff create more 'flashy' hydrological systems, where rainfall events generate faster and more intense runoff responses.

The effects of vegetation clearing extend beyond immediate hydrological impacts to influence broader geomorphological processes. When clearing occurs on erodible soils and steep terrain, the resulting increased runoff energy and reduced soil cohesion can trigger accelerated gully formation and channel incision. These geomorphic changes further alter catchment hydrology and sediment delivery processes, creating a cascading effect on water quality (Wilkinson et al. 2024). In the Daintree River, for example, areas where riparian vegetation has been cleared show streambank erosion rates up to 6.5 times higher than areas with intact vegetation (Bartley et al. 2008).

The extensive modification of coastal floodplains through vegetation clearing and drainage network installation also has ramifications for water quality, in addition to reducing infiltration and accelerating runoff.

Vegetation clearing continues to be ongoing in parts of the GBR catchment area, with the potential to exacerbate existing water quality issues. Therefore, understanding where vegetation clearing has been, or continues to be, a concern is an important step in targeting interventions to prevent further clearing and/or actively restore vegetation to mitigate water quality impacts.

Data considered in this assessment examine vegetation changes at three spatial scales: 1) the management unit and basin; 2) floodplain; and 3) riparian areas of streams and rivers and riparian areas of floodplain freshwater wetlands. For each scale, the historical levels of clearing and the remnant extent, the total extent of woody vegetation (including remnant and regrowth) and recent clearing rates of woody vegetation are explored.

2.2.1.1 Methods for calculating vegetation extent and clearing

Historical clearing of native vegetation prior to 2018

The Queensland biodiversity status of 2017 remnant regional ecosystems data (Neldner et al. 2023) was used to assess areas historically cleared of native vegetation prior to 2018. Regional ecosystems refer to vegetation communities consistently associated with specific combinations of geology, landform, and soil within a bioregion (Neldner et al. 2023). Remnant areas represent the remaining natural vegetation that has not been significantly disturbed or cleared. The area historically cleared prior to 2018 was determined by calculating the difference between the remnant (existing vegetation) extent in 2017 and the estimates of the original (pre-clearing) extent of regional ecosystems. For more details on the assessment and classification of remnant vegetation in Queensland, refer to Neldner et al. (2023).

Woody vegetation extent in 2019

Woody vegetation extent was assessed using the Statewide Landcover and Trees Study (SLATS) woody vegetation extent that uses Sentinel-2 satellite imagery (Department of the Environment, Tourism, Science and Innovation 2024a). Examining the woody vegetation extent in 2019 provides the basis for understanding recent clearing rates across the GBR catchments.

Woody vegetation comprises assemblages of woody plants. This includes stands of native vegetation, regrowth following clearing, plantations of native and exotic species, and woody weeds (Department of the Environment, Science and Innovation 2024).

Recent clearing of woody vegetation 2019 to 2022

Vegetation clearing data is based on woody vegetation and does not include non-woody vegetation. This is because non-woody vegetation includes grasses that can be highly seasonal and easily modified through grazing, fire or mechanical interference, and therefore is impractical to use when estimating clearing rates (Neldner et al. 2023).

Vegetation clearing since 2019 was assessed using the Queensland SLATS Sentinel-2 woody vegetation change data. The methodology monitors and reports change in the extent of woody vegetation against a 2018 woody vegetation extent baseline. The SLATS data is updated annually with clearing and regrowth mapping.

For this assessment, clearing rates were examined over a three-year period from 2019 onwards (2019–20, 2020–21, and 2021–22) (Department of the Environment, Tourism, Science and Innovation 2024a). The analysis considered both full and partial (major) clearing and identified the types of land uses associated with the clearing activities for each monitoring period. The cumulative area cleared since 2019 was determined by summing the cleared areas across the three-year period. Full clearing is classed as a human-induced clearing event that results in the complete removal or destruction of woody vegetation that converts an area from woody to non-woody (i.e. less than 10% woody crown cover remains). Partial clearing (major) relates to a human-induced clearing event that results in the partial but significant removal or destruction of woody vegetation. These are areas where greater than 50% of the woody vegetation has been affected by clearing but the area remains woody (i.e. greater than 10% crown cover remains). The land use categories for clearing activities are: pasture (i.e. grazing), crop (i.e. cropping or horticulture), infrastructure (e.g. roads,

railways, pipelines, mining), settlement (i.e. urban development, and other (e.g. timber plantations, forestry) (Department of the Environment, Tourism, Science and Innovation 2024a).

Scales considered in the analysis

The analysis considered vegetation extent and clearing at four different scales:

1. *Management Unit*: Changes in woody vegetation in the whole management unit was calculated.
2. *Floodplains*: Floodplain data was extracted from the Queensland biodiversity status of pre-clearing regional ecosystems (Department of the Environment, Tourism, Science and Innovation 2024b). The data include regional ecosystems that occur within floodplains or those that fall both within and outside floodplain boundaries but are situated on recent Quaternary alluvial systems (specifically, land zone 3) (Neldner et al. 2023).
3. *Riparian areas of floodplain freshwater wetlands*: Riparian areas of floodplain freshwater wetlands were estimated by creating a 200 m buffer zone around these wetland extents. These areas include wetlands classified as natural or semi-natural, lacustrine and palustrine floodplain wetland systems, where wetlands were the dominant feature within the polygon, excluding mosaic areas identified as sub-dominant or containing wetlands. The data were extracted using data originating from Queensland Wetland Areas (Department of Environment and Science 2023a, 2023c, 2023d). Natural wetlands included those defined as such by the hydrological modifier code H1. Semi-natural wetlands included those modified by bunding, excavation, or partial drainage (wetland habitat modification codes: H2-M2, H2-M2-a, H2-M2-c, H2-M9, H2-M9-a, H2-M9-b, H2-M11, H2-M11-a, H2-M11-b, H2-M12, H2-M12-c, H2-M12-d).
4. *Riparian areas of rivers and streams*: Riparian areas of rivers and streams as defined by the Riparian Vegetation Extent Monitoring Method, were mapped using a 50 m buffer around topographic drainage lines and riverine wetlands, excluding estuarine areas (Australian and Queensland governments 2024a). These areas encompass regions along watercourses, from small headwater creeks to major rivers.

2.2.1.2 Results for vegetation extent and clearing

Historical clearing of native vegetation prior to 2018

The data show significant regional variation in historical vegetation clearing across the GBR catchment area prior to 2018 (Figure 7, Appendix 2: Table 2). Floodplain vegetation has consistently experienced the highest historical clearing rates across all regions except Cape York. While the Wet Tropics region retains 78% of its overall vegetation, only 37% of its floodplain vegetation remains. This pattern is even more pronounced in the Mackay Whitsunday region, where just 20% of floodplain vegetation persists despite 56% overall vegetation retention. Floodplain wetland riparian vegetation also shows high levels of historical clearing in several regions, with the Fitzroy region retaining only 31% of its wetland riparian vegetation and some individual basins showing even lower retention rates (e.g. Calliope 2% and Boyne 3%, noting that floodplain wetlands in these management units were < 500 ha originally). Riparian vegetation along streams and rivers generally shows better retention rates than floodplain areas, though historically has still experienced significant clearing in the more developed regions. Clearing rates within regions and between individual basins vary.

Cape York region maintains the highest level of vegetation integrity, with 99% of all vegetation types remaining intact. This includes similarly high preservation rates for floodplain vegetation (99%), riparian stream and river vegetation (99%), and floodplain wetland riparian vegetation (99%). This near-pristine condition contrasts with more developed regions further south. This pattern is consistent across all basins in the Cape York region.

The Wet Tropics region demonstrates moderate levels of clearing, retaining 78% of its overall vegetation. However, certain vegetation types have experienced higher levels of historical clearing particularly floodplain vegetation, where only 37% remains intact and floodplain wetland riparian vegetation where only 55%

remains intact. Within this region, the Mossman basin shows particularly heavy vegetation clearing of floodplain areas (only 15% remaining) and floodplain wetland riparian vegetation (only 12% remaining) noting its original area of floodplain wetland riparian vegetation was relatively small to begin with (< 100 ha).

The Burdekin region maintains 74% of its overall vegetation, but with considerable variation between basins and management units. The Belyando basin has experienced extensive clearing, with only 48% of its overall vegetation remaining. The Burdekin Delta area shows even more extensive clearing, with just 36% of overall vegetation and 20% of floodplain vegetation remaining. This contrasts with areas like the Upper Burdekin, which still retains 97% of its overall vegetation.

The Mackay Whitsunday region demonstrates significant vegetation loss, retaining just 56% of its original vegetation. Floodplain vegetation has been particularly impacted, with only 20% remaining across the region, and only 49% of the floodplain wetland riparian vegetation remains intact. The O'Connell and Plane Creek basins show the most extensive clearing, with just 16% and 14% of floodplain vegetation remaining, respectively. All basins have seen significant decreases in terms of floodplain wetland riparian vegetation (42 to 59% lost).

The Fitzroy region shows extensive clearing, with only 42% of overall vegetation remaining. Floodplain vegetation and floodplain wetland riparian vegetation are both at 31%. Within this region, the Calliope only retains 31% of its original vegetation, and the Mackenzie, Lower Fitzroy and Dawson management units are among the most heavily cleared areas, retaining 35% or less of their overall vegetation. Heavy clearing of floodplain wetland riparian vegetation is particularly prevalent in the Fitzroy basin, ranging from 20% remaining in the Dawson management unit, up to 47% remaining in the Isaac.

The Burnett Mary region has experienced heavy vegetation clearing, with only 43% of its original vegetation remaining. Floodplain areas are particularly affected, with just 26% remaining. The Burnett basin shows extensive clearing across all vegetation types, with overall vegetation at 38%, and floodplain vegetation at only 14% of its original extent. Floodplain wetland riparian vegetation clearing has been significant in the Mary (44% of original extent remaining), Kolan (26% remaining) and the Burnett (18% remaining).

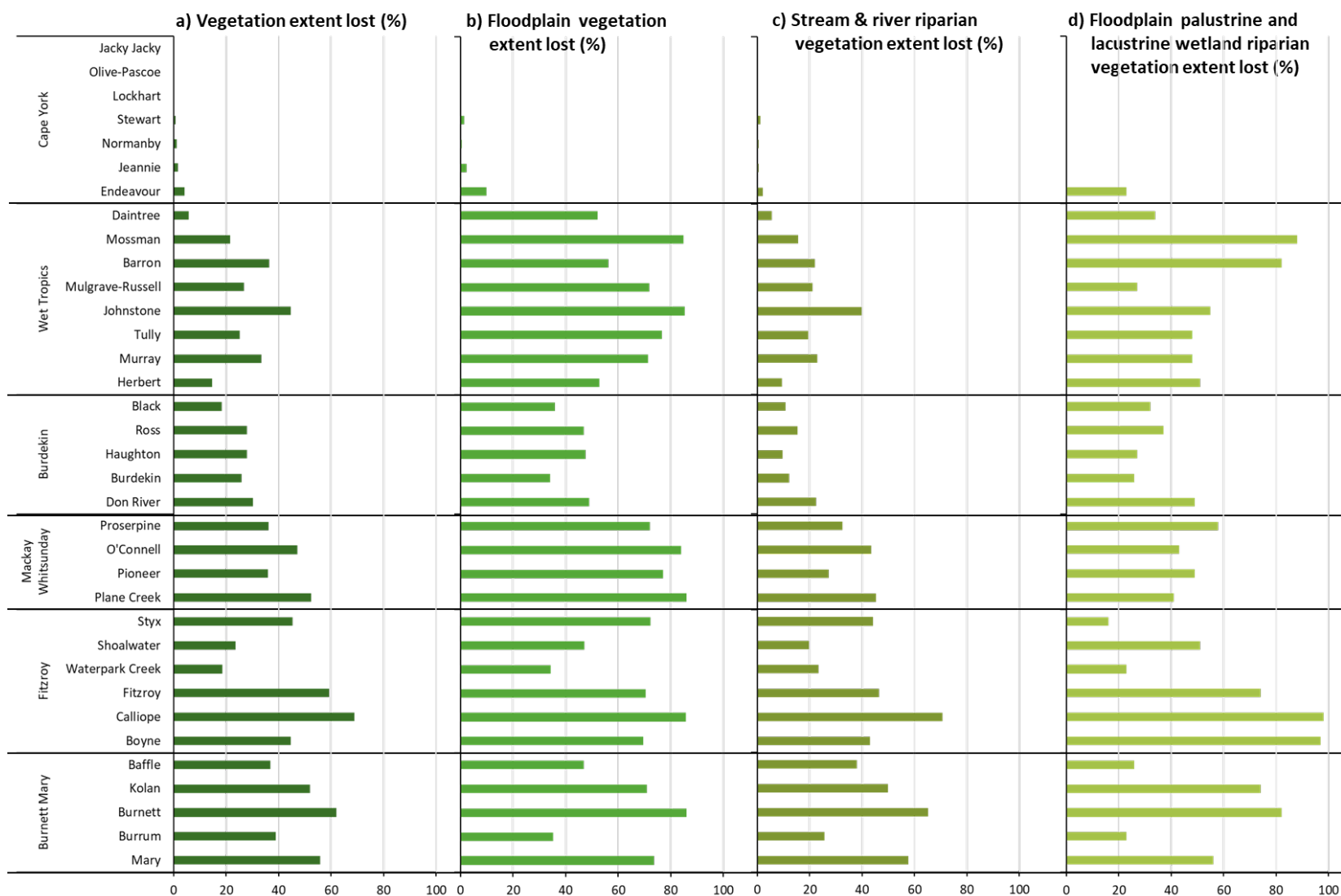


Figure 7. Historical vegetation losses in the GBR basins prior to 2018: a) overall vegetation extent loss; b) floodplain vegetation loss; c) stream and river riparian vegetation loss, and d) floodplain palustrine and lacustrine wetland riparian vegetation loss.

Recent vegetation clearing rates 2019 to 2022

Similar to the historical clearing patterns, analysis of more recent vegetation clearing in the GBR catchment between 2019 and 2022 shows spatial variation in both the extent (Figure 8 and Appendix 2: Table 3) and land use where the clearing has occurred (Appendix 2: Table 4).

Total vegetation clearing from 2019 to 2022 was most extensive in the Fitzroy region, which lost 218,629 ha (2.7% of its 2019 woody vegetation), followed by the Burnett Mary region with 85,634 ha (2.5%) and the Burdekin region with 135,839 ha (1.4%). In contrast, there was minimal clearing in the Cape York region, with just 1,408 ha (< 0.1%) lost during the three-year period. The Wet Tropics also had relatively low clearing rates, losing only 4,692 ha (0.3%).

At the basin and management unit scale, several areas stand out as experiencing higher levels of clearing. Within the Burdekin region, the Belyando management unit lost 3.7% of its woody vegetation while the Suttor management unit lost 3.1%. The Lower Fitzroy and Mackenzie management units within the Fitzroy region experienced 3.6 and 3.7% clearing, respectively. Compared to other basins, the Don River in the Burdekin region had particularly high levels of floodplain vegetation clearing at 5.6%, while the Mackenzie management unit in the Fitzroy region lost 6.4% of its floodplain vegetation.

Pasture development within the grazing land use was overwhelmingly the dominant purpose for clearing across all regions, accounting for approximately 75 to 90% of all clearing activity (Appendix 2: Table 4). This was particularly pronounced in the Burdekin (132,643 ha) and Fitzroy (205,526 ha) region. Clearing within cropping land uses was most significant in the Fitzroy (3,635 ha) and Burnett Mary regions (2,063 ha), while clearing within timber plantations and forestry land uses was heavily concentrated in the Burnett Mary (18,599 ha) and Fitzroy regions (8,191 ha).

Riparian floodplain wetland vegetation, despite representing smaller total areas, showed some of the highest percentage clearing rates in specific locations. In the Fitzroy basin, the Nogoia management unit lost 5.0% of its riparian floodplain wetland vegetation, while the Dawson management unit lost 4.0%, the Mackenzie lost 3.7% and the Lower Fitzroy lost 3.5%. The Burnett basin in the Burnett Mary region experienced relatively high riparian floodplain wetland clearing rates of 4.4% between 2019 and 2022. This suggests particular vulnerability of these ecologically important areas.

Riparian stream and river vegetation generally experienced lower clearing rates than floodplains across all regions. The Burnett Mary (1.8%) and Fitzroy (1.7%) regions showed the highest clearing rates for this vegetation type, though still lower than their respective rates for other vegetation categories.

A notable pattern emerges when comparing inland versus coastal management units within the same NRM regions. Inland management units such as the Belyando, Suttor, and Nogoia generally showed higher clearing rates than coastal management units. Additionally, the Burnett Mary region showed a higher proportion of clearing for timber plantation compared to other NRM regions, suggesting regional specialisation in land use transformation.

Similar to the historical patterns of clearing, the Cape York region has had minimal clearing across all vegetation types ($\leq 0.1\%$) between 2019 and 2022.

These findings highlight the uneven distribution of vegetation clearing across the GBR catchment, with certain regions and vegetation types experiencing higher pressure than others. In addition, the analysis shows that riparian areas in floodplain wetlands and across floodplains appear disproportionately impacted by vegetation clearing.

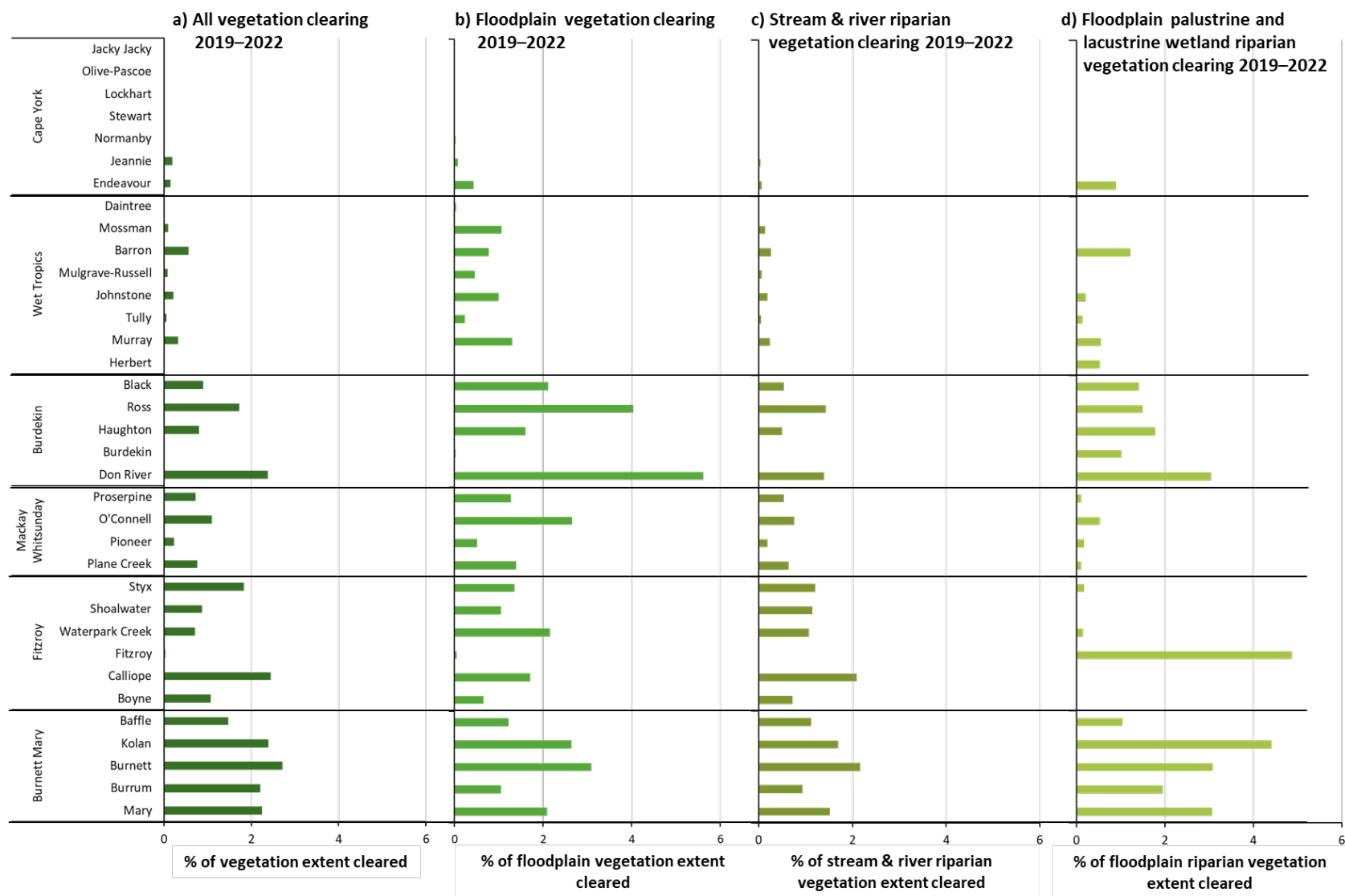


Figure 8. Percentage of recent vegetation cleared (extent cleared between 2019–2022 as a proportion of total woody extent in 2019) in the GBR basins on the following scales: a) overall vegetation extent loss; b) floodplain vegetation loss; c) stream and river riparian vegetation loss, and d) floodplain palustrine and lacustrine wetland riparian vegetation loss.

2.2.2 Floodplain wetland loss and modification

Floodplain wetlands serve as critical transition zones in the landscape, providing a multitude of ecosystem services ranging from biophysical (e.g. nutrient cycling) to biological (e.g. biodiversity), environmental (e.g. flood control and foreshore stabilisation), economic (e.g. tourism), and cultural (e.g. aesthetic) values. In the GBR catchment, these ecosystems can play a vital role in improving water quality by acting as natural filters that can process, retain, and in some cases transform pollutants, before they reach sensitive marine environments (Waltham et al. 2024). However, since European settlement (~1850), significant modifications to floodplains through land use changes have contributed to the degradation and loss of wetland habitats throughout the GBR catchments (Waterhouse et al. 2024a).

The loss or modification of wetlands, and the impacts on function, have direct implications for water quality outcomes in the GBR. When wetland areas are reduced through clearing, draining, or infilling, or are submitted to high modifications, the landscape's capacity to naturally process contaminants diminishes, placing greater pressure on remaining wetlands and increasing downstream pollutant loads which can contribute to increased nutrient and sediment delivery to the GBR (Waltham et al. 2024).

2.2.2.1 Method

Three different metrics were calculated to assess freshwater floodplain wetland loss and modification : 1) 'Wetland Modification and Loss up to 2017': compares the extent of natural unmodified wetlands in 2017 to their pre-clearing extent; 2) 'Wetland Loss 2017–2019': accounts for losses between 2017 and 2019 due to activities such as infilling and/or clearing and is divided into natural wetlands and slightly modified wetlands; 3) 'Wetland Modification 2017-2019': includes both slight and high modification between 2017 and 2019. Slight modifications were included in calculations for natural wetlands only, while high modifications were assessed for both natural and slightly modified wetlands.

The focus of the assessment was floodplain palustrine (vegetated swamp) and lacustrine (lake) wetlands. Slightly modified wetlands are defined as retaining many of their functional and ecological characteristics, while highly modified wetlands are considered to have significantly degraded characteristics. The metrics were calculated using the Queensland Wetland Mapping Method (Department of Environment and Science 2023a). The calculations were based on time-series data from pre-clearing, 2017, and 2019 (and the losses between pre-clearing extent and 2017 extent, and between 2017 extent and 2019 extent), using Queensland Wetland Mapping version 6.

Data interpretation limitations: The wetland pre-clear mapping is a derived dataset, as there was no aerial survey or detailed inventory pre-clearing, and therefore there are limitations with the scale and accuracy of the data. Additionally, actual wetland loss between years is very difficult to determine and the wetland change methodology may sometimes attribute changes in vegetation loss as complete wetland loss. For example, a decline in vegetation cover might be classified as habitat loss, even though a wetland area can still persist.

2.2.2.2 Results

The 2017 extent of natural unmodified floodplain wetlands as a percentage of historical pre-clearing extent shows that some regions maintained a highly preserved extent of natural unmodified wetlands, particularly in northern basins like the Jacky Jacky and Olive-Pascoe where it is estimated that 100% of the pre-clear wetland extent remains (Figure 9). In contrast, other areas have had significant wetland modification or loss, with the extent of natural unmodified wetlands severely reduced in some basins. For example, the Boyne and Mossman basins have always contained relatively small areas of floodplain wetland but these areas have been significantly reduced with an estimate of only 3% of natural unmodified wetland remaining in 2017. However, the Pioneer basin decline has been considerable, declining from an estimated 2,883 ha historical extent, to 227 ha (8%) of natural unmodified wetland remaining in 2017. Fifteen of the 35 basins have less than 50% of their historical natural unmodified wetlands remaining. The Wet Tropics, Mackay Whitsunday and Burnett Mary regions have the greatest reductions of natural unmodified floodplain wetland extent. In most basins, the extent of natural unmodified wetland areas affected by infilling or clearing from 2017 to

2019 was minimal. However, the Mackenzie management unit in the Fitzroy basin had the greatest loss (27 ha) of natural unmodified wetlands from activities such as infilling or clearing, and the Haughton, Baffle, and Tully lost more than 5 ha between 2017 and 2019. No 'slight' or 'high' modifications were reported for natural unmodified wetlands between 2017 and 2019.

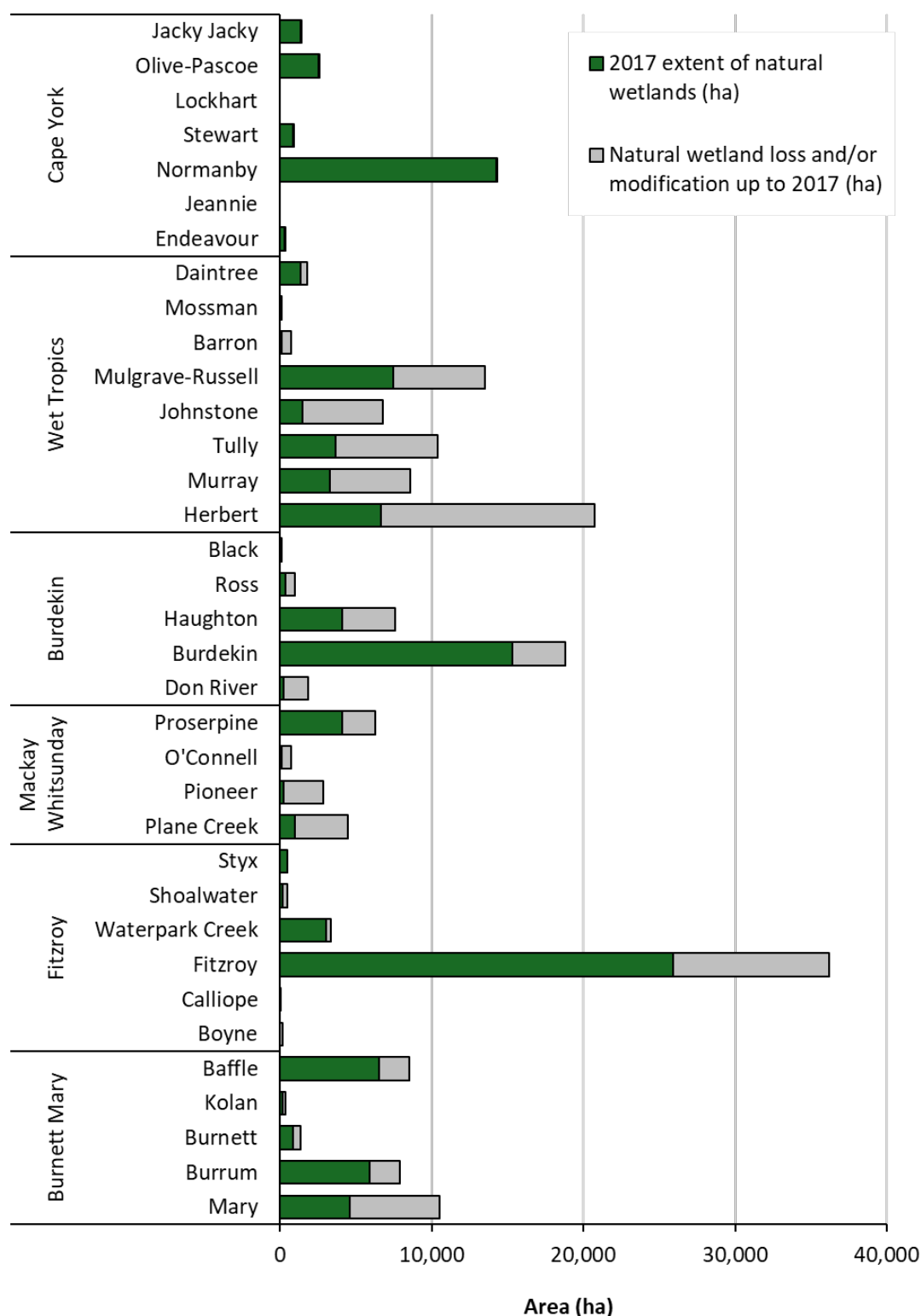


Figure 9. Extent of natural floodplain wetlands. Collectively, the green and grey bars total the pre-clearing extent of wetlands up to 2017, with the green bar showing the extent remaining in 2017, and the grey bar showing the extent that had been lost or modified up to 2017.

2.2.3 Groundcover and land condition

Groundcover is a critical factor in protecting soil and maintaining water quality within the GBR catchments. It consists of vegetation (both living and dead) and biological crusts that contact soil surfaces, providing essential protection from erosion and drought. Groundcover serves multiple environmental functions critical to reducing runoff, particularly in sediment retention. As highlighted by Wilkinson et al. (2024), the relationship between groundcover levels and hillslope erosion rates is non-linear, with erosion increasing sharply when cover declines below 30-50%. Lower groundcover provides less protection from direct raindrop impact, enabling greater mobilisation of sediment. Research has established that a minimum of 70–75% groundcover is required to effectively protect soil surfaces from rain splash and scour erosion while sustaining the biota that maintain soil structure. Groundcover and land condition is critical for landscape remediation activities (gully and streambank) as it facilitates water infiltration, and reduced velocity of water moving through the landscape after large rainfall events (Bartley et al. 2018; Bartley et al. 2020).

Rainfall variability in rangelands grazing results in large fluctuations in pasture growth and subsequent groundcover (O'Reagain et al. 2009). Adjusting and matching stocking rates to carrying capacity, is therefore extremely important in maintaining sustainable pasture growth and the presence of productive, palatable and perennial (3P) grass species without impacting on or causing a decline in land condition (Hunt 2008; Orr and O'Reagain 2011; Hunt et al. 2014). Hillslope erosion occurs from declined cover which is strongly linked to matching stocking rates with carrying capacity, forage budgeting, end of dry season pasture targets and management strategies related to those areas that are considered vulnerable (Hunt 2008; McIvor 2012; Bartley et al. 2014).

Management strategies used to rehabilitate groundcover include lower pasture utilisation rates (Hunt 2008), wet season and rotational spelling strategies (Ash et al. 2000; O'Reagain et al. 2011) and moderate to low and variable stocking rates at or around the long-term carrying capacity (Ash et al. 2000; O'Reagain et al. 2011; Orr and O'Reagain 2011).

Land condition changes have often been explained as ecological responses to changes in pasture composition and groundcover along with grazing pressure (Ash et al. 1995). Extreme pressure on rangeland resources through overgrazing has the potential to have severe consequences for these resources and their future productivity, both economically and ecologically (MacLeod and McIvor 2008). Inappropriate grazing strategies, particularly in response to climatic variability, has resulted in the depletion of native grasses and decline in land condition (MacLeod and McIvor 2006).

Land condition has been defined by the Grazing Land Management framework (Chilcott et al. 2005) as the capacity of land to respond to rain and produce useful forage and is a measure of how well the grazing ecosystem is functioning. The ABCD land condition framework, developed by Meat and Livestock Australia (MLA) in partnership with the then Queensland Department of Primary Industries and Fisheries, classifies land condition through pasture species composition, weeds, woodland thickening, bare ground, scalds and soil condition.

2.2.3.1 Methods

Two methods were applied to understand groundcover and land condition across the 48 management units:

- Median groundcover which is captured as a component of the P2R program Groundcover objective.
- Land condition: Land Condition Assessment Tool (LCAT) Water Quality Hazard assessment which assesses the risk of sediment being transported to a waterway.

Median groundcover

The P2R program objective for groundcover is for 90% of grazing lands in the GBR catchment area to have more than 70% groundcover in the late dry season. This target recognises that groundcover can be highly variable depending on annual and longer-term rainfall patterns, with some areas naturally supporting higher levels of groundcover due to factors such as high soil fertility and consistent annual rainfall. Groundcover is measured and reported annually as part of the P2R program. The metric focuses on late dry season

groundcover, as this represents the highest risk for hillslope erosion and subsequent gully and streambank erosion to occur at the break of wet season. The period which groundcover was analysed was from 1988 to 2023.

Measurement of groundcover for reporting is based on fractional groundcover data derived following methods described in Scarth et al. (2010), Guerschman et al. (2015) and Trevithick et al. (2014). The fractional groundcover method measures the proportion of green cover, nongreen cover and bare ground using reflectance information from late dry season from several sources of satellite imagery. Groundcover data sets were built on approximately 15 years of research that, in its current iteration, produces seasonal (four/year) estimates of ground cover in 30-m pixel resolution for about 95% of Queensland (Beutel et al. 2014). Mean cover images have been available in various iterations for a long time with categories based on groupings of Australian Land Use and Management Classification (ALUMC) classes from the 2021 Queensland Land Use Mapping Program (QLUMP) mapping. These images simply average pixel values at any point across a series of dates. The choice of dates is flexible (spring imagery for the 35 years 1988–2023 inclusive was chosen to more closely align to the Source Modelling period), and the imagery has limitation for assessing groundcover under treed areas greater than 60% and therefore the Cape York basins are not reported under the P2R program. The main drawback of this imagery is that it largely reflects average rainfall and hence can confound management and climatic impacts on cover.

It is important to note that averaging groundcover across whole regions can mask localised areas of lower or higher cover, particularly in large catchments with a strong rainfall gradient (e.g. the Burdekin and Fitzroy). Therefore, the median groundcover reported is indicative of general levels of groundcover within the reporting region.

Land Condition – LCAT Water Quality Hazard

The LCAT¹⁰ is a science-based assessment framework to determine the state of the land, by evaluating indicators of long-term land condition. The tool considers land condition values such as pasture composition, density and 'quality', groundcover, erosion processes, pest plant impacts and vegetation densities, and grazing land management practices can also be considered. There are 2,722 sites collected across the GBR catchments. The LCAT Water Quality Hazard assessment can be used to determine the risk of sediment being transported to a waterway or waterbody. It incorporates a range of variables including dominant pasture; dominant pasture density; dominant pasture growth phase; total perennial pasture density; pasture quality; groundcover; land surface condition; slope; distance from water; management of the riparian zone; riparian area disturbance; stream bank erosion; total grazing pressure; and site impacts. The assessment is based on logic and thresholds, for example the lower the groundcover and the steeper the slope, the greater the risk of the soil surface being eroded, and sediment transported. It is important to note that results from this assessment report the risk of reduced water quality based on the landscape and natural resource values but does not specifically indicate that there is reduced water quality.

2.2.3.2 Groundcover and land condition results

Median groundcover results

The groundcover results for the Paddock to Reef objective of 70% of end of season dry cover was on average met by all management units. The Johnstone, Mulgrave-Russell, Murray and Tully in the Wet Tropics, Cape Campaspe and Suttor in the Burdekin basin, and the Comet, Isaac, Mackenzie, Nogoia, and Theresa Creek in the Fitzroy basin were the only management units that did not meet the ground cover objective (Figure 10). The median across such a large area was in all years over the groundcover objective.

¹⁰ <https://www.stateoftheenvironment.des.qld.gov.au/liveability/case-studies/case-study-2>

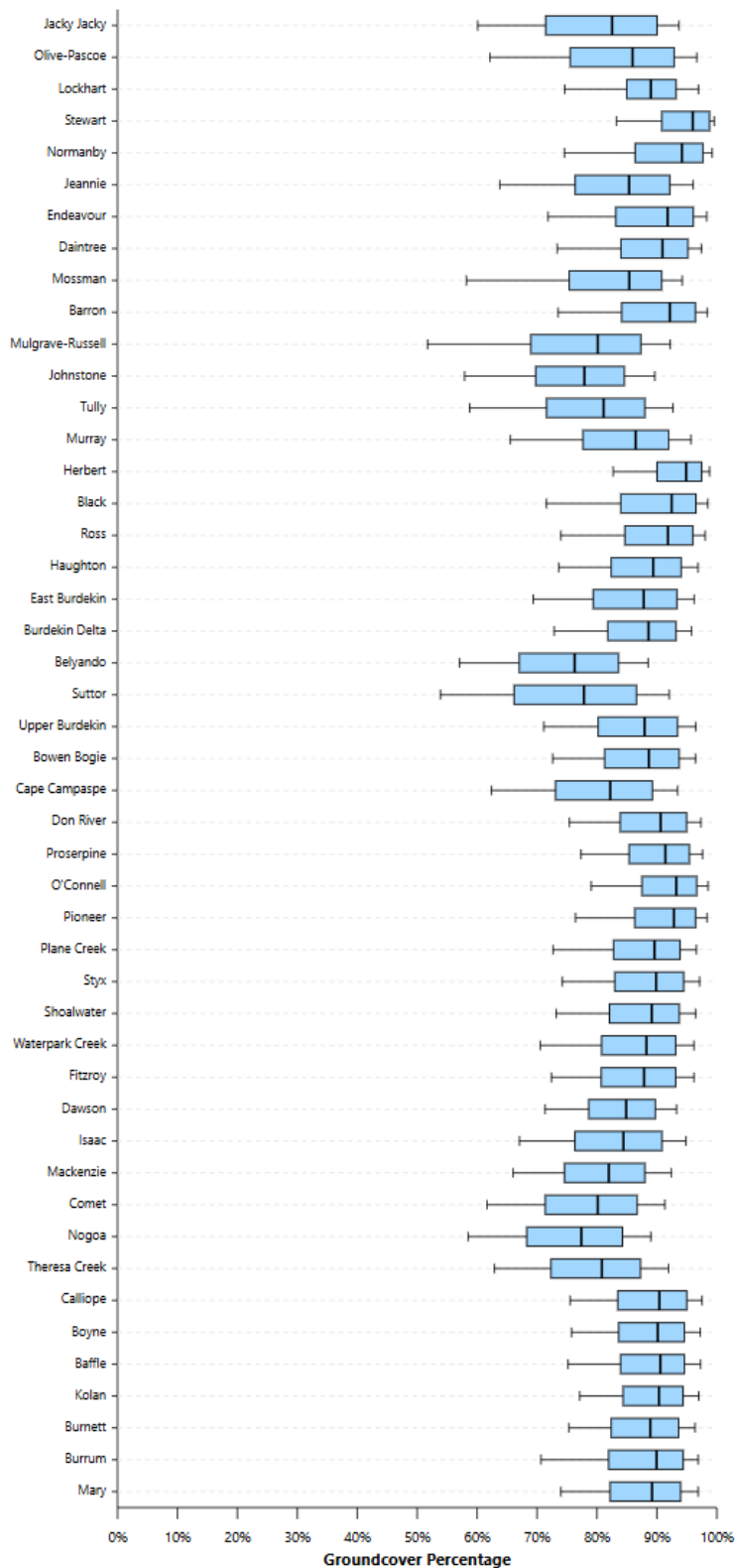


Figure 10. Late dry season groundcover for management units in the GBR between 1988 and 2023. The dark line in the bar represents the median, the hinges represent the 25th and 75th percentiles and the whiskers represent the 10th and 90th percentiles.

Land Condition – LCAT Water Quality Hazard

The LCAT Water Quality Hazard provides insights into observed data points across the GBR catchment area. It highlights the proportionally high and very high risk sites of the Suttor and Lower Fitzroy, as well as the

Upper Burdekin, Bowen Bogie and Burnett (Table 3). Although the sampling is not evenly distributed in sub-catchments it provides further insights into where scope is required for change. Very High Risk sites potentially require landscape remediation actions to reduce the water quality hazard.

Table 3. Count of Water Quality Risk Values in GBR basins and management units from observed data points. Adapted From Hassett (2022).

NRM region and Management Unit	Lower risk	Moderate risk	High risk	Very high risk	No Data	Total
Cape York NRM					81	81
Normanby	-	-	-	-	54	54
Jeannie	-	-	-	-	6	6
Endeavour	-	-	-	-	21	21
Wet Tropics NRM		-	2	8	16	26
Johnstone	-	-	1	7	16	24
Herbert	-	-	1	1	-	2
Burdekin NRM	70	106	147	313	311	947
Black	-	-	1	2	-	3
Ross	1	1	-	7	3	12
Haughton	2	3	2	7	23	37
Burdekin basin						
Lower Burdekin	2	6	12	46	85	151
Upper Burdekin	31	40	38	87	118	314
Suttor	30	45	61	103	43	282
Bowen Bogie	4	9	24	46	24	107
Don	-	2	9	15	15	41
Mackay Whitsunday NRM	22	80	67	49	4	222
O'Connell	5	33	32	26	-	96
Pioneer	4	16	14	14	-	48
Plane	7	13	11	1	4	36
Proserpine	6	18	10	8	-	42
Fitzroy NRM	112	241	189	296	162	1000
Styx	-	-	8	6	-	14
Shoalwater	3	4	1	-	5	13
Waterpark	-	-	1	3	-	4
Fitzroy basin						
Lower Fitzroy	23	55	35	83	69	265
Dawson	29	59	42	71	47	248
Isaac	15	36	42	36	16	145
Mackenzie	2	11	10	17	15	55
Comet	17	17	10	17	1	62
Nogoa	21	52	34	58	-	165
Calliope	2	2	3	2	9	18
Boyne	-	5	3	3	-	11
Burnett Mary NRM	39	99	96	140	72	446
Baffle	7	18	15	12	8	60
Burnett	22	48	41	76	19	206
Burrum	1	1	2	5	16	25

2.2.4 Gully density and erosion hotspots

Gully, hillslope and streambank erosion are the primary sources of sediment to the GBR (Wilkinson et al. 2024). Approximately 52% of the total fine sediment load comes from gully erosion, with the remaining 48% distributed equally between hillslope and streambank erosion.

Gullies form when surface water concentrates and scours out channels in the landscape, creating deep, often permanent incisions in the soil. Vegetation degradation and surface disturbance are the primary biophysical drivers contributing to, and accelerating, gully erosion processes (Wilkinson et al. 2024). Clearing of woody vegetation and reduced groundcover increase soil exposure to rainfall impact and runoff, while surface disturbance from activities such as cattle trampling can further exacerbate erosion, particularly in areas already prone to gully formation. Both these factors contribute to the initiation and expansion of gully networks, which, once formed, can persist as significant sediment sources for decades or longer (Wilkinson et al. 2024).

Beyond their role as sediment sources, gullies also act as efficient pathways for delivering fine sediment and associated particulate nutrients directly to stream networks. The high connectivity of these erosion features to mainstream channels means that sediment and nutrients from gullies often have minimal opportunity for deposition before reaching the GBR lagoon (Brooks et al. 2024). Understanding the initiation process, spatial distribution and intensity of gully and channel erosion can therefore provide valuable insights to inform targeted land management and remediation efforts in areas most affected by erosion.

2.2.4.1 Method

Method

To understand the scale of gullies and sediment supply associated with gully erosion across the GBR catchment area, the following metrics were assessed based on the data produced by the Queensland Government gully mapping program (Darr & Pringle 2017) and the associated Source Catchment model developed using this data:

- **Total average annual sediment supply (AASS):** This metric shows the total sediment output from gully erosion calculated as kilotonnes per year.
- **Total gully length:** Total length of the gully system calculated in kilometres.
- **Gully erosion rate:** Intensity of gully erosion calculated as tonnes per year per kilometre.

Gully Average Annual Sediment Supply (AASS)

The AASS is calculated in the Paddock to Reef Source Catchment model developed by the Queensland Government (McCloskey et al. 2021). The AASS metric represents the total eroded soil mass (fine sediment and coarse sediment) whereas the end-of-catchment loads focus on the fine sediment proportion as this is the dominant fraction that is transported into the GBR lagoon. This difference results in higher gully erosion figures from the AASS metric compared to the outputs of the Source Catchments model run presented in Section 3 which reports fine sediment. However, the findings still provide an accurate representation of areas that may benefit from a greater focus on gully management and potentially have greater relevance at a local scale where deposition of coarser material may occur.

The linear gully erosion model used to estimate the AASS is derived from:

- gully density and the area of each Functional Unit at the sub-catchment scale (i.e. land use),
- cross-sectional area,
- soil bulk density value, and
- the time period the erosion has occurred over.

The AASS model is calculated over the period 1970 to 2023 to capture a broad range of climatic conditions and runoff rates and enable the calculation of the long-term average annual gully erosion load.

Gully Length

Gully length was calculated at the sub-catchment scale by determining the total length of gully features

within each area. These values were also determined for each Functional Unit. The resulting lengths were then aggregated by management unit.

Gully Erosion Rate

The gully erosion rate for each management unit is calculated by dividing the total AASS by the corresponding gully length.

Gully results

Gully Average Annual Sediment Supply (AASS)

The analysis of the Average Annual Sediment Supply (AASS) across the GBR catchments reveals substantial spatial variability in sediment contributions from gully erosion (Figure 11, Figure 12a; Appendix 2: Table 11).

When examining the data by NRM regions (Appendix 2: Table 11), the Burdekin region has by far the highest total Gully Average Annual Sediment Supply (AASS), contributing over 6,000 kilotonnes per year, with the largest sources from this region concentrated in the Upper Burdekin (2,260 kt yr⁻¹) and Bowen Bogie (1,247 kt yr⁻¹) management units. The Fitzroy region follows with an estimated 4,332 kilotonnes per year, primarily driven by high sediment contributions from the Dawson (1,345 kt yr⁻¹) and the Isaac (1,237 kt yr⁻¹) management units in the Fitzroy basin. These results are consistent with known erosion hotspots in central Queensland's grazing lands.

The Cape York region shows an estimated 659 kilotonnes per year, with gully erosion largely confined to the Normanby (628 kt yr⁻¹). The Burnett Mary region contributes a total of 188 kilotonnes per year, primarily from with the Burnett basin (153 kt yr⁻¹) accounting for the majority of supply. In the Wet Tropics region, AASS totals 94 kilotonnes per year, with contributions dominated by supply from the Herbert basin (83 kt yr⁻¹), mainly from the Upper Herbert (75 kt yr⁻¹), followed by the Barron (7.5 kt yr⁻¹). The Mackay Whitsunday region reports the lowest overall supply at 69 kilotonnes per year, with the Proserpine being the primary source (39 kt yr⁻¹), followed by the O'Connell (16 kt yr⁻¹).

Gully length data

The total length of gullies varies considerably among the six NRM regions, indicating significant differences in the spatial extent of gully networks (Figure 11, Figure 12b; Appendix 2: Table 11). The Fitzroy region has the longest gully network (49,948 km), followed by the Burdekin region (47,035 km). These two regions account for most of the gully length across the GBR catchments, reflecting the extensive and active erosion processes in these areas. The Mackay Whitsunday region has the shortest total gully length suggesting lower gully density and potentially more stable landscapes in that area.

The Fitzroy basin has the highest total gully length, with approximately 48,007 km, dominated by extensive gully lengths in the Dawson (18,960 km), Isaac (8,307 km), Nogoa (6,661 km), Comet (5,362 km), and Mackenzie (3,547 km) management units.

The total length of mapped gullies in the Burdekin basin is around 44,119 km. This is primarily driven by high length of gullies in the Upper Burdekin (18,057 km), Belyando (7,911 km), Bowen Bogie (6,301 km), and Suttor (5,751 km) management units, with additional notable contributions from Cape Campaspe (4,444 km) and East Burdekin (1,620 km).

The Wet Tropics region has a total gully length of 3,431 km, with the majority concentrated in the Upper Herbert (2,739 km), and smaller contributions from the Lower Herbert (276 km) and the Barron (272 km).

In the Cape York region, a total of 10,896 km of gully length was recorded, largely due to the Normanby (9,692 km), but with some gullies in the Jeannie (654 km) and Stewart (206 km).

The Burnett Mary region recorded a total of 5,885 km, predominantly found in the Burnett (4,820 km), followed by the Mary (407 km) and the Kolan (400 km).

Finally, the Mackay Whitsunday region had the lowest total length of gullies, with 684 km, mainly from Proserpine (381 km) and O'Connell (161 km).

Gully Erosion Rate

Across the GBR catchments, average gully erosion rates vary considerably between NRM regions, reflecting the differing geomorphic, land use, and rainfall conditions influencing erosion processes (Figure 11, Figure 12c; Appendix 2: Table 11). The Burdekin region stands out with the highest average rate, followed by the Mackay Whitsunday and Fitzroy regions. In contrast, the Cape York, Burnett Mary and Wet Tropics regions have substantially lower rates.

The Burdekin region again has the highest erosion rate, with an average of 131 t yr⁻¹ per km, and all basins have an average gully erosion rate close to or over 100 t yr⁻¹ per km. The highest values are from the East Burdekin (375 t yr⁻¹ km⁻¹) management unit, almost double that of the second highest erosion rate which is found in the Bowen Bogie (198 t yr⁻¹ km⁻¹). Other management units with erosion rates >100 t yr⁻¹ km⁻¹ in the Burdekin basin are the Upper Burdekin (125 t yr⁻¹ km⁻¹), and Cape Campaspe (102 t yr⁻¹ km⁻¹). The Black (104 t yr⁻¹ km⁻¹), Ross (102 t yr⁻¹ km⁻¹), Haughton (102 t yr⁻¹ km⁻¹), and Don River (95 t yr⁻¹ km⁻¹) also contribute to this elevated regional average.

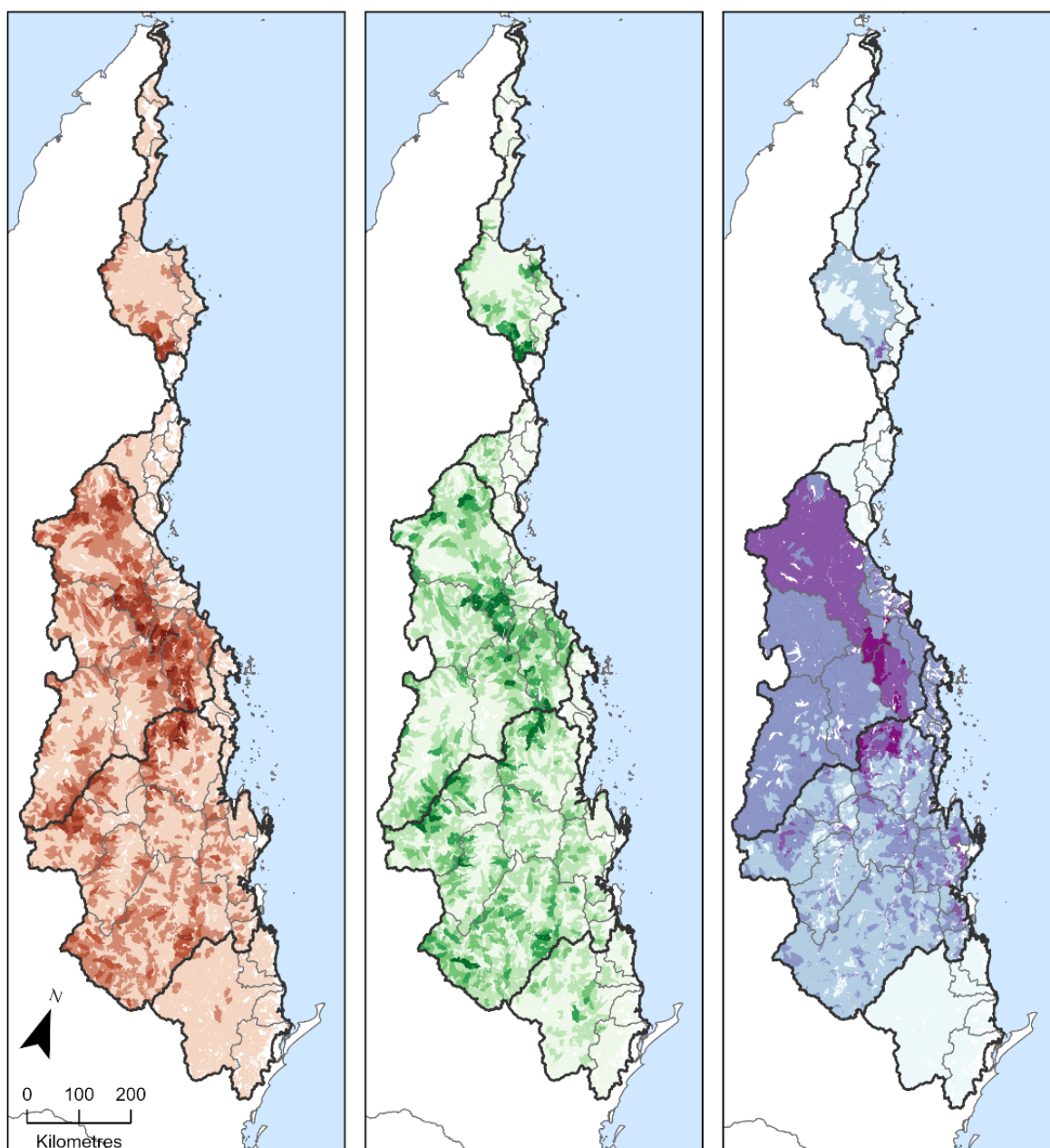
The Fitzroy region follows with an average of 86 t yr⁻¹ per km, driven by high erosion rates in the Isaac management unit (149 t yr⁻¹ km⁻¹). Erosion rates of basins and management units in the Fitzroy region typically range between 70 and 90 t yr⁻¹ per km.

The Mackay Whitsunday region has an average erosion rate of around 100 t yr⁻¹ per km, however this may be an overestimate due to the legacy model parameterisation and will be refined in future models.

The gully erosion rate in the Burnett Mary region averages 32 t yr⁻¹ per km, with relatively uniform values across its basins, ranging from 38 t yr⁻¹ per km in the Baffle to 30 t yr⁻¹ km in the Burrum.

In the Cape York region, the average erosion rate is 31 t yr⁻¹ per km, primarily influenced by a high value for the Normanby (65 t yr⁻¹ km⁻¹), whereas the gully erosion rate in other Cape York basins ranges from 21 t yr⁻¹ per km in the Olive-Pascoe to 29 t yr⁻¹ per km in the Lockhart.

The Wet Tropics region has the lowest gully erosion rate on average (25 t yr⁻¹ km⁻¹), with most values ranging between 20 and 30 t yr⁻¹ per km. The Lower Herbert has the highest gully erosion rate in the region of 30 t yr⁻¹ per km, followed by the Barron and Upper Herbert (both 28 t yr⁻¹ km⁻¹).



Legend

AASS (t/y)

- 0 - 2045
- 2045 - 7191
- 7191 - 17442
- 17442 - 42539
- 42539 - 105679

Gully Length (km)

- 0 - 16
- 16 - 50
- 50 - 104
- 104 - 194
- 194 - 433

Gully Erosion Rate (t/y per km)

- 11 - 48
- 48 - 81
- 81 - 115
- 115 - 246
- 246 - 671

Figure 11. (Left) Gully Annual Average Sediment Supply (AASS); (Centre) Gully length within sub-catchments; (Right) Annual gully erosion rate (tonnes per km of gully) across the GBR.

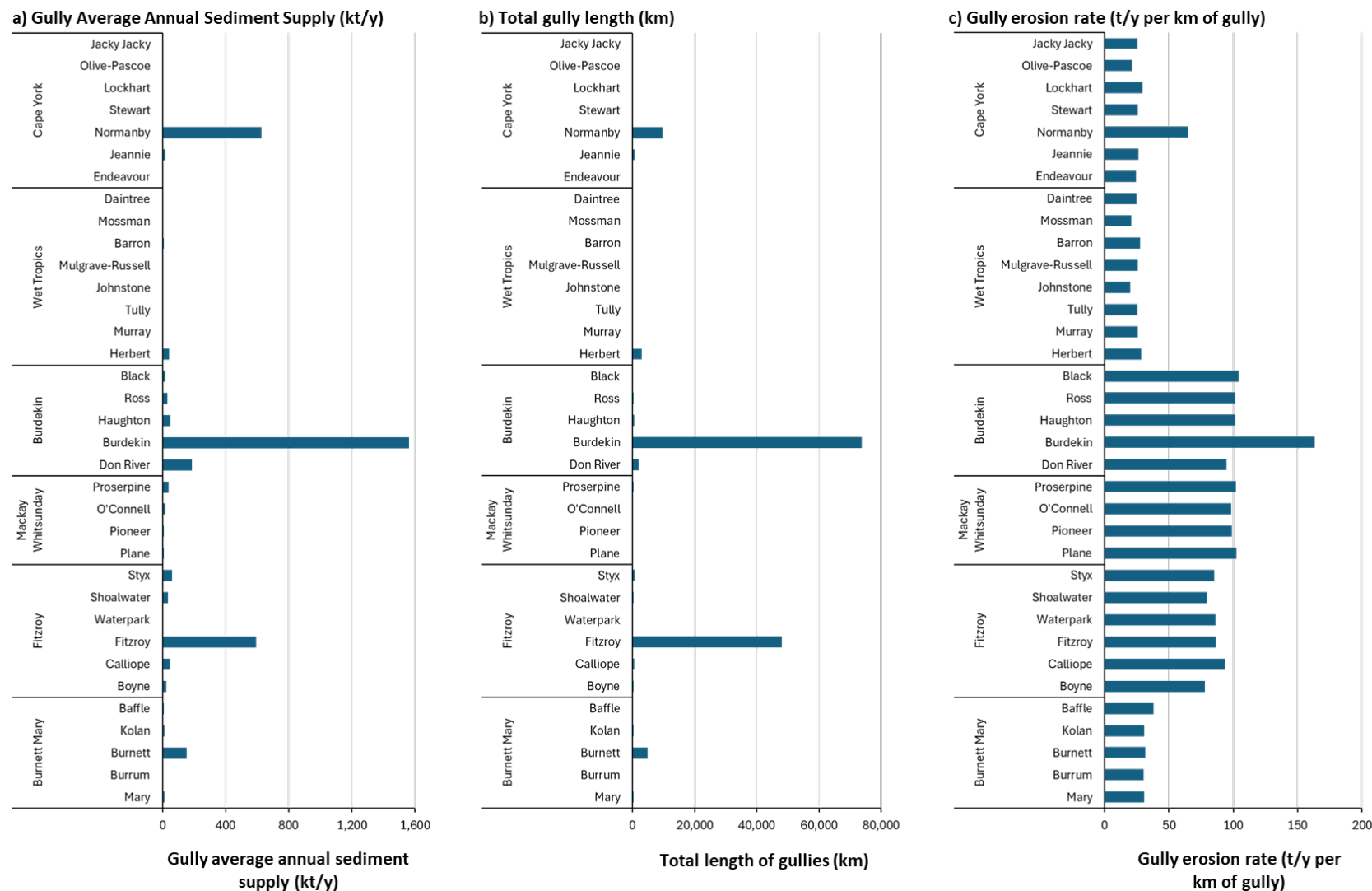


Figure 12. a) Gully Annual Average Sediment Supply (AASS); b) Gully length within sub-catchments; c) Annual gully erosion rate (tonnes per km of gully) across the GBR.

3. Pollutant sources and loads

This part of the assessment identifies the primary sources of pollutants examining which basins and management units have relatively high pollutant generation, what land uses are contributing to the loads, and where relevant, identifies the dominant erosion processes and runoff pathways. This section focuses on the most common pollutants in the GBR catchment area that have sufficient measured data to be modelled. The pollutants are dissolved nutrients, specifically dissolved inorganic nitrogen (DIN), fine sediments and particulate nutrients (nitrogen and phosphorus, PN and PP). Dissolved P is not included because there is limited information on the relationship between land-based sources of dissolved P and marine ecosystem response (N is considered to be the limiting nutrient in the GBR; refer to Robson et al. 2024). Pesticide data is collected and processed using a different method and is presented as pesticide risk.

Pesticide sources are considered at the catchment scale (rather than management unit) and include all areas upstream of the monitoring location. The source of pesticide risk is considered at two levels: firstly, identifying which pesticides are the primary contributors to the risk and evaluating their physico-chemical and ecotoxicity profiles; and secondly, the land use relationships with pesticide risk (Warne et al. 2020) are considered.

3.1 Methods for nutrient and sediment loads

Evidence of the sources of pollutants in the GBR catchment area is predominantly informed by catchment modelling described below. However, these models are supported by an extensive understanding of pollutant processing and transport and are validated and calibrated with monitoring data. The catchment modelling outputs are used in this assessment as the most consistent information related to pollutant sources across the GBR catchment area.

The main purpose of the GBR Paddock and Catchment Modelling Program is to estimate average annual loads of key pollutants (sediment and nutrients) from each of the 35 basins draining to the GBR. The models are used to report on baseline levels and the change in loads for the reporting year due to the adoption of improved land management practices, and to report progress towards the water quality targets. Due to the success of the modelling program, it is now applied in the Reef 2050 WQIP water quality target setting, broadscale prioritisation of “hotspots” for investment (this project), support for the Paddock to Reef Projector tool (www.p2rprojector.net.au) for site-based prioritisation and allocation of Reef Credits, and linking the model outputs to marine modelling.

The catchment modelling (GBR Dynamic SedNet models) provides estimates of fine sediment, dissolved inorganic and organic nutrient (nitrogen and phosphorus) and particulate nutrient export loads to the GBR, including the likely sources and processes that drive these loads. The catchment modelling provides the information for evaluating and reporting progress towards Reef 2050 WQIP targets through the Reef Water Quality Report Card. Six GBR Dynamic SedNet models have been built to represent each of the NRM regions (Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy, Burnett Mary) within the GBR catchment area. The GBR Dynamic SedNet models are built on eWater Source, upon a network of sub-catchments, links and nodes within these catchments. Sub-catchments are the basic spatial unit in the models and can be further delineated into Functional Units based on land use, common hydrological and water quality response or characteristics. For a full description on how constituent generation, transport, and loss, are represented, including the various data inputs, see McCloskey et al. (2021a; 2021b). The GBR Dynamic SedNet model estimates daily loads of fine sediment, particulate and dissolved nutrients from each of the end-of-catchment river outflows in the GBR catchment area that are dispersed by the eReefs marine model.

The GBR Dynamic SedNet model operates under a continuous improvement framework where model rebuilds occur every three to five years. This model improvement cycle (i.e. model updates), including the model calibration and validation approach, means that the end-of-catchment loads, and respective increase factors, vary between model iterations. This is the case for the modelled loads published in McCloskey et al. (2021a; 2021b), and for the loads reported herein (Catchment model V2.0, DETSI 2024c). The improvement cycle for the data presented in this report (Catchment model V2.0) included:

- Minor network updates in the Burdekin and Cape York models (for improved stream delineation, especially in the flat coastal areas).
- Hydrology recalibration using an approach consistent with Queensland Hydrology (the unit responsible for water planning modelling; Egan 2024) which has significantly improved the model performance.
- Land use updated to 2021.
- Updates to soil input datasets including surface and subsurface nitrogen (N) and phosphorus (P) concentration, surface and subsurface clay silt fraction, rock factor, K factor (soil erodibility), among others.
- Updated gully density and cross-sectional information based on the Queensland Government gully mapping program.
- Significant improvements to the streambank model, including better representation of bankfull flow, use of LiDAR to parameterise stream cross sections and build regressions for parameter application, updated riparian vegetation, floodplain area and erodibility, and disabling instream deposition and remobilisation in Cape York and the Wet Tropics.
- Adjustment to storage trapping to better represent the 20 µm fraction.
- Updated sewage treatment plant data.
- Incorporation of the reference water quality data from areas with a lower level of catchment modification (e.g. conservation areas) to improve the pre-development load estimates (see further explanation below).
- Updated cropping data.
- Updated paddock models, including improved nutrient modelling, new soils data, and changes to sugarcane management resulting from stakeholder workshops.

Importantly, the model is calibrated and validated using the growing availability of measured total suspended solids and nutrient loads data from the GBR Catchment Loads Monitoring Program¹¹ which includes 26 end-of-catchment sites, 22 sub-catchment sites and eight fine-scale monitoring sites (Water Quality & Investigations 2024a). The latest available GBR Dynamic SedNet model also draws on water quality data that can assist in improving the pre-development (i.e. pre-European arrival) load outputs. Lewis et al. (2023) summarised data from reference locations with recommended event mean and dry weather concentrations for use in the model. A series of assumptions on catchment condition and erosion have been used to model an estimate of the pre-development load. For example, ground cover was increased to 95% in open grazing area, gully cross sectional area was reduced by 90%, and the reference site data generated by Lewis et al. (2023) have been incorporated. The full set of model assumptions are available in McCloskey et al. (2021a).

An important aspect to note is that the hydrology has not been altered (from the baseline model) in the pre-development model and hence river flow volumes are assumed to be identical in the pre-development period. However, the available evidence shows that river discharge volumes have increased considerably since 1850 and again from the 1970s as a likely result of climate variability coupled with increased rainfall-runoff from catchment clearing and hardening (reviewed in Lewis et al. 2024a). The implications of the differences in hydrology vary between basins. For example, in the larger basins such as the Burdekin, the flood events in the 90th percentile have approximately doubled in volume and occur more frequently (Lough et al. 2015) which would imply that the pre-development loads could have been lower than those estimated in the pre-development catchment modelling scenario. However, the consideration of other lines of evidence such as coral coring and tracing studies also provide insight to the current estimates of pre-development loads.

The model draws upon the latest available fine-scale monitoring and tracing data (e.g. Bainbridge et al. 2014; 2023) to improve the estimates of the smaller scale sub-catchment and tributary contributions within the

¹¹ [Modelling and monitoring | Reef 2050 Water Quality Improvement Plan \(reefplan.qld.gov.au\)](https://reefplan.qld.gov.au)

individual basins of the GBR catchment area. Collectively, these improvements to the estimates of the baseline and pre-development loads increase confidence in the model performance.

The fourth international review of the GBR Paddock and Catchment Modelling Program was recently undertaken (Jakeman et al. 2024) which recognised the *“Program is overall the equal of any catchment modelling program in the world in terms of its scale, direction, leadership, scientific quality and achievements”*, and noted that *“substantial progress [has been] made with respect to previous recommendations, including on model development and methods used in the modelling.”* These reviews provide an opportunity for scrutiny of the modelling program by an independent expert review panel, and for continuous improvement building on previous reviews (held in 2012, 2015, and 2019). Typically, these reviews align with the major rebuild of the models, every three to five years.

The detailed results of modelled pollutant loads are presented for all basins and management units in Appendix 3 for DIN (Table 12), fine sediments (Table 13), PN (Table 14) and PP (Table 15)¹². Further information about pollutant load estimates from urban sources is presented in Section 6.2.

3.2 Modelled end-of-catchment DIN loads and sources

Approximately 10,599 tonnes of DIN are generated and enter GBR waterways each year, of which over half (55%) is estimated to come from anthropogenic activities (Figure 13). The Wet Tropics region dominates DIN contributions to the GBR, delivering over half (50.5%) of the total DIN load despite its relatively small area, with the Herbert and Johnstone basins being particularly significant sources.

Sugarcane production is the primary anthropogenic source of DIN (44% of total across the GBR) and is the dominant source of DIN in several basins, contributing 4,600 tonnes of the total DIN load. Sugarcane is a major contributor to total DIN loads in the Herbert (1,393 t, 79% of basin DIN load), the Tully (334 t) and the Mulgrave-Russell (332 t) basins in the Wet Tropics, and the Burdekin Delta (367 t) and Haughton basin (307 t) in the Burdekin region. Sugarcane is the dominant source of DIN across all basins in the Mackay Whitsunday region, especially in the Pioneer (168 t, 74% of basin DIN load). In the Burnett Mary region, sugarcane makes a major contribution to the total DIN loads in the Mary (352 t, 52% of basin DIN load) and Burnett (139 t, 57% of basin DIN load) basins.

Grazing is the second largest contributor of total DIN loads (25%), particularly in the drier regions of the GBR including the Fitzroy (705 t, 77% of the basin DIN load) and the Burdekin (611 t, 51% of basin DIN load) basins (Figure 14). Banana cultivation contributes 7.6% of the DIN load despite occupying a much smaller land area, indicating its high per-hectare nitrogen loss rate. Bananas are a significant source of DIN in the Wet Tropics region, contributing 806 tonnes in total or 15% of the Wet Tropics DIN load. Within the Wet Tropics region, the Johnstone is the most significant source of total DIN (376 t) from banana cultivation, followed by the Tully (248 t) and Mulgrave-Russell (118 t).

While urban areas and sewage treatment plants (STPs) contribute around 4% of the total GBR DIN load (446 tonnes per year), the inputs can be highly localised. Urban runoff contributes the majority of this load at 254 tonnes (57%), while STPs account for 192 tonnes (43%) (Figure 15). The highest combined DIN loads are observed in the Ross (58 tonnes), Fitzroy (51 tonnes), and Barron (50 tonnes) basins. At the regional level, there is minimal runoff associated with urban land uses in the Cape York region, with only the Endeavour basin recording any urban influence (0.7 tonnes). There are significant regional variations in the distribution of loads between urban and STP sources. The Wet Tropics region experiences the greatest runoff associated with urban areas and STPs (139 tonnes), of which urban-derived DIN input accounts for 87 tonnes. The Mackay Whitsunday region has the second highest urban-derived DIN load of 74 tonnes. In the Burnett Mary

¹² Note that the pollutant loads have been further refined since the presentation and interpretation of the data in Version 1.2 of this report. The associated Catchment Profiles contain updated pollutant load information (Catchment model V3.0, DETSI 2026), resulting in some minor inconsistencies between these products.

region, the Mary basin is notable for having the highest DIN load from urban areas across the GBR (41 tonnes). Urban runoff is the dominant contributor in the Mackay Whitsunday (87%) and Burnett Mary (78%) regions, while STP discharges constitute a larger proportion in the Fitzroy region (84%) due to high loads in the Fitzroy basin, and the Burdekin region (76%) primarily from the Ross. The relative priority of basins for urban management in the GBR catchment area has been assessed by DETSI (2025) and presented in Section 6.1.3.

The transport pathways for DIN are primarily diffuse dissolved sources (48%) and seepage (40%), reflecting the soluble nature of this pollutant (Figure 16), with a small proportion of point sources (1.8%).

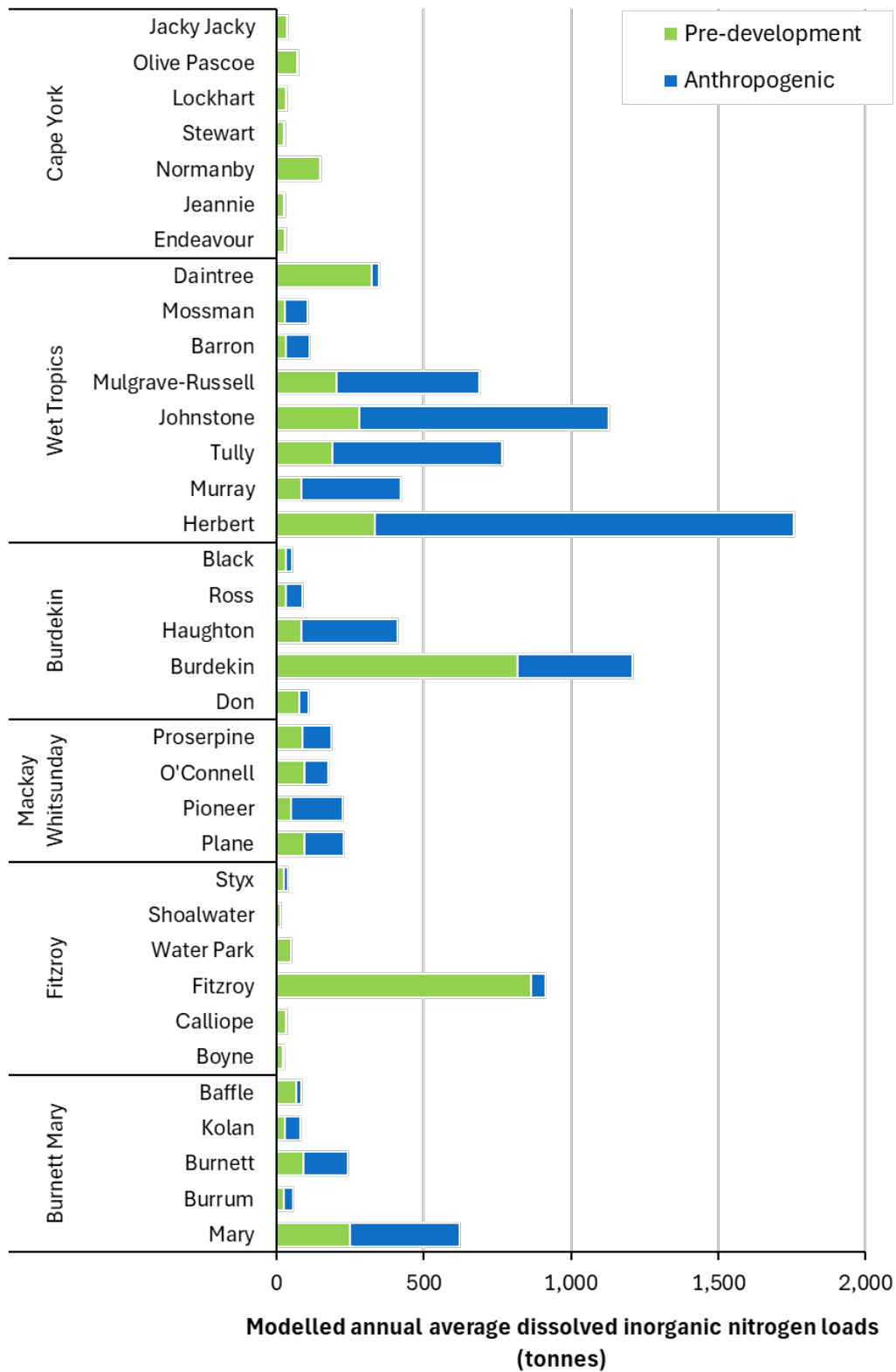


Figure 13. Modelled annual average pre-development and anthropogenic end-of-catchment dissolved inorganic nitrogen loads (tonnes).

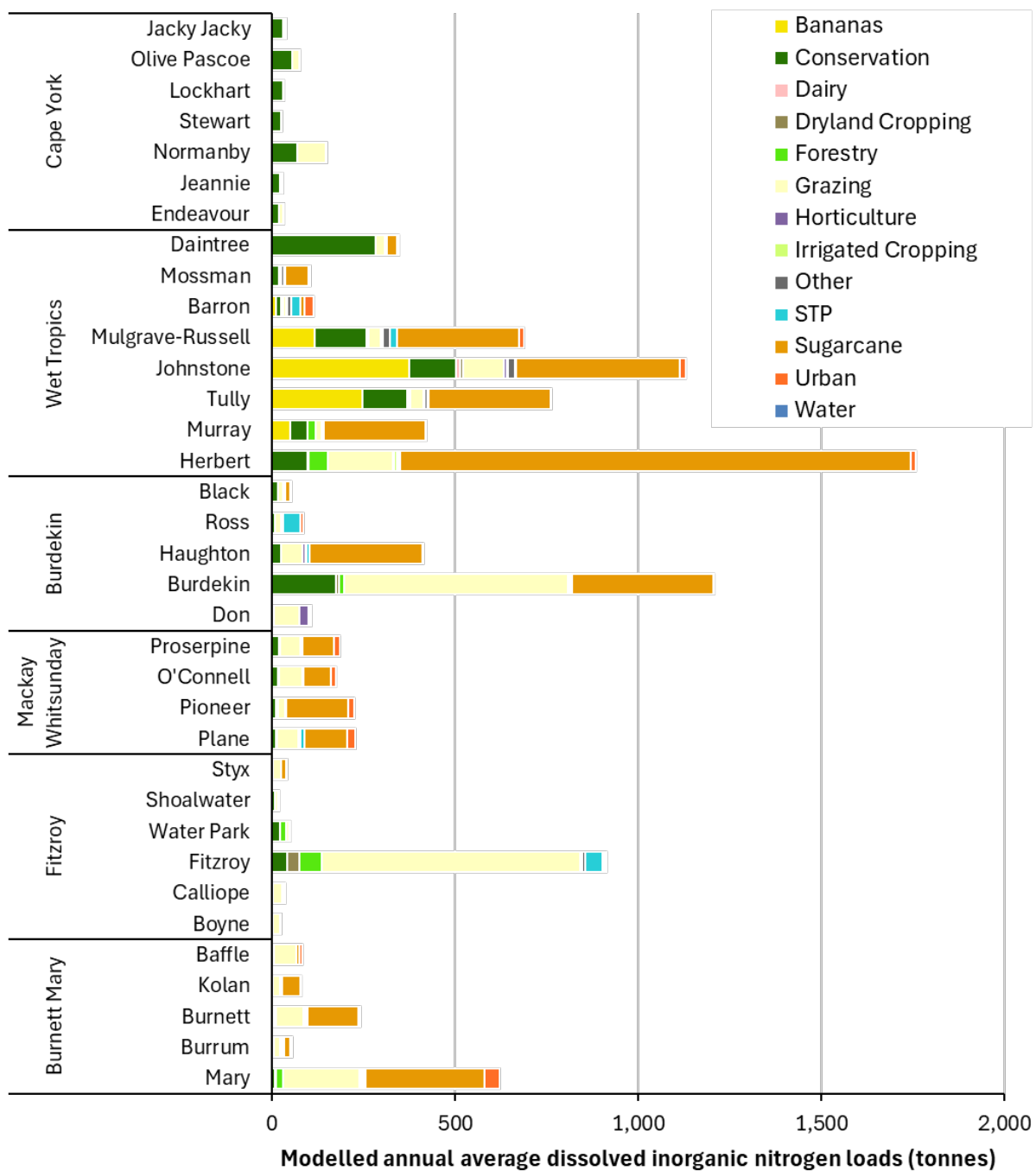


Figure 14. Modelled total annual average end-of-catchment dissolved inorganic nitrogen loads (tonnes) by land use.

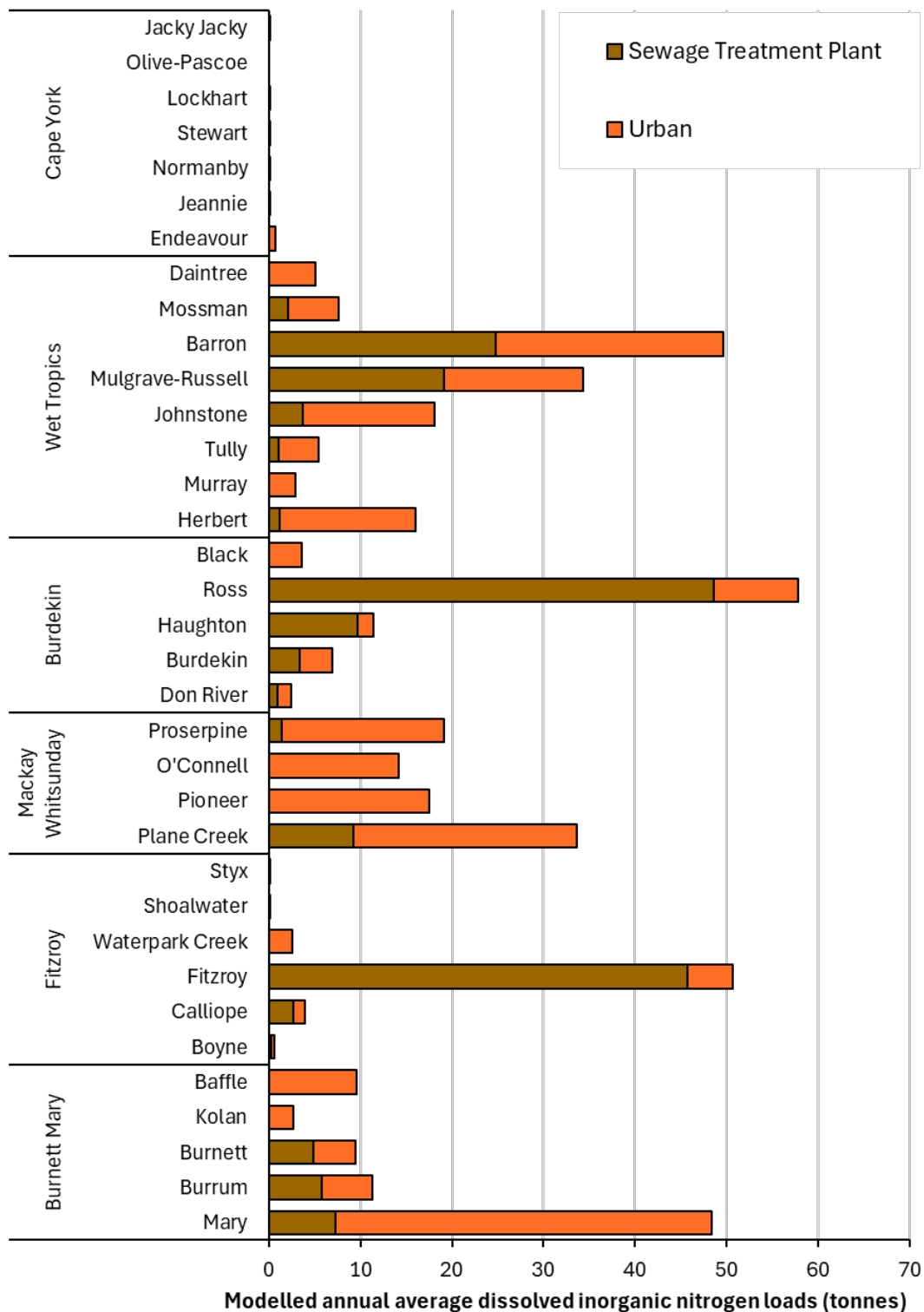


Figure 15. Modelled annual average end-of-catchment dissolved inorganic nitrogen loads (tonnes) from STPs and urban areas.

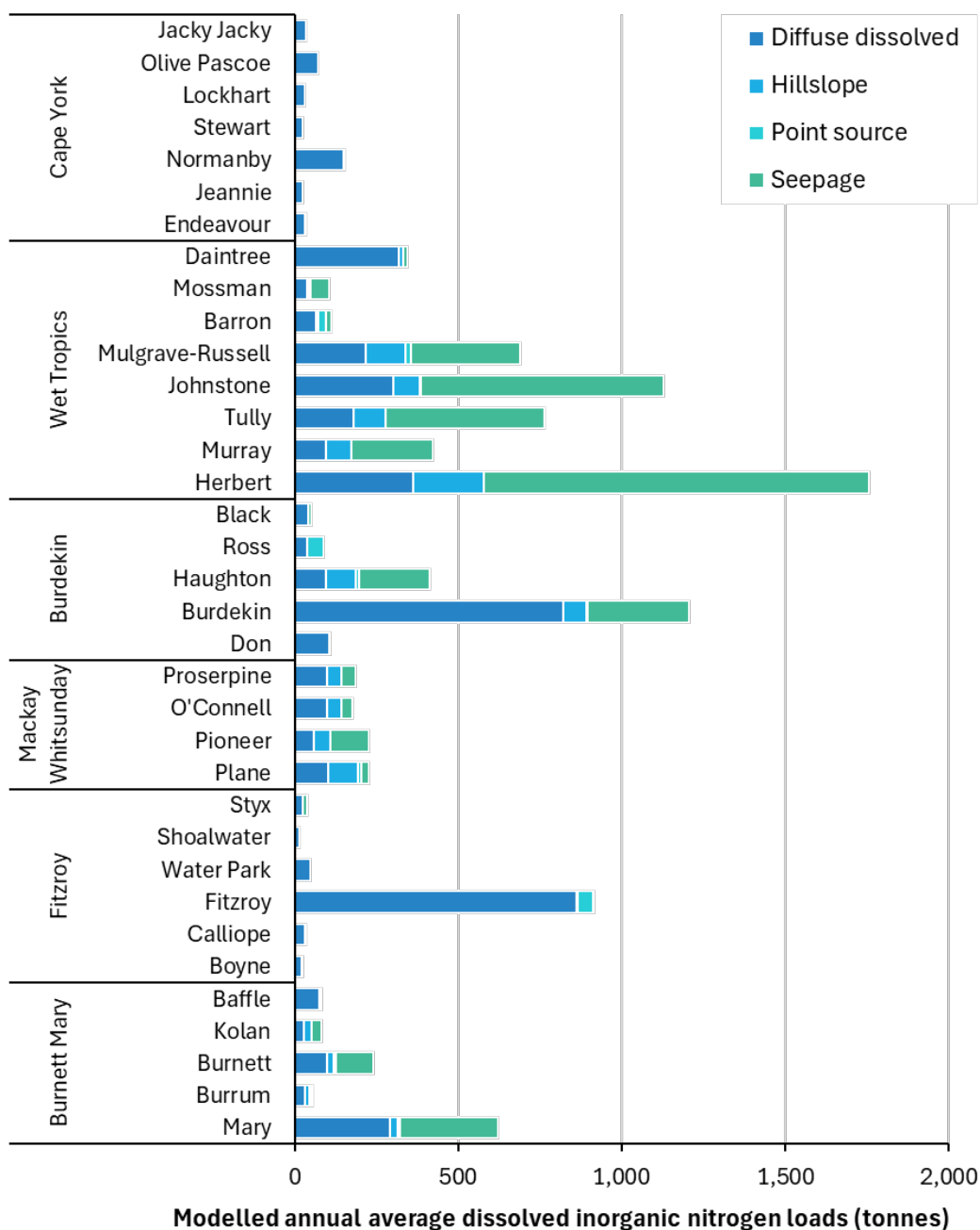


Figure 16. Modelled total annual average end-of-catchment dissolved inorganic nitrogen loads (tonnes) by loss pathway.

3.3 Modelled fine sediments and particulate nutrient end-of-catchment loads and their sources

Fine sediments constitute the largest pollutant load by volume, with a total annual average of approximately 7,950 kt exported from the basins of the GBR catchment area. More than three-quarters (77%) of this fine sediment load is attributed to anthropogenic sources, indicating significant human impact on sediment loads since pre-European development (Figure 17). The spatial distribution of sediment sources is highly concentrated, with the Burdekin region alone contributing nearly half (49%) of all fine sediments to the GBR, followed by the Fitzroy (21%) and Wet Tropics (15%) regions. The Upper Burdekin management unit

contributes 1,035 kt (13% of the total GBR load) and in the Fitzroy basin, the Dawson management unit is the largest contributor at 534 kt.

Grazing land use dominates sediment contributions, responsible for 58% of the total load, highlighting the impact of this extensive land use across the GBR catchment (Figure 18). Grazing overwhelmingly dominates sediment generation in the Burdekin region (3,290 kt, 85% of regional sediment), particularly within the Bowen Bogie management unit (1,730 kt, 94% of its sediment contribution; Appendix 3: Table 13). Grazing is also the primary source in the Fitzroy region (784 kt, 47% of regional sediment load), as is streambank erosion (707 kt, 43% of regional load). In the Burnett Mary region, 293 kt (60% of total sediment load) comes from streambank erosion, with a significant proportion of that derived from the Mary (188 kt, 72% of basin load). In the Cape York region, conservation areas are the primary source of sediment (207 kt, 71% of the regional sediment load). The physical processes driving sediment movement are primarily through gully erosion (52%), followed by hillslope erosion (24%) and streambank erosion (24%) (Figure 19). Long-term monitoring data (Howley and Shellburg, unpublished) indicates that the current end-of-catchment load estimates for the Normanby and Endeavour basin are likely to be underestimated. These are currently being revised as part of the new model build for the next Reef Water Quality Report Card.

As with DIN, urban areas can make a notable contribution to fine sediments but this is highly localised. The most significant contribution from urban areas is in the Mary Basin (32 kt), followed by the basins in the Wet Tropics with the highest contributions from the Johnstone, Mulgrave-Russell and Barron basins. However, it should be noted that these estimates are also being reviewed as part of the new model build. The relative contribution of each basin to the total TSS loads from urban areas in the GBR catchment area has been assessed by DETSI (2025). This work informs the prioritisation of basins for managing urban pollutant sources across the GBR presented in Section 6.2.

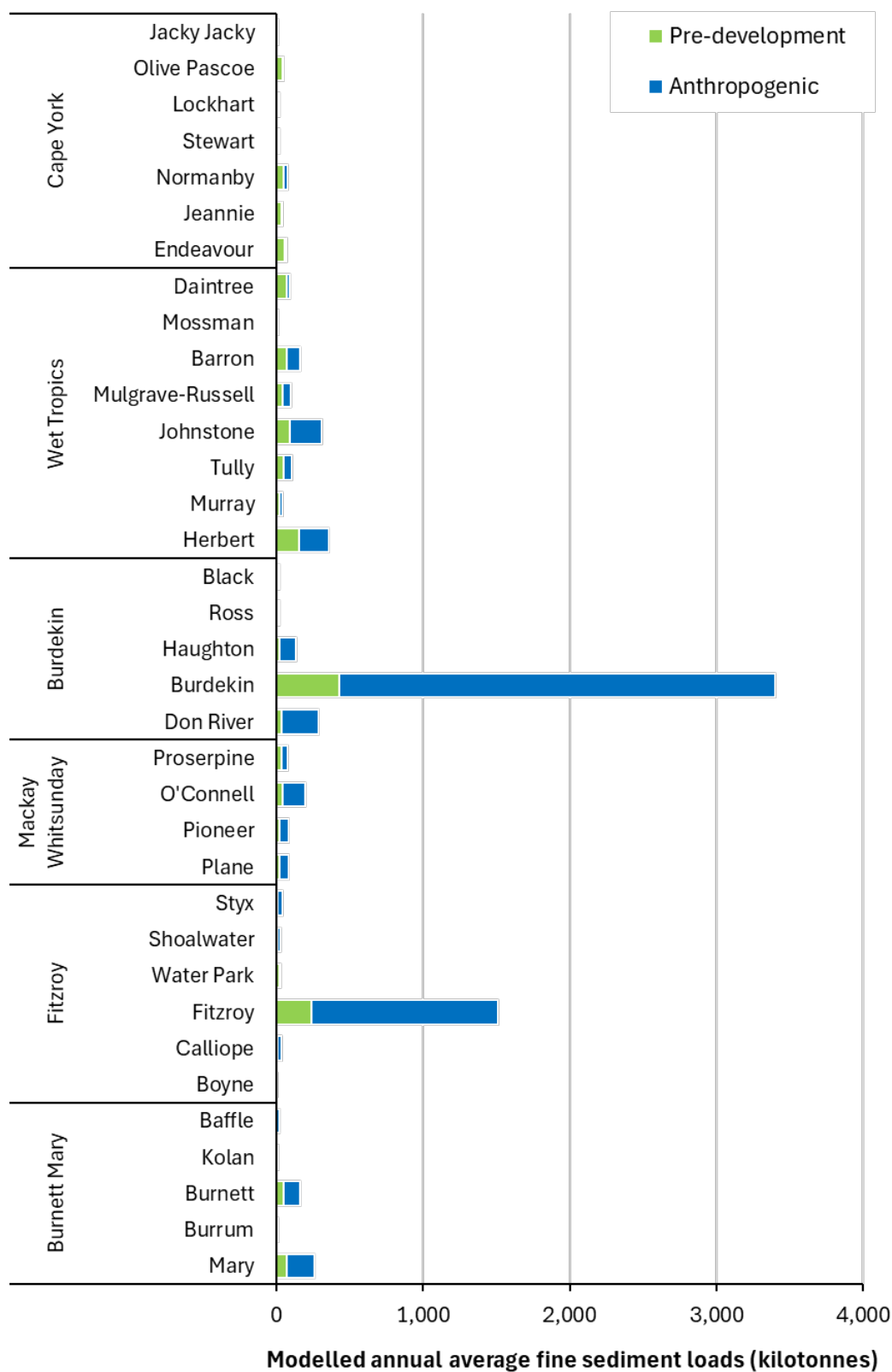


Figure 17. Modelled annual average pre-development and anthropogenic end-of-catchment loads for fine sediments (kilotonnes).

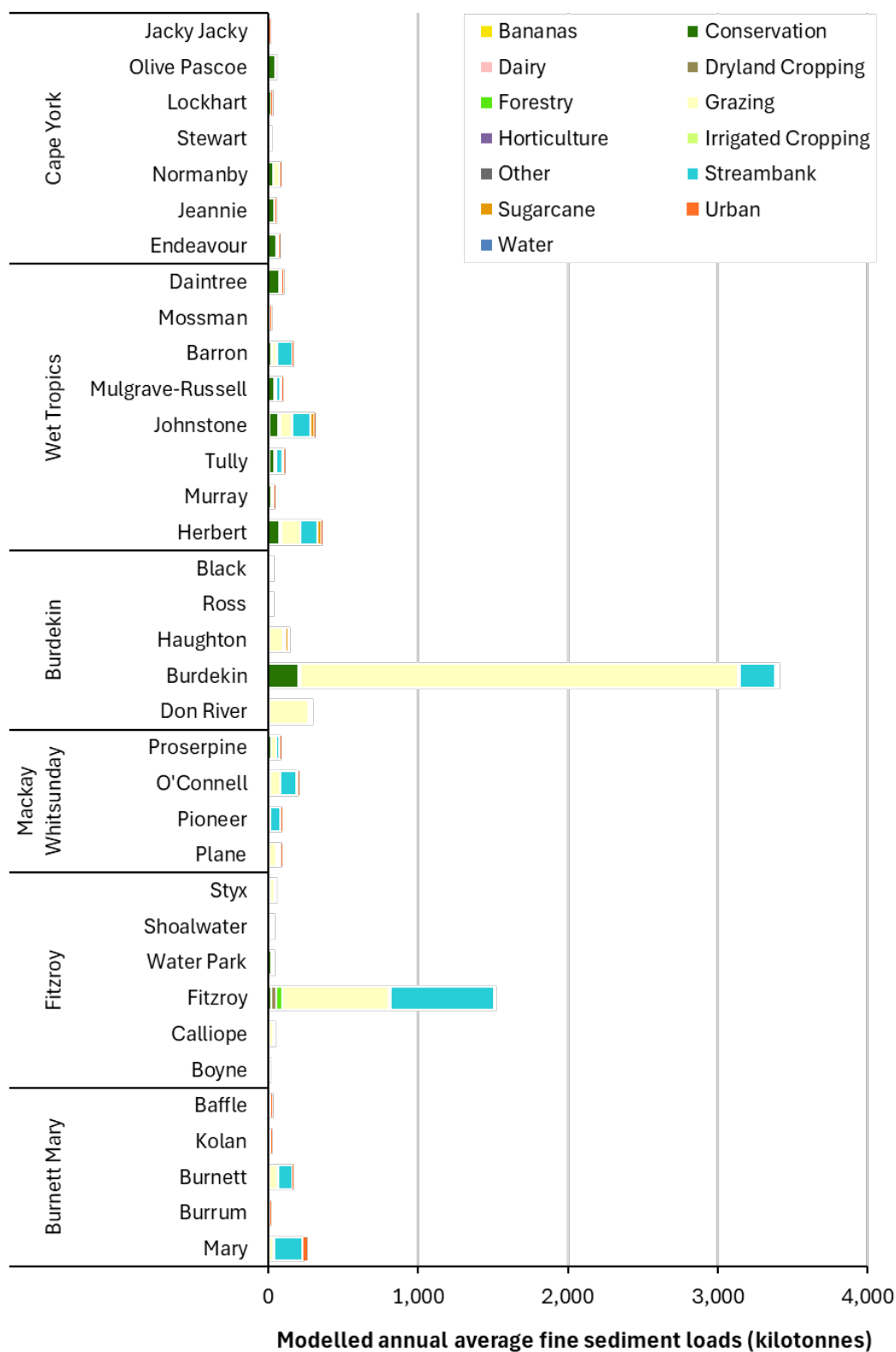


Figure 18. Modelled total annual average end-of-catchment fine sediment loads (kilotonnes) by land use.

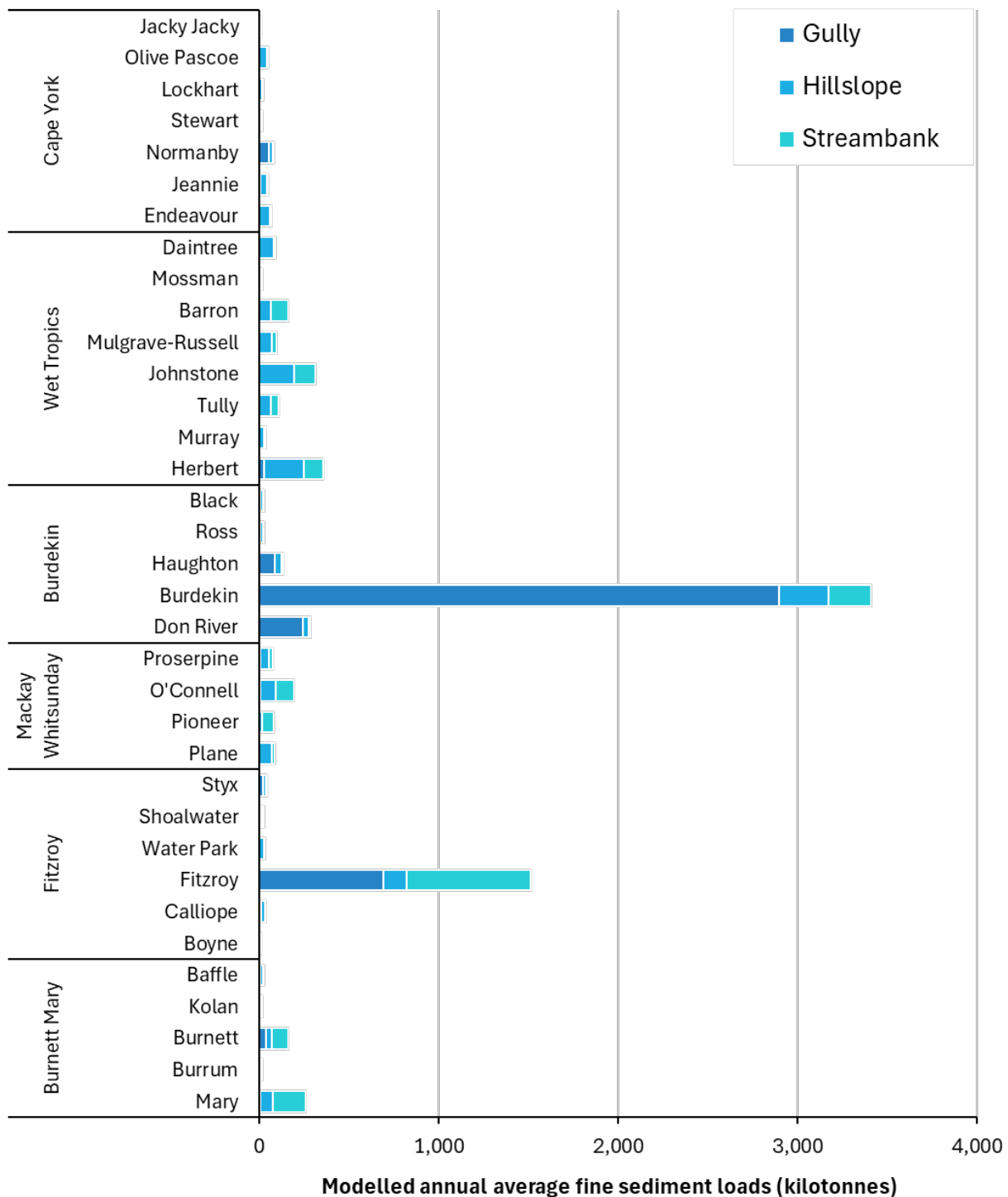


Figure 19. Modelled total annual average end-of-catchment fine sediment loads (kilotonnes) by loss pathway.

Approximately 17,180 tonnes of particulate nitrogen (PN) enter GBR waterways each year, with anthropogenic sources accounting for 59% of this load (Figure 20). The regional distribution shows a relatively even split between the Burdekin (30%) and Wet Tropics (31%) regions as the largest contributors, with the Fitzroy also providing a substantial proportion (21%).

Grazing lands represent the dominant source of PN (51% of the total), followed by conservation areas (20%) and streambank erosion (14%) (Figure 21). The principal transport mechanism is hillslope erosion (51%), followed by gully erosion (25%), indicating the importance of surface runoff in mobilising particulate

nutrients (Figure 22). Within the major contributing regions, certain hotspots emerge—particularly the Bowen Bogie management unit in the Burdekin (14% of total PN across the GBR; Appendix 3: Table 14) and the Johnstone basin in the Wet Tropics (11%).

Annual loads of particulate phosphorus (PP) are approximately 6,770 tonnes, with around two-thirds (66%) attributed to anthropogenic sources (Figure 23). The regional distribution mirrors the pattern seen for PN, with the Burdekin region contributing the largest share (35%), followed by the Fitzroy (27%) and Wet Tropics (21%). This similarity reflects the common transport mechanisms for particulate nutrients, though phosphorus shows a slightly higher concentration in the more erosion-prone Burdekin and Fitzroy landscapes compared to nitrogen.

The land use sources of PP are dominated by grazing (51% of total), with streambank erosion (25%) and conservation areas (14%) also being significant contributors (Figure 24). Like PN, the primary transport pathway is hillslope erosion (39%), but with proportionally greater contributions from gully erosion (30%) and streambank erosion (25%) (Figure 25). Key hotspots include the Bowen Bogie management unit in the Burdekin, which alone contributes 15% of the total GBR PP load, and the Fitzroy basin (24% of total). Of relevance to Section 6 and 7, the strong correlation between areas generating high sediment loads and those producing high PP loads suggests that management interventions targeting sediment will generally also address phosphorus, though the higher contribution from streambank erosion for phosphorus may require additional riparian-specific management actions.

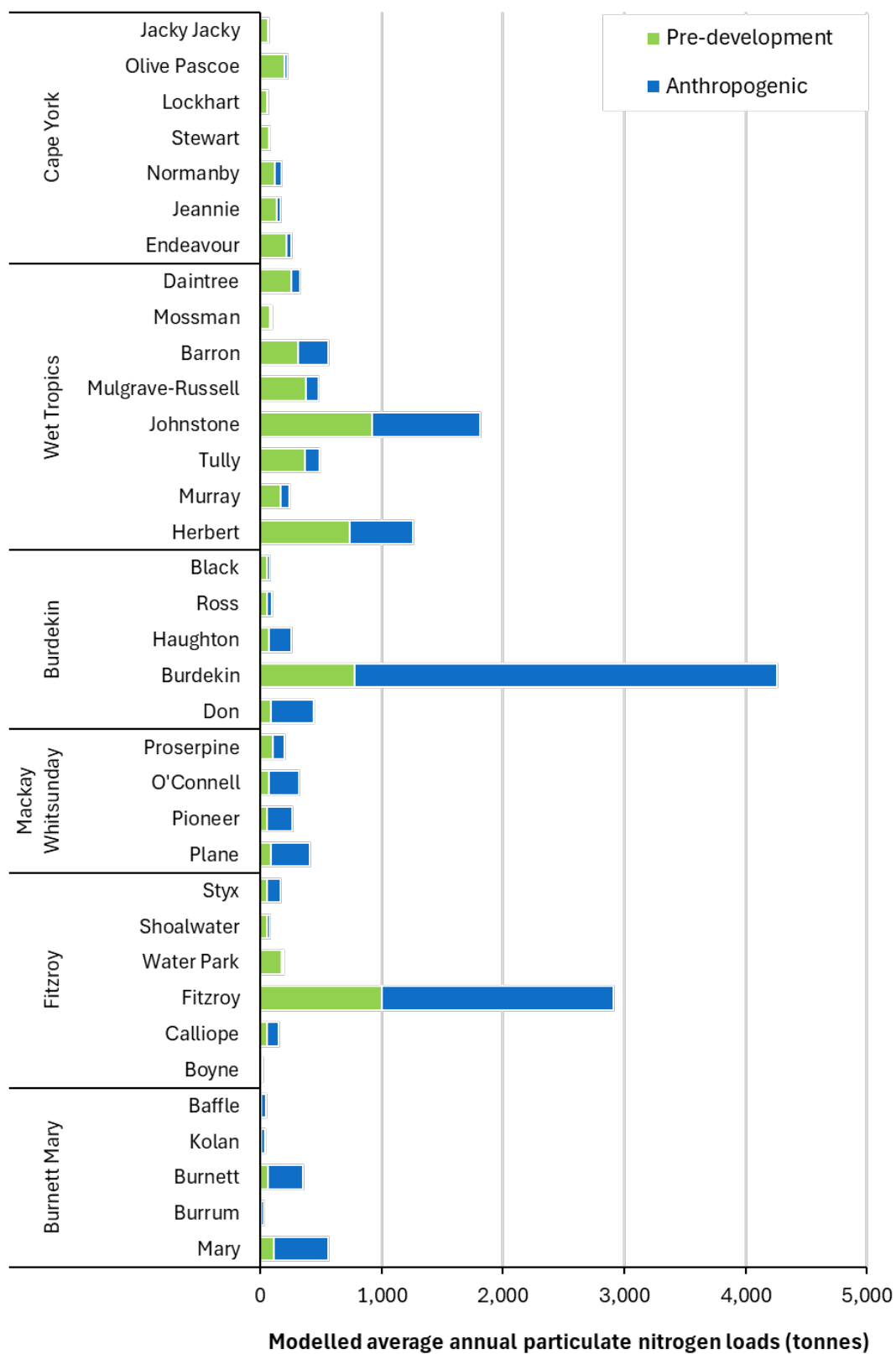


Figure 20. Modelled annual average end-of-catchment pre-development and anthropogenic loads for particulate nitrogen (tonnes).

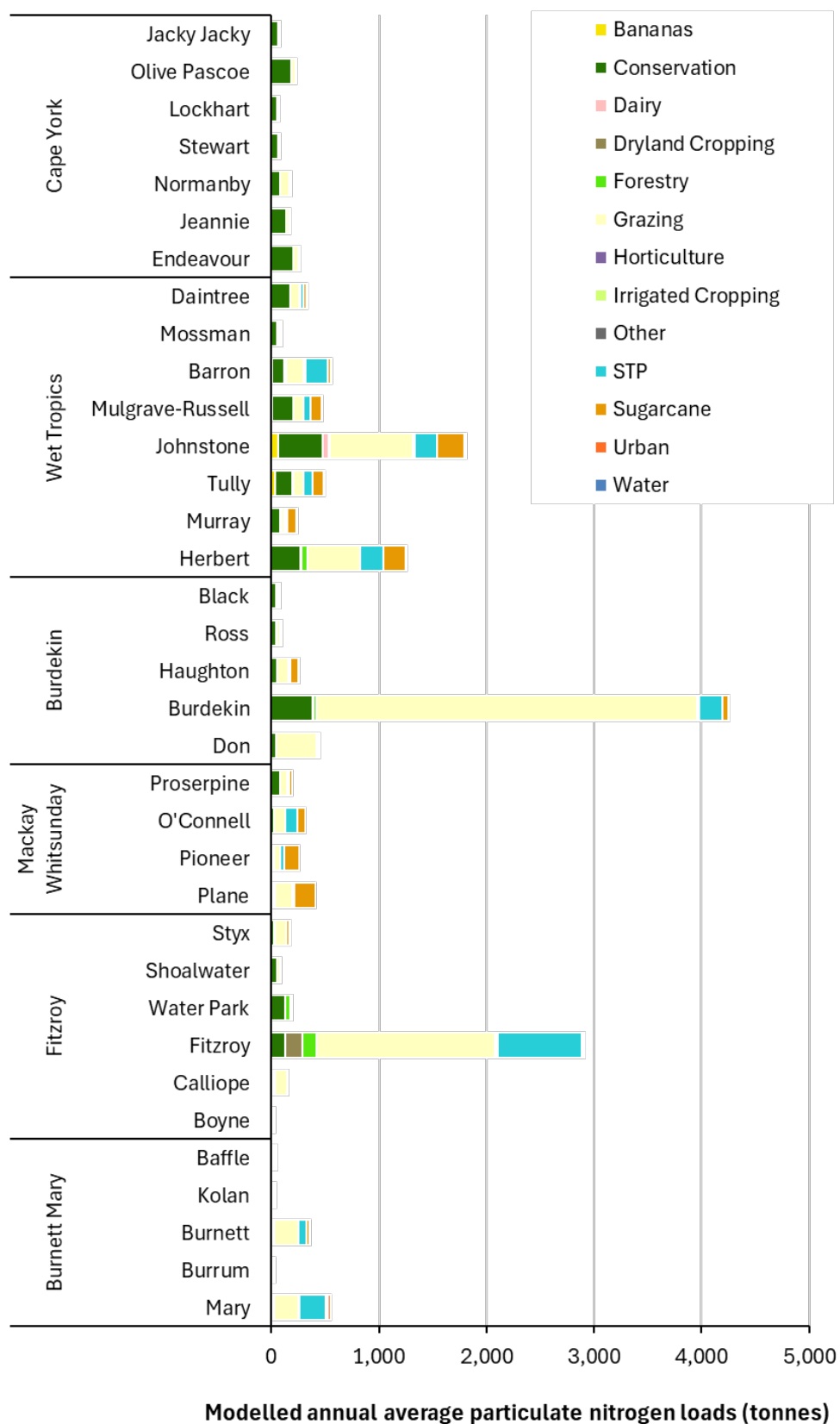


Figure 21. Modelled total annual average end-of-catchment particulate nitrogen loads (tonnes) by land use.

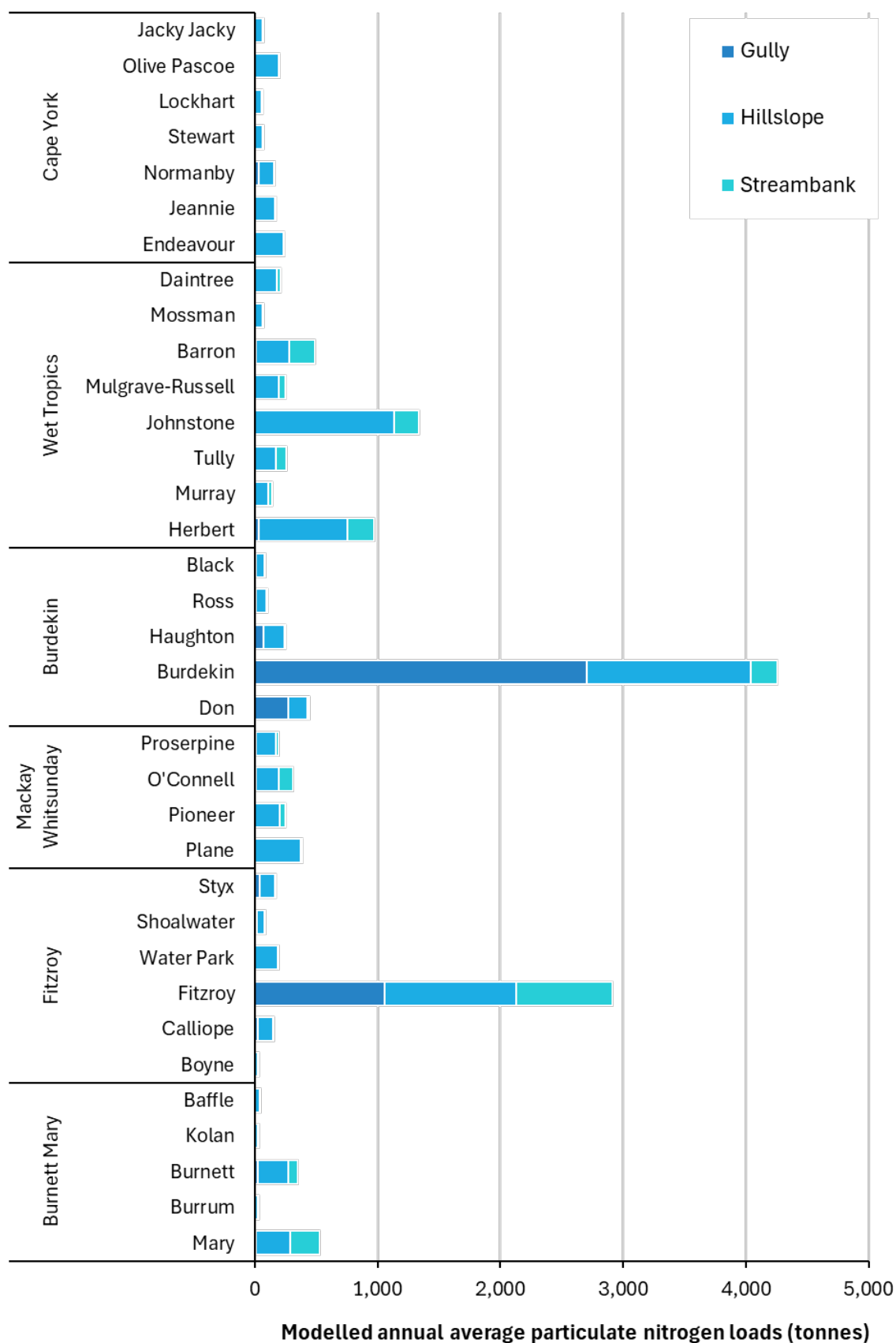


Figure 22. Modelled annual average end-of-catchment particulate nitrogen loads (tonnes) by loss pathway.

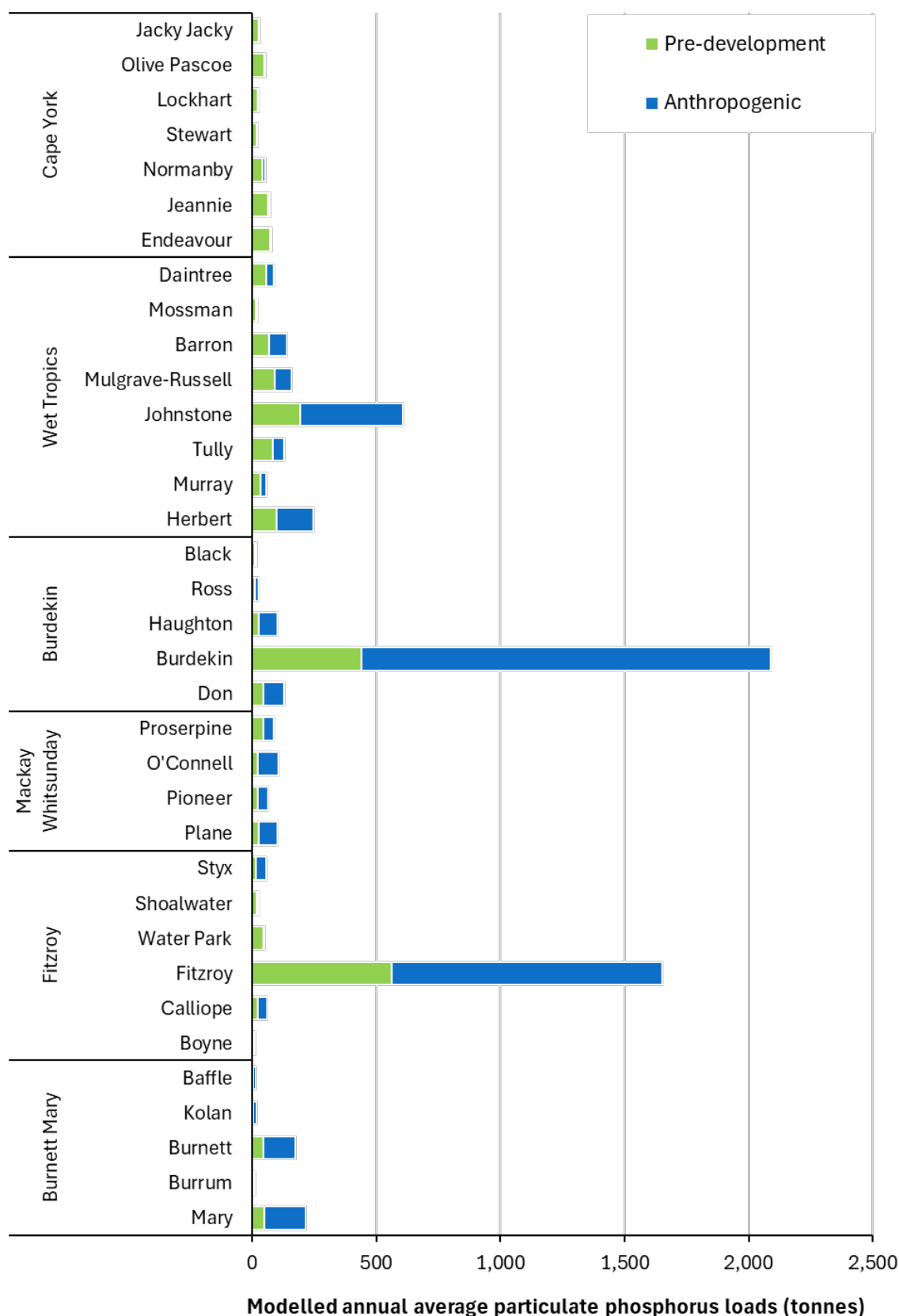


Figure 23. Modelled total annual average end-of-catchment pre-development and anthropogenic loads for particulate phosphorus (tonnes).



Figure 24. Modelled annual average end-of-catchment particulate phosphorus loads (tonnes) by land use.

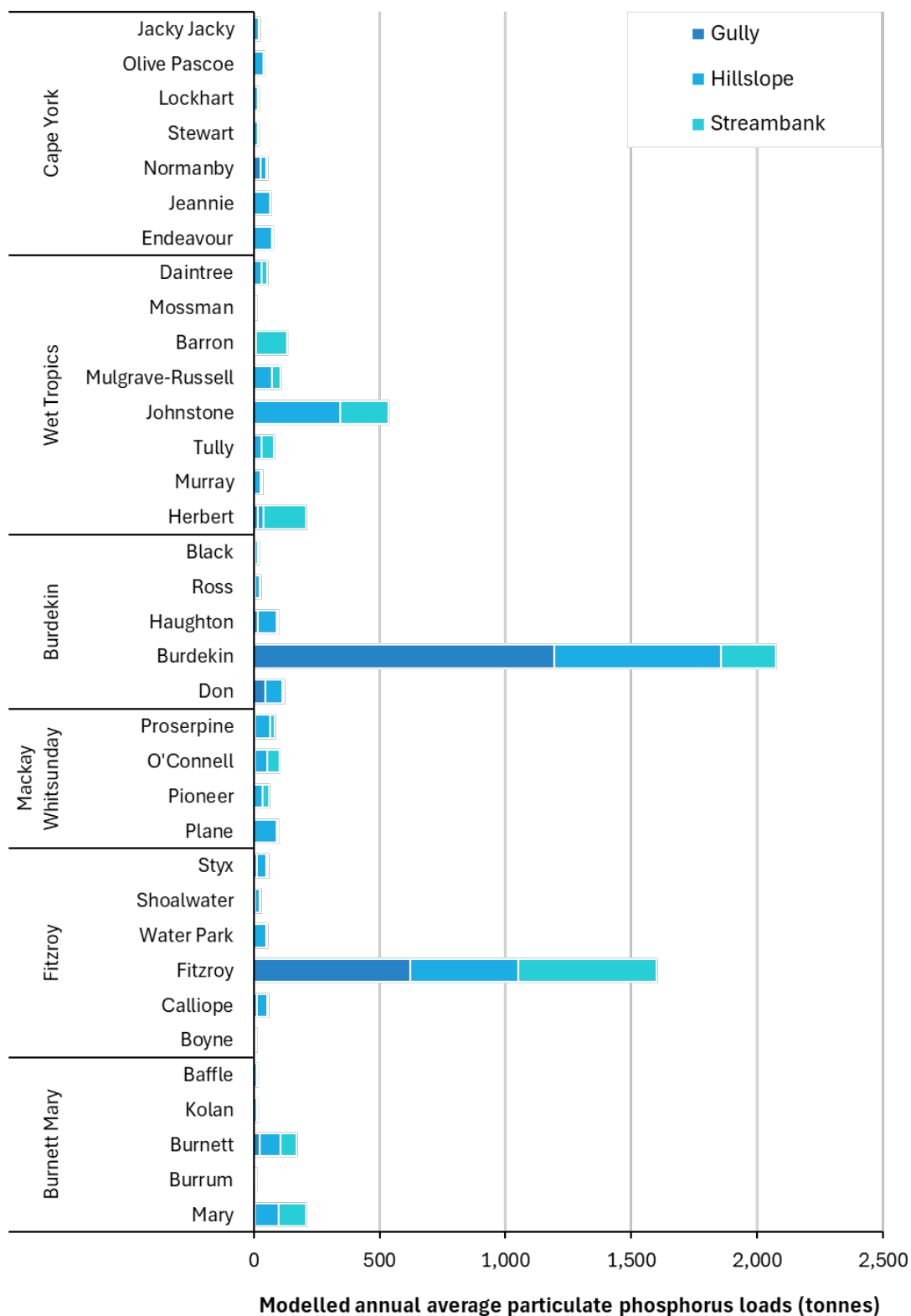


Figure 25. Modelled annual average end-of-catchment particulate phosphorus loads (tonnes) by loss pathway.

3.4 Pesticide risk

Pesticides are ubiquitous across many of the GBR's aquatic ecosystems including creeks and rivers, palustrine wetlands and in estuarine and nearshore marine habitats (Negri et al. 2024). Typically, pesticides follow a gradient from source to sea, with the ecosystems closest to the source of pesticide runoff (e.g. wetlands, creeks, drainage ditches, and upper reaches of rivers) exposed to the highest concentrations (Negri et al. 2024 and references within).

Pesticides and mixtures vary by basins and are associated with a range of factors including upstream land use, distance from source, pesticide type, rainfall, catchment topography, degradation processes and management strategies (Mitchell et al. 2005; Davis et al. 2014; Shaw et al. 2014). Several processes influence pesticide profiles as water moves downstream from the runoff source: waters mixed from multiple areas with pesticide application can generate complex mixture profiles; dilution from tributary inflows with low or no pesticide use can decrease pesticide concentrations; natural breakdown or compartmentalisation of some pesticides into metabolites can reduce concentrations and alter profiles; and mixing with tidal and marine waters can cause further dilution. These interacting, catchment-specific influences play an important role in the spatial variability of pesticides and are particularly important for management planning (Templeman and McDonald 2024 and references within).

Pesticides enter GBR waterways primarily through surface runoff (Davis et al. 2012; Devlin et al. 2015) and therefore their presence in aquatic ecosystems is closely tied with rainfall or irrigation events. Thus, pesticides occurrence in catchments downstream of agricultural land uses, is most commonly associated with the GBR wet season (i.e. December to March) (Hook et al. 2024), representing a high-risk window for aquatic organisms (Negri et al. 2024). Pulses of pesticide concentrations, in parallel with runoff events, are generally highest at the start of the wet season and dissipate towards the end of the wet season (Smith et al. 2012). This temporal variability presents a complex exposure pattern for aquatic organisms, with potential exposure to very high levels for short periods (often referred to as acute exposure), intermittent with periods of recovery, but overall a window of up to six months or more of chronic exposure. The Pesticide Risk Metric (PRM) captures this complex exposure pattern by providing an integrated assessment over the entire 182-day wet season window (Warne et al. 2020), incorporating both peak exposure events and recovery periods.

3.4.1 Methods

Pesticides are reported differently from nutrients and sediments in the GBR catchments. While nutrients and sediments use a loads-based assessment, pesticides are evaluated using a risk-based approach that considers their concentrations and potential impacts on aquatic ecosystems. This different approach (reported since 2016) is necessary because:

1. The risk to aquatic organisms depends on both the frequency and magnitude (concentration) of exposure, rather than total load.
2. Different pesticides can act together (as a mixture) to generate combined impacts.
3. Pesticides have different levels of toxicity (i.e. the level of harm they exert on an organism) and different modes of action in how they exert their toxicity.
4. Impacts of pesticides also vary between species of organism – with some more sensitive than others (Smith et al. 2017; Templeman and McDonald 2024).

Pesticide concentrations measured in water samples are collected by the DETSI (Department of the Environment, Tourism, Science and Innovation) GBR Catchment Loads Monitoring Program (GBRCLMP) according to methods reported annually by Water Quality and Investigations (2024a, and earlier versions). End-of-catchment water samples were analysed for a general suite of pesticides collected primarily during the wet season to capture runoff events. The data presented here covers the 2015–2016 to the 2022–2023 wet seasons, from 41 catchments and sub-catchments across the 6 regions of the GBR, noting that not all catchments are sampled for the full 8-year period. Upstream land use data from end-of catchment

monitoring sites was also obtained from the GBRCLMP (Ten Napel et al. 2019a, 2019b; Water Quality & Investigations 2020, 2021, 2023, 2024c, 2024d).

Pesticide risk is reported using a hierarchical structure of different risk measures, each building upon the same foundational ecotoxicity data while incorporating additional variables and scales to increase comprehensiveness in reporting. The scales of reporting cover variation in chemical toxicity (i.e. from individual pesticides to mixtures of pesticides) and temporal variations (i.e. from single point in time observations to seasonal estimates) as described in Table 4. The pesticide risk metric (PRM) is most commonly used, which estimates the potentially affected fraction (PAF) of species from mixtures of a standard set of 22 pesticides over a wet season (Warne et al. 2020), and reports values as a wet season average % species affected or its inverse, % species protected. The 22 pesticides include nine photosystem II (PSII) inhibiting herbicides, ten other herbicides with varying modes of action and three insecticides (imidacloprid, chlorpyrifos, fipronil). These pesticides were selected based on their significant contributions to risk, as identified through catchment and marine monitoring.

Using this approach, pesticide concentrations are converted to a common risk scale that allows for their direct comparison in terms of their potential ecological impacts. The contributions of each pesticide to the “total pesticide risk” (i.e. the total PAF) can then be estimated according to the following equation (Water Quality and Investigations 2024a):

$$\text{Relative contribution (\%)} = \frac{PAF_{\text{chemical } 1}}{Tot\ PAF}$$

$$Tot\ PAF = \sum PAF_{All\ chemicals}$$

Where $PAF_{\text{Chemical } 1}$ is the percent of species affected (or potentially affected fraction) for Chemical 1 calculated using the pesticide risk metric. Tot PAF is the potentially affected fraction of the combined mixture of all 22 pesticides, calculated using the pesticide risk metric.

Table 4. Measures used for reporting pesticide risk at different hierarchical levels of assessment.

Measure	Description
Default guideline values (DGVs) or Environmental threshold values (ETVs)	Used for individual pesticides. - Based on species sensitivity distributions from ecotoxicity data. - Used to evaluate single pesticide concentrations against ecosystem protection levels (e.g. Australian and New Zealand water quality guidelines). - Provides the basic reference points for more complex risk assessments. - Often reported in scientific papers, reports or dashboards reporting results of monitoring data for individual pesticides, e.g. marine monitoring program.
Multi-substance Potentially Affected Fraction (ms-PAF)	Used for mixtures of pesticides, often for single observations/ samples. - Integrates ecotoxicity data from multiple pesticides. - Accounts for multiple pesticides and their varying toxicities. - Estimates the percentage of species potentially affected (or protected when the inverse is reported) from the combined risk of a mixture of pesticides. - Represents risk for an individual observation or sample — it can be used for grab samples (single point in time) or passive samplers (time integrated observation). - Also referred to as the daily PRM (Pesticide Risk Metric) when calculated as a daily average value for a standard set of 22 pesticides. - Often reported in scientific papers, reports and dashboards that show the percentage of species affected over time or individual marine samples (e.g. passive sampler data).
Pesticide Risk Metric (PRM)	Used for mixtures of pesticides, over time and at a specific location. Comprehensive temporal risk metric extending from ms-PAF.

Measure	Description
	• Uses a combination of daily monitored ms-PAF values and interpolated daily ms-PAF values for each day (not sampled) over a 182-day wet season period (i.e. the wet season window when exposure is most likely). The daily average PAF is then estimated over this period. See Warne et al. 2020 for detailed description of the approach. • It is based on a standard set of 22 pesticides (although the number of pesticides included is set to increase in the near future). • Accounts for changes in pesticide concentrations and mixtures over time. • Provides site-specific assessment (represents the area upstream of the monitoring site). • The standard 182-day window enables comparison between catchments and across years with minimal climatic influence. • Often reported to show annual catchment pesticide risk in reports, regional report cards and dashboards.
Pesticide risk condition	Used for mixtures of pesticides, over time, extrapolated to larger spatial areas (basin, region). • Highest level of risk evaluation. • Builds on PRM data to assess risk at larger scales. • Incorporates spatial variation through land use relationships (Warne et al., 2020). • Enables the comparison of risk across basin, regional, and GBR-wide scales. • Most often reported in the Reef Water Quality report cards as % species protected.

Pesticide risk levels, reported as percentage of species affected or protected, use two corresponding risk grading systems: Very Good to Very Poor and Very Low to Very High risk, as per Table 5 (Australian and Queensland governments 2024b). The grades align with the Australian and New Zealand water quality guideline ecosystem protection levels (ANZG 2018). The 99% species protection level corresponds with the GBR water quality target for pesticides (Australian and Queensland governments 2018) and the protection level for high ecological value aquatic ecosystems in Australia (ANZG 2018). For Report Card reporting against the pesticide target (e.g. Reef Water Quality Report Cards) the percent of species protected is used and risk categories of Very Good to Very Poor.

For the purposes of this report the percent species affected will be used as reporting individual pesticide contributions is more accurately described using this metric. In addition, the risk levels will be described using very low to very high risk, as this terminology is more aligned with risk assessment language.

Table 5. Pesticide risk classification systems.

Risk Category	% Species Protected	% Species Affected (PAF)	Risk Level
Very Good	≥99%	≤1%	Very Low Risk
Good	95–99%	1–5%	Low Risk
Moderate	90–95%	5–10%	Moderate Risk
Poor	80–90%	10–20%	High Risk
Very Poor	<80%	>20%	Very High Risk

3.4.2 Sources of catchment-scale pesticide risk

There are limitations in using end-of-catchment monitoring data for identifying which upstream land uses and activities are the source of pesticide risk, compared with the modelling techniques used for sediments and nutrients. From the monitoring data alone, the pesticides driving the risk can be confidently identified and it can be used to confirm if they originate from somewhere in the upstream catchment but cannot

pinpoint specific sub-catchments or exact land uses contributing these pesticides. Therefore, to examine the sources of pesticide risk in GBR ecosystems, catchments that had a level of pesticide risk entering marine ecosystems above the target level (1% species affected) were identified first. Next, the specific pesticides that were the primary contributors to that risk were determined by analysing their relative contributions to the total PAF. These results were then interpreted using contextual information from the 2022 SCS and other sources, including the physical-chemical properties of key contributing pesticides, their behaviour in various environmental conditions, and patterns of upstream land use. For some basins, small catchments that drain directly to the inshore marine zone may also transport pesticides but lack monitoring data. In these cases, judgments about potential pesticide sources can be made based on land use patterns and pesticide risk profiles from monitored catchments within the same basin, which is the basis of the “Pesticide risk condition” estimations (Table 4).

End-of-catchment pesticide risk is presented in Table 6, demonstrating the estimated range of percent species affected (minimum – maximum wet season averages) and the risk levels according to Table 5. Catchments in the Mackay Whitsunday region had the highest risk levels (except Plane Creek), followed by the Murray River (Wet Tropics) and Barratta Creek (Haughton basin, Burdekin region). Other catchments in the Wet Tropics, i.e. Herbert, Tully, Johnstone, Mulgrave-Russell and Mossman, ranged from Low to Moderate risk, as did the Haughton River, Plane Creek and Fitzroy River. Mary, Kolan and Gregory (Burrum basin) rivers in the Burnett Mary region reached Moderate risk levels in some years, but for most years and catchments in this region, the risk levels were Very Low or Low at the end-of-catchments. All other catchments were Low or Very Low risk.

Table 6. Pesticide risk for Great Barrier Reef catchments monitored from 2015 to 2023. Risk is estimated at the catchment scale using the Pesticide Risk Metric (PRM) and reported as the range of percent species affected (minimum - maximum), and the equivalent risk classification. See Appendix 4 for the full dataset of Pesticide Risk Metric values estimated for each year.

Catchment (monitoring site)	No. of years monitored	Pesticide risk		
		Min PAF	Max PAF	Catchment risk levels*
Cape York				
Normanby River at Kalpowar Crossing	1	0	0	Very Low
Wet Tropics				
Daintree River at Lower Daintree	6	0.1	0.8	Very Low
Barron River at Rinks Close Jetty	2	0.5	0.6	Very Low
Mossman River at Bonnie Doon	4	3.2	5.2	Low to Moderate
Mulgrave River at Deeral	8	1.5	6	Low to Moderate
Russell River at East Russell	8	2.1	6.7	Low to Moderate
Johnstone River at Coquette Point	8	1.7	4.9	Low
Tully River at Euramo	8	3.1	8.9	Low to Moderate
Murray River at Bilyana	5	10.4	19	High
Herbert River at John Row Bridge	8	2.5	6	Low to Moderate
Burdekin				
Black River at Bruce Highway	6	0	1	Very Low
Ross River at Aplins Weir Headwater	6	0.1	0.9	Very Low
Haughton River at Giru Weir Tailwater	6	2.5	9	Low to Moderate
East Barratta Creek at Jerona Road (sub-catchment site)	6	9.5	16.2	Moderate to High
Burdekin River at Home Hill Inkerman Bridge	8	0.3	4.2	Very Low to Low
Don River at Bowen	5	0.8	3.5	Very Low to Low**
Mackay Whitsunday				

Catchment (monitoring site)	No. of years monitored	Pesticide risk		
		Min PAF	Max PAF	Catchment risk levels*
Proserpine River at Glen Isla	7	26.4	34.5	Very High
O'Connell River at Caravan Park	8	7.7	12.9	Moderate to High
Pioneer River at Dumbleton Pump Station Headwater	8	14.5	24.9	High to Very High
Sandy Creek at Homebush (sub-catchment site)	8	33.4	42.3	Very High
Plane Creek at Sucrogen Weir	6	4.1	7.2	Low to Moderate
Fitzroy				
Styx River at Ogmoo	2	0	0.1	Very Low
Waterpark Creek at Corbett's Landing	2	0	0	Very Low
Fitzroy River at Fitzroy River Water	8	1.7	8.3	Low to Moderate
Calliope River at Old Bruce Highway	3	0	0.2	Very Low
Boyne River at Boyne Island	2	0	0.1	Very Low
Burnett Mary				
Baffle Creek at Newton Road	2	0.1	0.2	Very Low
Kolan River at Barrage	4	0.3	7.5	Very Low to Moderate
Burnett River at Quay Street Bridge	6	1	4.3	Very Low to Low
Gregory River at Jarretts Road (sub-catchment site)	6	0	7.5	Very Low to Moderate
Elliott River at Riverview Boat Ramp (sub-catchment site)	2	0.3	4.7	Very Low to Low
Burrum River at Buxton Boat Ramp	2	0.1	0.3	Very Low
Mary River at Churchill Street	6	2.4	5.9	Low to Moderate

*Catchment-scale risk gradings as per Table 5. Note that these gradings are different to the exposure gradings used to categorise exposure in the Management Response Framework (see Section 6).

**The pesticide risk for the Don River in 2022 indicated a High risk level, however this was considered not representative of other years, due to dry conditions throughout the wet season in that year that reduced water sampling opportunities and there were insufficient water samples representing both event (high flow) and ambient (low flow) conditions. Therefore, the risk estimates for the 2021–2022 wet season were not included.

3.4.2.1 Pesticide types

An analysis ranking the percent contributions of each of the 22 pesticides to the total PAF (wet season average) was undertaken for all catchments and years monitored with a total PAF of >1% species affected. In total there were 149 combinations of catchments and years and pesticides were ranked according to their contribution to the total PAF (Table 7). Diuron ranked first or second in 82% of cases, with metolachlor as the next highest contributor ranking first in 30% of cases. Imidacloprid ranked first in 21% of cases but was most frequently ranked in second place. Atrazine typically ranked third or fourth in their contribution to total pesticide risk across catchments. At the other end, fipronil and four PSII inhibiting herbicides (metribuzin, terbuthylazine, simazine and hexazinone) were frequently ranked in the lowest positions.

Although there are 22 pesticides included in the Pesticide Risk Metric, it was found that the majority of the risk was from a small number of pesticides; the first five top ranked pesticides made up > 83% of the Total PAF and the first seven made up > 93%. For the majority of the High and Very High risk catchments, diuron and imidacloprid were the highest contributors to the total PAF (Table 8), with the top five pesticides making up 80% of the risk. Notable exceptions to these rankings include East Barratta Creek at Jerona, where imidacloprid was ranked between 9th and 12th positions, and the Don River at Bowen where imidacloprid and diuron were ranked as 13th and 18th respectively.

Table 7. Ranking of the 22 pesticides used in the Pesticide Risk Metric for the catchments graded as Low to Very High Risk.

Ranking was based on the contribution of each pesticide to the total percent of species affected (estimated using the Pesticide Risk Metric). Values represent the percent of times (i.e. catchments and years) that the pesticide ranked 1st to 22nd, noting that not all 22 pesticides were detected across all catchments and years. Pesticides are grouped based on groupings used in the Reef Water Quality Report Cards.

Pesticide Grouping	Pesticide	Ranking based on contribution to total percent species affected (n = 149)																					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
PSII	Diuron	43.6	38.3	2.7	4.0	2.7	0.7	1.3	0.0	0.0	0.7	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Herbicide	Metolachlor	29.5	10.7	22.8	14.8	12.1	4.7	4.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Insecticide	Imidacloprid	20.8	26.8	8.7	3.4	4.7	5.4	4.7	4.0	4.0	0.7	3.4	3.4	2.7	2.7	1.3	0.7	0.7	0.0	0.0	0.0	0.0	0.0
PSII	Atrazine	0.7	12.8	33.6	26.8	15.4	6.7	2.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Other Herbicide	Imazapic	0.0	0.7	8.7	20.8	32.2	26.2	2.0	3.4	3.4	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Herbicide	MCPA	0.0	6.7	9.4	17.4	16.8	31.5	11.4	2.7	0.0	0.0	0.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Herbicide	Triclopyr	0.0	0.7	4.0	5.4	5.4	8.7	12.1	22.1	14.1	7.4	8.7	4.0	2.7	2.0	2.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Other Herbicide	Metsulfuron	4.7	2.0	5.4	3.4	1.3	4.0	14.1	9.4	1.3	4.0	0.0	2.0	4.0	7.4	5.4	8.1	8.1	3.4	2.7	0.0	0.0	0.0
Insecticide	Chlorpyrifos	0.0	0.7	0.7	0.0	0.7	2.7	15.4	12.8	16.8	12.1	5.4	5.4	6.0	8.1	0.0	2.0	1.3	0.7	0.7	8.1	0.7	0.0
PSII	Ametryn	0.0	0.0	0.0	0.7	2.7	3.4	12.1	13.4	10.1	4.0	5.4	7.4	8.7	7.4	6.0	6.0	0.7	4.7	0.7	0.7	0.0	0.0
Other Herbicide	Isoxaflutole	0.0	0.0	0.0	1.3	1.3	0.7	5.4	6.7	8.7	5.4	6.0	4.7	4.0	0.0	2.0	5.4	3.4	2.7	0.0	2.0	2.7	0.7
Other Herbicide	Fluroxypyr	0.0	0.0	0.0	0.0	0.0	0.7	1.3	4.0	7.4	8.7	15.4	14.1	13.4	7.4	7.4	4.7	0.0	0.0	0.0	0.0	0.0	0.0
PSII	Tebuthiuron	0.0	0.0	2.7	0.7	0.7	2.7	4.7	5.4	6.7	12.1	4.7	4.0	4.0	2.7	2.0	1.3	0.7	0.0	0.0	0.0	0.0	0.7
PSII	Prometryn	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.3	4.0	6.7	9.4	10.1	7.4	12.8	10.1	6.0	6.0	5.4	4.0	0.0	0.0	0.0
Other Herbicide	2,4-D	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	4.0	9.4	14.1	12.8	9.4	6.7	3.4	3.4	4.7	10.7	10.7	2.7	1.3	4.0
Other Herbicide	Pendimethalin	0.0	0.0	0.0	0.0	0.0	0.7	0.7	2.0	4.7	5.4	6.7	9.4	9.4	6.7	13.4	9.4	6.7	4.0	4.7	1.3	0.7	1.3
Other Herbicide	Haloxypop	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	4.0	6.0	7.4	4.7	6.0	6.7	5.4	6.0	5.4	0.0	0.0	0.0	0.0	0.0
PSII	Hexazinone	0.0	0.0	0.7	0.7	0.0	0.7	3.4	1.3	2.0	2.7	2.0	3.4	2.7	4.0	4.0	4.7	12.8	12.8	10.7	4.7	4.0	2.0
PSII	Simazine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.0	7.4	5.4	7.4	6.7	6.0	6.7	4.7	4.0	4.0	1.3	0.7	2.7	0.0
PSII	Terbuthylazine	0.0	0.7	0.0	0.0	2.7	0.0	2.0	4.0	5.4	4.0	2.7	2.0	0.7	0.7	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.7
PSII	Metribuzin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.7	0.7	0.0	0.7	2.0	1.3	3.4	6.0	4.7	6.7	7.4	2.7	1.3
Insecticide	Fipronil	0.7	0.0	0.7	0.7	1.3	0.7	0.0	0.7	0.0	0.0	0.0	0.7	0.7	0.0	0.0	0.0	4.7	13.4	20.8	20.8	14.8	3.4

Table 8. Ranking of the top 7 pesticides for the six catchments graded as High or Very High Risk (Table 6).

Ranking was based on the contribution of each pesticide to the total percent of species affected (estimated using the Pesticide Risk Metric). Values represent the percent of times (i.e. catchments and years) that the pesticide ranked 1st to 7th. Pesticides are grouped based on groupings used in the Reef Water Quality Report Cards.

Pesticide Grouping	Pesticide	Ranking based on contribution to total percent species affected (n = 40)						
		1	2	3	4	5	6	7
PSII herbicide	Diuron	67.5	30.0	0.0	0.0	0.0	0.0	0.0
Insecticide	Imidacloprid	30.0	55.0	0.0	0.0	0.0	0.0	0.0
PSII herbicide	Atrazine	0.0	12.5	55.0	17.5	7.5	7.5	0.0
Other Herbicide	Metolachlor	0.0	2.5	32.5	27.5	25.0	12.5	0.0
Other Herbicide	Imazapic	0.0	0.0	7.5	35.0	45.0	10.0	0.0
Other Herbicide	MCPA	0.0	0.0	2.5	10.0	17.5	50.0	15.0
Other Herbicide	Isoxaflutole	0.0	0.0	0.0	5.0	5.0	0.0	12.5

The contributions to risk from key pesticides are reflected in Figure 26 and Figure 27, grouped according to the risk levels. When examining the trends in the % species affected for each pesticide across the different risk categories, an increasing trend from Low risk to Very High risk can be observed (Figure 26). In particular, a substantial increase occurs in diuron and imidacloprid in the High and Very High categories. These trends can provide some insight into the drivers of the pesticide risk, for example, a consistent increase in % species affected across key pesticides might indicate dilution (or lack thereof) being the biggest driver of the pesticide risk level – i.e. dilution resulting from a decrease in the proportion of land in the basin with high pesticide application, or temporal variations in rainfall and runoff. However, when the contributions of those pesticides to the total PAF (Figure 27) are considered, the relationships are less clear. If dilution was the primary driver, then more equal contributions across the different risk categories might be expected. Rather, there are statistically significant trends (Jonckheere-Terpstra test; Appendix 4) for the key pesticides detected, including diuron, imidacloprid, imazapic, metolachlor, triclopyr, ametryn and atrazine and no trend for metsulfuron methyl and MCPA). In addition, there is considerable variation in the contributions for each risk category, as demonstrated by the relatively large error bars.

In summary, these results demonstrate that pesticide risk in GBR catchment area is largely driven by a subset of ~ five – seven pesticides, and the pesticides making up this subset is fairly consistent across the different risk categories. The High and Very High risk levels in basins are driven largely by increased levels of diuron and imidacloprid. While dilution may contribute to the trends, contrasting patterns and large variations in the contributions to risk suggests that other factors play an important role, such as levels of use and catchment-specific factors (e.g. soil type, application timing, or farming practices). A review of the sources of pesticides confirms similar trends: PSII herbicides have the greatest contribution in general across catchments, followed by other (non-PSII) herbicides and insecticides (Templeman and McDonald 2024). Although, as shown here, those contributions (particularly for imidacloprid) vary considerably depending on the risk level of the catchment and, by far, the main PSII herbicide contributing to risk is diuron.

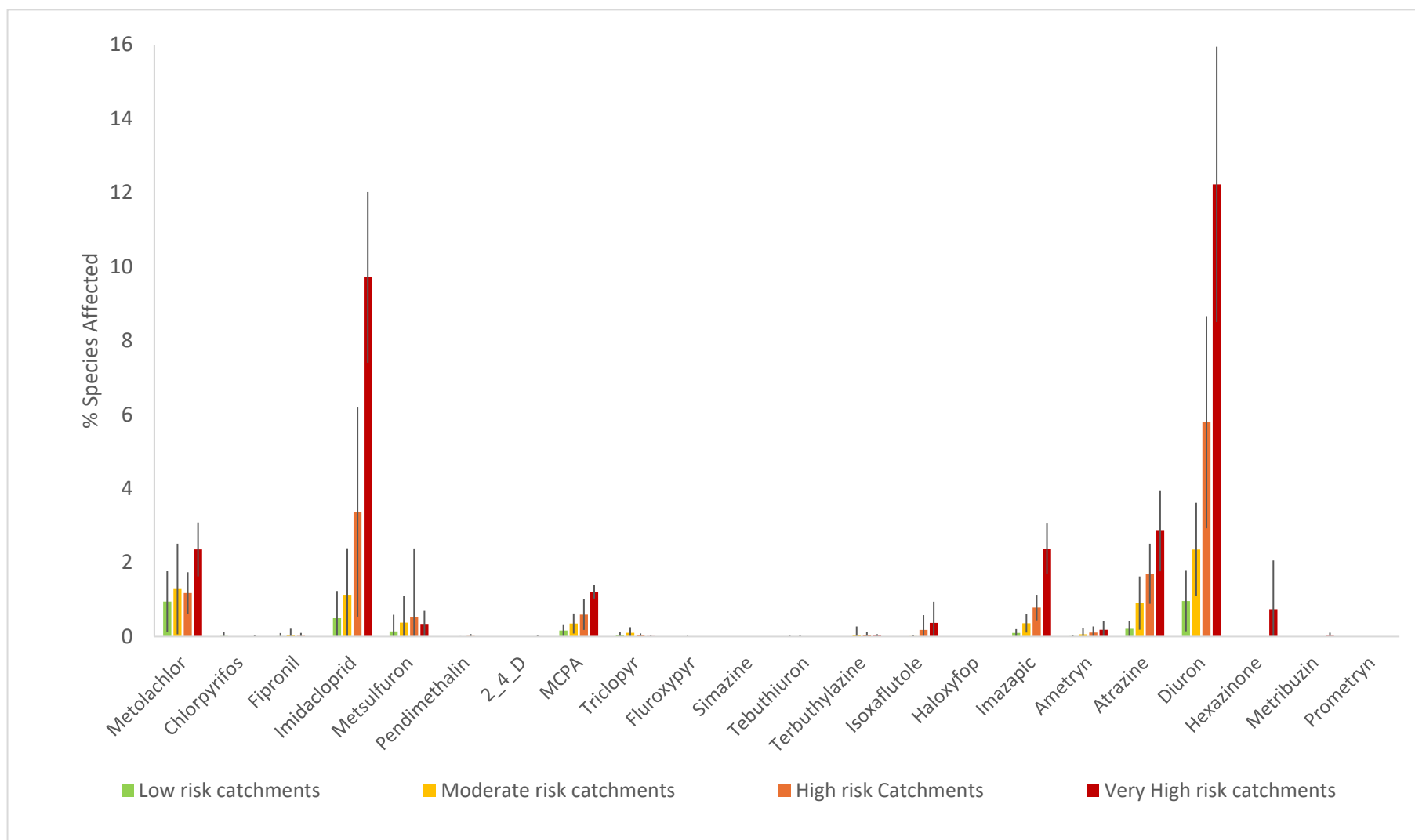


Figure 26. Percent of species affected of each of the 22 pesticides that are included in the Pesticide Risk Metric. Bars indicate the average ($\pm$ standard deviation, for $y \geq 0$) for each risk category; Low to Very High.

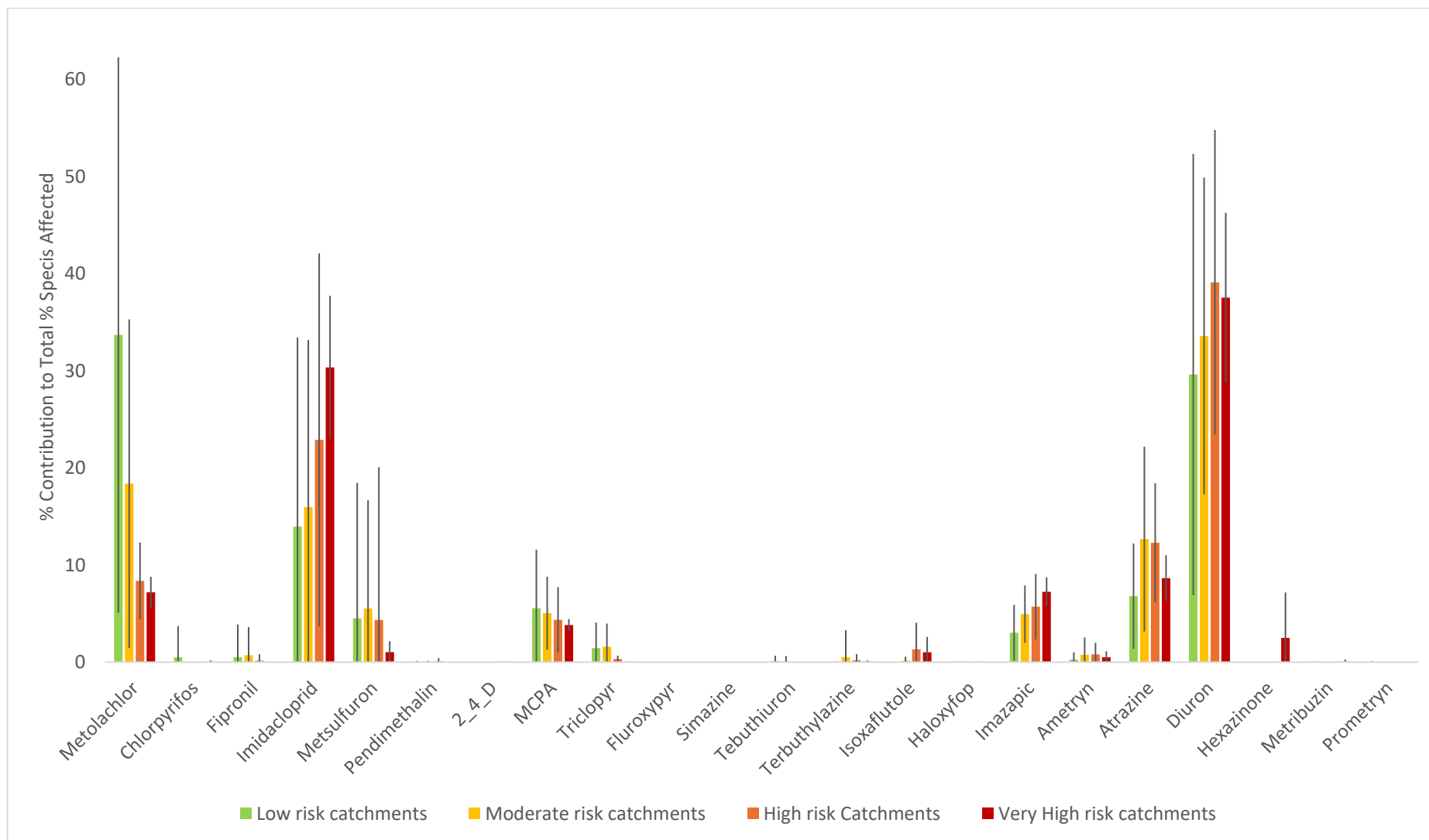


Figure 27. Percent contribution of each of the 22 pesticides to the total percent of species affected (as calculated using the Pesticide Risk Metric). Bars indicate the average ($\pm$ standard deviation, for $y \geq 0$) for each risk category; Low to Very High.

3.4.2.2 Pesticide characteristics

When examining the chemical profiles of the key contributing pesticides, physico-chemical characteristics that make them prone to runoff, i.e. they are persistent or have moderate mobility and solubility, can be observed (Table 9). Diuron and imidacloprid, the key contributing pesticides in High and Very High risk catchments, have both these characteristics. This indicates that they persist in the soil for relatively long periods after application and when rain events occur, have the capacity to become mobile and transported with runoff into receiving waters. These characteristics are particularly important when considering the timing of application, which along with application rates, are the two major drivers of pesticide export at the local level (see Templeman and McDonald, 2024 and references within). Local environmental factors, such as soil characteristics and sorption properties can also interact with the chemical profiles, for example organic matter content can influence the persistence of diuron in soils and pH levels can also affect adsorption levels of more acidic compounds (e.g. MCPA). In addition, the key contributing pesticides have relatively low ecotoxicity threshold values, so their presence in catchments is likely to present a risk to exposed aquatic organisms even at “low” environmental concentrations.

Table 9. Chemical profile of the key pesticides contributing to the majority of risk in GBR catchments. Grading descriptions (i.e. High, Moderate, Persistent, etc.) are adopted from the Pesticide Properties Database (Lewis et al. 2024b).

PESTICIDE (PESTICIDE GROUPING)	SOIL INTERFACE		MOVEMENT PATHWAYS	RECEIVING WATERS	
	Persistence (soil half-life)	Variation across soil characteristics	Mobility & solubility	Persistence (Aquatic half- life)	Ecotoxicity (aquatic species) (PC95, $\mu\text{g L}^{-1}$) ^a
Diuron (PSII herbicide)	Persistent in soils (soil half- life 146.6–229 days).	Influenced by soil type – organic matter content can affect binding, persistence varies across soil types ^{b,c} .	Slightly mobile (Koc 680 mL g^{-1}) Moderate solubility (35.6 mg L^{-1}).	Moderately fast (water- sediment half- life 48 days)	0.22
Imidacloprid (Insecticide)	Persistent (soil half-life 174– 189 days)		Moderately mobile (Koc 118 mL g^{-1}). Moderate solubility (610 mg L^{-1}).	Slow (water- sediment half- life 129 days)	0.13
Atrazine (PSII herbicide)	Non- or Moderately persistent (soil half-life 29–75 days).		Moderately mobile (100 mL g^{-1}). Moderate solubility (35 mg L^{-1}).	Moderately fast (water- sediment half- life 80 days)	1.2
Metolachlor (Other herbicide)	Non – or Moderately persistent (soil half-life 21–90 days)		Moderately mobile (Koc 120 mL g^{-1}) Moderate solubility (530 mg L^{-1}).	Stable (Water- sediment half- life 365 days)	0.4
Imazapic (Other herbicide)	Persistent (soil half-life 120– 232 days).	Strong acid.	Moderately mobile (Koc 137 mL g^{-1}). High solubility (2,230 mg L^{-1}).	Fast (Only an aqueous photolysis half- life available, likely to be	0.44

PESTICIDE (PESTICIDE GROUPING)	SOIL INTERFACE		MOVEMENT PATHWAYS	RECEIVING WATERS	
	Persistence (soil half-life)	Variation across soil characteristics	Mobility & solubility	Persistence (Aquatic half- life)	Ecotoxicity (aquatic species) (PC95, $\mu\text{g L}^{-1}$) ^a
				longer due to presence of tannins in river waters)	
MCPA (Other herbicide)	Non- persistent (soil half-life 12–25 days).	Weak acid. Adsorption decreases with increasing soil pH.	Mobile (Koc 73.88 mL g^{-1}). High solubility (250,000 mg L^{-1}).	Fast (water- sediment half- life 17 days)	1.5
Isoxaflutole (Other herbicide)	Non- persistent (soil half-life 0.9– 1.3 days).	Not pH sensitive.	Moderately mobile (Koc 145 mL g^{-1}). Low solubility (6.2 mg L^{-1}).	Fast (water- sediment half- life 0.36 days)	0.69
Triclopy (Other herbicide)	Non- to Moderately persistent (soil half-life 18.8– 30 days).	Weak acid, not pH sensitive.	Mobile (Koc 27 mL g^{-1}). High solubility (8,100 mg L^{-1}).	Fast (water- sediment half- life 29.2 days)	4.2

^a Warne et al. 2020

^b González-Pradas et al. 1992

^c Shaw et al. 2013

3.4.2.3 Land use sources of pesticides

According to the 2022 SCS, sugarcane remains the dominant source of pesticides in GBR catchments (Templeman and McDonald 2024). Warne et al. (2020) examined land use relationships with end-of-catchment % species affected values (estimated using the Pesticide Risk Metric), finding that the relationships between land use and the potential for pesticide risk varies between land use types, as presented below:

Risk of pesticide runoff to receiving waterways	Land use
Higher potential ↓	• Sugarcane, bananas, horticulture, dryland & irrigated cropping
Lower potential ↓	• Forestry, urban, grazing (open grazing and forested grazing), dairy
Minimal	• Conservation, water, wetlands, other

In fact, conservation land use had a strong negative correlation with pesticide presence confirming that areas that act as sources of dilution (i.e. runoff from areas where no or small volumes of pesticides are applied) are important influences on the pesticide risk at the end-of-catchment. This is depicted in Figure 28

which ranks catchments from left to right according to their highest recorded end-of-catchment pesticide risk (wet season average) and maps the land use proportions. For easy visual interpretation, land uses have been grouped based on those aligned with higher, lower and minimal pesticide risk (purple shading, green-brown shading and grey shading, respectively). Those catchments with higher risk generally have the highest proportion of sugarcane. Catchments with more Moderate risk levels, have smaller proportions of sugarcane but with large proportions of land uses such as forestry and grazing. Interestingly, metolachlor, a non-PSII herbicide, is often ranked highest for catchments with a moderate risk. Those catchments with Very Low risk have minimal land uses associated with the higher pesticide risk (yellow shading). The exceptions to this are the Burrum, Gregory and Elliot catchments in the Burnett Mary that have land uses with higher potential for pesticide risk, yet end-of-catchment monitoring data indicates a Very Low pesticide risk. This highlights a limitation in the pesticide risk metric's standard set of 22 pesticides that at this stage does not include some key pesticides used in horticulture and banana land use areas. Future updates of the pesticide risk metric will expand the standard suite of pesticides included in the metric to help overcome this issue.

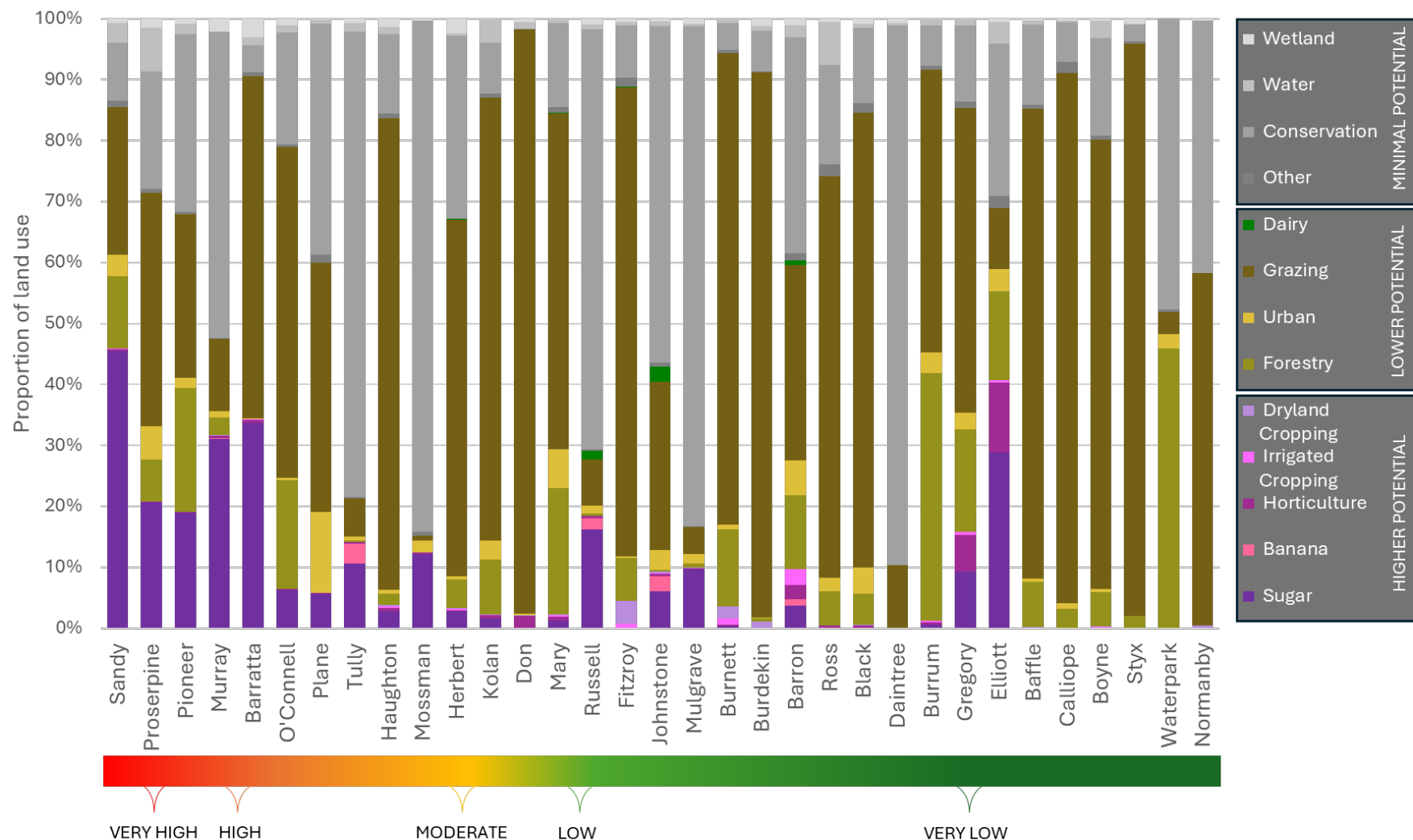


Figure 28. Proportion of land use for areas upstream of GBR Catchment Loads Monitoring Program pesticide monitoring sites. Catchments are ordered left – right based on their pesticide risk levels Very High – Very Low colour gradient bar). Land uses are grouped according to their potential for pesticide risk: land uses associated (with a higher potential) are coloured in shades of purple, those with lower potential are coloured in shades of green-brown, and land uses with minimal potential are coloured in shades of grey.

The end-of-catchment monitoring sites do not cover all areas of the basins, and therefore there may be some areas that are missed that present additional sources of pesticide risk to the marine zone. Warne et al. (2020) examined the spatial coverage of the monitored catchment areas relative to their basins and developed land use relationships that could help account for this missing area (see Table 4). The results indicated that the proportion of land use where pesticide application is high had positive correlations with pesticide risk, whereas the proportion of conservation land use had a negative correlation with pesticide risk (as runoff from these areas contributes to the dilution of pesticide concentrations in catchments). For basins where those proportions differed from the monitored area, generally there was a commensurate change in the risk level (Warne et al. 2020). In some cases, the pesticide risk was greater at the basin level as there were additional land uses downstream of the monitoring sites or in other unmonitored parts of the basin that were likely to contribute additional pesticides (Warne et al. 2020). Lastly, there were two catchments where the basin-level pesticide risk would likely be lower, as the proportion of conservation land use was greater at the basin level compared to the monitored catchment (Warne et al. 2020). A summary of the catchments/ basins where the difference resulted in a change in risk levels is presented in Table 10.

Table 10. Summary of the catchment vs basin risk assessment differences (based on Warne et al. 2020).

Catchment	Average catchment risk level*	Basin risk level**	Risk Classification Change	Primary Explanation
Mossman River	Low to Moderate risk	Moderate risk	↑ Risk	Basin has less conservation area (75% vs 84%) and monitoring site is close to river mouth (AMTD 2.1 km).
Mulgrave River	Low to Moderate risk	Moderate risk	↑ Risk	Additional pesticide sources from downstream land uses not captured at monitoring site.
Russell River	Low to Moderate risk		↑ Risk	Additional pesticide sources from downstream land uses not captured at monitoring site.
Johnstone River	Low risk	Moderate risk	↑ Risk	Additional land not included in monitored catchment contributing to higher pesticide levels.
Murray River	High risk	Moderate risk	↓ Risk	Basin has high conservation area (63%) and low sugarcane compared to monitored area.
Herbert River	Low to Moderate risk	Moderate risk	↑ Risk	Basin contains additional land uses downstream of monitoring site that could contribute additional pesticides.
Proserpine River	Very High risk	Moderate risk	↓ Risk	Basin has ~50% more conservation area (29.1% vs 20.6%) and half the sugarcane (9.6% vs 20.8%) compared to the monitored area.
O'Connell River	Moderate to High risk	High risk	↑ Risk	Greater proportion of sugarcane land use at basin scale (13%) compared to the monitored area (6%).
Pioneer River	High to Very High risk	Very High risk	↑ Risk	Lower proportion of conservation at basin scale (20%) compared to monitored area (31%).
Sandy Creek	Very High risk	Very High risk	Same	Basin has higher proportion of sugarcane in the northern area where Sandy Creek is located, the southern area where Plane Creek is located has a lower proportion of sugarcane.
Plane Creek	Moderate risk		↑ Risk	

Catchment	Average catchment risk level*	Basin risk level**	Risk Classification Change	Primary Explanation
Burrum River	Low risk	Moderate risk		Basin contains an additional 6000 ha of sugarcane downstream of monitoring sites that could contribute additional pesticides.

*Based on Table 6.

**Based on Warne et al. 2020 (Table 28, pg 76). Data is based on the 2015–2018 monitoring years.

4. Pollutant hazard, exposure and/or risk to ecosystems

4.1 Freshwater (floodplain) wetlands hazard and exposure

Freshwater (floodplain) wetlands are highly susceptible to the delivery of pollutants as they receive water directly flushed through agricultural and other land uses. The likelihood of degraded water flushing into floodplain wetlands is closely linked to their hydrology and connectivity, the climate and any factors that affect the water cycle.

The drivers and sources of pressures on floodplain wetlands within the GBR catchment have been broadly described (DESI 2013; Tilden et al. 2023). However, there are presently few data available on the generation, pathways and fate of potential pollutants in relation to floodplain wetlands, whether from sub-catchment, basin or GBR-wide perspectives (Waterhouse et al. 2024a). As such, hazard and exposure of floodplain wetlands was determined using data from one of the few GBR catchment-wide studies available (Department of Science, Information Technology and Innovation 2015), which mapped the level of hazard to floodplain wetlands from nutrient, sediment and pesticide pressures associated with land-use drivers. The wetland hazard assessment methodology does not specifically distinguish nutrient forms or constituents associated with different land uses.

4.1.1 Nutrients

Floodplain wetlands can receive nutrients continuously through groundwater and during flood pulses. Negative effects can occur during runoff pulses with high pollutant concentrations and oxygen demand. In the GBR catchment, these nutrients can affect organism growth, species composition, and ecosystem functions (Brodie and Mitchell 2005; Pearson et al. 2015). Excess nutrients can also help invasive plants thrive, outcompeting native plants (Adame et al. 2019). There is limited knowledge of the impact of different forms of nutrients on freshwater floodplain wetland ecosystems, however, dissolved nutrients are immediately bioavailable. In the short term, high nutrient levels can boost plant and algal growth if suspended sediments are low, but excessive algae can harm invertebrates by reducing light and habitats (Connolly and Pearson 2007). High nutrient levels can also cause water toxicity through algal blooms and promote exotic weeds (Brodie and Mitchell 2005) and floating weed mats (MacKinnon and Herbert 1996). Poor water quality can be fatal for animals, especially during the first flood of the wet season, when hypoxia and fish deaths can occur (Townsend and Edwards 2003). The most significant negative impacts of degraded water quality are often seen in the dry season, particularly in shallow wetlands visited by ungulates (e.g. cattle and pigs) (Pettit et al. 2012) because pollutants are less diluted.

4.1.1.1 Methods

The exposure of freshwater floodplain wetlands to hazard from nutrient (total nutrients, including different nutrient forms) pollutant pressure was calculated for each management unit relative to the total area of freshwater floodplain wetlands in the management unit, and relative to the total area of freshwater floodplain wetlands in the GBR catchment area exposed to the hazard. To this end, the extent of hazard was first determined by calculating for each management unit (i) the spatial extent of High and/or Very High hazard for nutrient pollutant pressure, (ii) the spatial extent of areas categorised as High and/or Very High hazard *that also contain wetlands*, and (iii) the area in hectares and percentage area of hazard and non-hazard areas. Recognising upstream hazards can affect downstream wetlands, in addition to the very high and high hazard categories, the next three downstream Aquatic Conservation Assessment (ACA) mapping units were also included (see below for more information on ACAs).

Next, the following equation was used to determine exposure relative to the total area of wetlands in the management unit (MU):

$$Exposure (MU) = \frac{a_i}{b_i} \times 100$$

where

a_i = Hectares of floodplain wetland within management unit i that are exposed to nutrient pollutant hazard (High and/or Very High hazard).

b_i = hectares of floodplain wetlands in management unit i .

Exposure (MU) is the percentage of floodplain wetland area exposed to nutrient pollutant hazard within a management unit relative to the total floodplain wetland area in that management unit. This measure of exposure was used in the water quality management response assessment, outlined in Section 7. The resultant percentages were converted to exposure categories of minimal, low, moderate and high as follows: < 0.5% exposure = minimal; 0.5–5% exposure = low; > 5–25% exposure = moderate; > 25% exposure = high.

The exposure of wetlands to the hazard from nutrient pollutant pressure relative to the GBR catchment area wetland area exposed was determined using the formula:

$$Exposure(GBRCA) = \frac{a_i}{\sum_{i=1}^n a_i} \times 100$$

where

a_i = Hectares of floodplain wetland within management unit i that are exposed to nutrient pollutant hazard (High and/or Very High hazard).

n = total number of management units within the GBR catchment.

Exposure (GBRCA) is the percentage of floodplain wetland area exposed to nutrient pollutant hazard within a management unit *relative to the total GBR floodplain wetland area exposed* to the nutrient pollutant hazard. As such, Exposure (GBRCA) is a relative measure of floodplain wetland exposure that may be of interest when comparing management unit exposures across the GBR catchment. Percentages were converted to categories of minimal, low, moderate and high as follows: < 0.5 % exposure = minimal; > 0.5–4.5% exposure = low; > 4.5–9.5 % exposure = moderate; ≥ 9.5% exposure = high.

To determine the spatial extent of the hazard, hazard maps were generated for nutrient pressures across the GBR catchment area based on the method outlined by the Department of Science, Information Technology, Innovation, and the Arts (2015). This approach specifically identifies hazards related to anthropogenic land use within the landscape, providing a conceptual link between land uses and pressures. The maps were generated using Geographic Information System (GIS) technology using land use and ACA mapping. The attribution of current land use (2021) is based on aggregated Australian Land Use Management Classification (ALUMC) (Department of Environment and Science 2023b). To ensure appropriate hazard rankings were applied, the spatial extents attributed to ALUMC codes 5.30–5.38 (Manufacturing and Industrial), 5.70–5.75 (Transport and Communication), 5.9.0–5.9.5 (Waste treatment and disposal), and 5.2.5 (Aquaculture) were drawn from the previous version of land use (with disaggregated ALUMC). The ACA mapping units were used as the basis for assigning hazard levels across the landscape. ACA, defined under the Aquatic Biodiversity Assessment and Mapping Method (AquaBAMM) by Clayton et al. (2006), is designed to support natural resource management, water resource planning, prioritising protection efforts, regulation, rehabilitation, and investment strategies for aquatic ecosystems. The ACA mapping units, called sub-sections, are specified study areas (usually a sub-catchment) used for the assessment of the ACA.

Within each ACA mapping unit, the percentage area covered by each land use group was assessed. Natural water bodies (e.g. rivers, lakes) were excluded from the land use mapping to focus solely on terrestrial areas. Weightings were then assigned to each land use group based on their potential to contribute to the nutrient (total nutrients, i.e. dissolved and particulate forms of nitrogen and phosphorus) pollutant pressure. The weightings were determined by an expert panel, considering the influence of each land use type on wetland conditions (Department of Science, Information Technology, Innovation, and the Arts 2015). For each mapping unit, the percentage area of each land use group was then multiplied by its corresponding weight. The results of these land use × weight calculations were summed to produce a single land use hazard score for each ACA mapping unit. Mapping units were then attributed hazard scores for pollutant pressure, which were categorised into five classes: Very Minor (1), Minor (> 1 to 2), Moderate (> 2 to 3), High (> 3 to 4) and Very High (> 4 to 5) hazard.

To determine the spatial extent of freshwater floodplain wetlands, areas were extracted that met the criteria of natural or semi-natural, lacustrine and palustrine floodplain wetland systems where wetlands were the dominant feature within the polygon, excluding mosaic areas identified as sub-dominant or containing wetlands (these are wetlands that are too small to map at the current mapping scale). The data were extracted from Queensland Wetland Areas (Department of Environment and Science 2023a, 2023c, 2023d). Natural wetlands included those defined as such by the hydrological modifier code H1. Semi-natural wetlands included those modified by bunding, excavation, or partial drainage (wetland habitat modification codes: H2-M2, H2-M2-a, H2-M2-c, H2-M9, H2-M9-a, H2-M9-b, H2-M11, H2-M11-a, H2-M11-b, H2-M12, H2-M12-c, H2-M12-d).

4.1.1.2 Nutrient hazard and hazard exposure results

Several management units contain areas with Very High and High hazard areas for nutrient pressures (Figure 29; Table 11). Approximately 57,736 ha of floodplain wetlands within the GBR catchment lie within and immediately downstream of Very High and High hazard areas for nutrient pressures. All but nine of the 48 management units (Jacky Jacky, Olive-Pascoe, Lockhart, Stewart, Jeannie, Daintree, Mossman, Styx and Shoalwater) had floodplain wetlands in and/or immediately downstream of Very High or High nutrient hazard areas (Figure 30).

Exposure (Management Unit)

In addition to the nine management units mentioned above that had no wetland area exposed to High or Very High nutrient hazard (i.e. they were in the minimal Exposure (MU) category), there were three management units in the low exposure category (0.5 to 5% wetland area exposed): Normanby, Mulgrave-Russell and Waterpark Creek (Figure 31; Table 11). Note that there is a mapping error identified in the boundaries of the Waterpark Creek basin, which resulted in an error in the results, thus giving an incorrect hazard exposure rating for nutrients and sediments. Six management units were in the moderate exposure category (>5 to 25% wetland area exposed to High or Very High hazard): Endeavour, Ross, Belyando, Suttor, Upper Burdekin and Calliope (Figure 31; Table 11). The remainder (30 management units) were in the high Exposure (MU) category, having more than 25% of their total wetland area exposed to High or Very High nutrient hazard (Figure 31; Table 11). Out of these, the Lower Herbert, Haughton, Burdekin Delta, Don River, Proserpine (99.7%), Boyne (100%) and Burnett had > 75% of their wetland area exposed to High and Very High nutrient hazard.

Exposure (GBR Catchment area)

Relative to the total GBR catchment freshwater wetland area exposed to High and Very High nutrient hazard, the Lower Fitzroy (16%) management unit had the largest area exposed to High or Very High nutrient hazard relative to other areas (Table 11). Seven management units had floodplain wetlands with moderate nutrient exposure (Haughton, Comet, Lower Herbert, Proserpine, Dawson, Baffle, Mary), 16 had floodplain wetlands with low nutrient exposure (0.5 to 4.5%) and 24 had floodplain wetlands with minimal nutrient exposure (<0.5 to 4.5%) relative to the GBRCA wetland area exposed.

Table 11. Area (ha) of freshwater floodplain wetlands in and immediately downstream of pollutant hazard areas, by management unit (MU), and the exposure to pollutant hazard relative to the area of wetlands in the management unit (Exposure-MU) and to the total area of freshwater floodplain wetlands in the GBR catchment exposed to pollutant hazard (Exposure-GBRCA). See Section 4.1 for methods. Percentages for Exposure-MU were converted to exposure categories of minimal (white), low (blue), moderate (yellow) and high (red) as follows: < 0.5% exposure = minimal; 0.5–5% exposure = low; > 5–25% exposure = moderate; > 25% exposure = high. Percentages for Exposure-GBRCA were converted to categories of minimal (white), low (blue), moderate (yellow) and high (red) as follows: < 0.5 % exposure = minimal; > 0.5–4.5% exposure = low; > 4.5–9.5 % exposure = moderate; ≥ 9.5% exposure = high. For pesticide hazard Very High, High and Moderate hazard categories were used in the assessment. Very High and High categories were used in the nutrient and sediment hazard assessment. * MUs with spatial under-representation of nutrient hazard due to smaller areas of high hazard being offset by larger areas of low hazard within ACA mapping units; # MUs with large areas exposed to nutrient hazard but with only a small area of wetlands.

Management Unit	Wetland area in MU (ha)	Nutrients			Sediments			Pesticides		
		Area (Ha)	Exposure-MU (%)	Exposure-GBRCA (%)	Area (Ha)	Exposure-MU (%)	Exposure-GBRCA (%)	Area (Ha)	Exposure-MU (%)	Exposure-GBRCA (%)
Jacky Jacky	1,354	0	0.0	0.0	76	5.6 ¹	0.1	0	0.0	0.0
Olive-Pascoe	2,558	0	0.0	0.0	2	0.1	0.0	0	0.0	0.0
Lockhart	0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Stewart	857	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Normanby	14,264	470	3.3	0.8	2,091	14.7	2.5	0	0.0	0.0
Jeannie	0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Endeavour	277	43	15.6	0.1	48	17.5	0.1	0	0.0	0.0
Daintree*	1,351	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Mossman	4	0	0.0	0.0	0	0.0	0.0	2	51.8	0.0
Barron	150	47	31.6	0.1	50	33.3	0.1	72	48.3	0.2
Mulgrave-Russell*	7,470	39	0.5	0.1	39	0.5	0.0	1,900	25.4	5.9
Johnstone	1,510	525	34.8	0.9	566	37.5	0.7	811	53.7	2.5
Tully	3,729	1,901	51.0	3.3	1,953	52.4	2.3	3,290	88.2	10.2
Murray	3,326	1,999	60.1	3.5	2,098	63.1	2.5	2,618	78.7	8.1
Upper Herbert	1,954	1,066	54.6	1.8	1,856	95.0	2.2	343	17.6	1.1
Lower Herbert	5,305	4,848	91.4	8.4	5,109	96.3	6.1	4,517	85.1	14.0
Black#	57	15	26.1	0.0	20	34.4	0.0	6	10.2	0.0
Ross	958	121	12.6	0.2	342	35.7	0.4	42	4.3	0.1
Haughton	6,552	5,038	76.9	8.7	5,210	79.5	6.2	4,902	74.8	15.2

Management Unit	Wetland area in MU (ha)	Nutrients			Sediments			Pesticides		
		Area (Ha)	Exposure-MU (%)	Exposure-GBRCA (%)	Area (Ha)	Exposure-MU (%)	Exposure-GBRCA (%)	Area (Ha)	Exposure-MU (%)	Exposure-GBRCA (%)
East Burdekin#	57	22	38.3	0.0	57	100.0	0.1	22	38.3	0.1
Burdekin Delta	2,058	1,962	95.3	3.4	1,948	94.6	2.3	1,966	95.5	6.1
Belyando	4,653	965	20.7	1.7	4,646	99.8	5.5	0	0.0	0.0
Suttor	688	81	11.8	0.1	688	100.0	0.8	13	1.8	0.0
Upper Burdekin	5,166	768	14.9	1.3	4,186	81.0	5.0	0	0.0	0.0
Bowen Bogie#	38	12	31.5	0.0	34	89.2	0.0	0	0.0	0.0
Cape Campaspe	5,245	1,697	32.3	2.9	5,224	99.6	6.2	0	0.0	0.0
Don River	571	476	83.3	0.8	517	90.6	0.6	30	5.3	0.1
Proserpine	4,350	4,336	99.7	7.5	4,338	99.7	5.1	2,530	58.2	7.9
O'Connell	175	92	52.3	0.2	92	52.3	0.1	46	26.4	0.1
Pioneer	228	163	71.4	0.3	130	57.0	0.2	197	86.6	0.6
Plane Creek	1,018	410	40.3	0.7	130	12.8	0.2	535	52.5	1.7
Styx	539	0	0.0	0.0	50	9.3	0.1	0	0.0	0.0
Shoalwater	374	0	0.0	0.0	95	25.3 ²	0.1	0	0.0	0.0
Waterpark Creek	3,514	21	0.6 ³	0.0	21	0.6 ³	0.0	0	0.0	0.0
Lower Fitzroy	14,176	9,511	67.1	16.5	11,300	79.7	13.4	0	0.0	0.0
Dawson	8,920	4,138	46.4	7.2	8,754	98.1	10.4	1,219	13.7	3.8
Isaac	1,555	609	39.1	1.1	1,476	94.9	1.7	200	12.9	0.6
Mackenzie	2,181	1,360	62.3	2.4	2,056	94.2	2.4	173	7.9	0.5
Comet	6,096	4,894	80.3	8.5	6,085	99.8	7.2	212	3.5	0.7
Nogoa	1,637	804	49.1	1.4	1,631	99.6	1.9	304	18.6	0.9
Theresa Creek	199	97	48.6	0.2	199	100.0	0.2	54	27.3	0.2
Calliope#	44	6	12.7	0.0	44	100.0	0.1	0	0.0	0.0
Boyne#	40	40	100.0	0.1	40	100.0	0.0	0	0.0	0.0
Baffle	6,810	3,879	57.0	6.7	5,339	78.4	6.3	936	13.7	2.9
Kolan	207	133	64.5	0.2	132	63.7	0.2	103	50.0	0.3

Management Unit	Wetland area in MU (ha)	Nutrients			Sediments			Pesticides		
		Area (Ha)	Exposure-MU (%)	Exposure-GBRCA (%)	Area (Ha)	Exposure-MU (%)	Exposure-GBRCA (%)	Area (Ha)	Exposure-MU (%)	Exposure-GBRCA (%)
Burnett	971	815	84.0	1.4	889	91.6	1.1	375	38.6	1.2
Burrum	6,084	1,530	25.1	2.6	1,863	30.6	2.2	1,272	20.9	4.0
Mary	4,937	2,806	56.8	4.9	3,009	60.9	3.6	3,477	70.4	10.8

¹ Jacky Jacky Exposure MU for sediments reduced from Moderate to Low exposure in the water quality management response assessment (Section 7). The mapped wetlands are in grazing land use which results in a High sediment hazard rating. The area is relatively pristine and there is no evidence of high sediment hazard to wetlands in the basin.

² Shoalwater Exposure-MU for sediments reduced from High to Moderate exposure in the water quality management response assessment (Section 7). Of the many ACA mapping units, the Shoalwater ACA is the fourth largest (150,372 ha) within the entire GBR catchment area, and it encompasses a larger area than most ACA mapping units. The unusual configuration of this large ACA mapping unit caused locations not directly hydrologically connected to the hazard exposed areas to be given an incorrect hazard exposure rating for sediments.

³ Waterpark Creek Exposure-MU scores for nutrients and sediments reduced from Low to Minimal in the water quality management response assessment (Section 7). There is a mapping error identified in the boundaries of the Waterpark Creek basin, which resulted in an error in the results, thus giving an incorrect hazard exposure rating for nutrients and sediments.

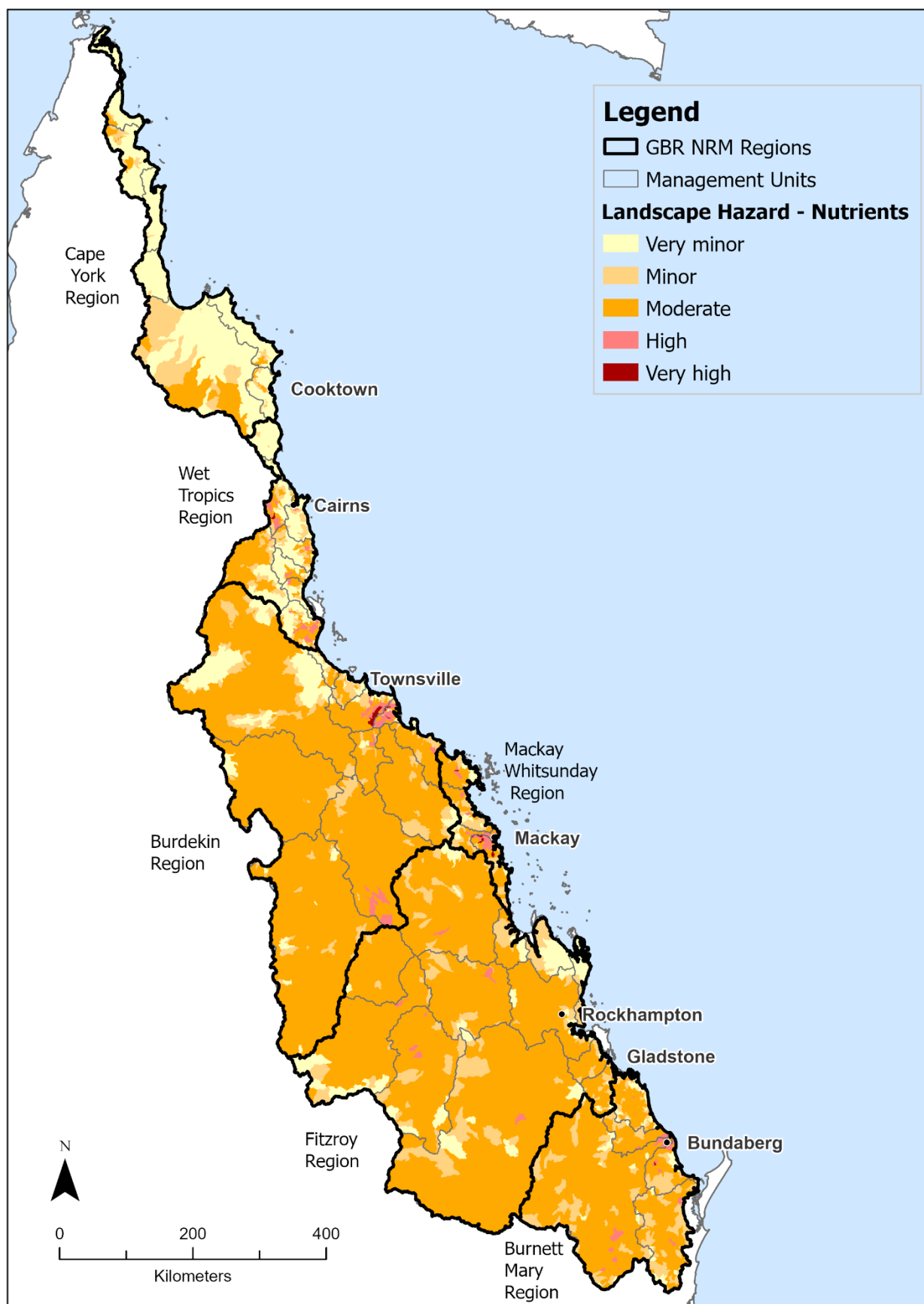


Figure 29. Hazard map for nutrient pressures across the GBR catchment area (refer to Table 11).

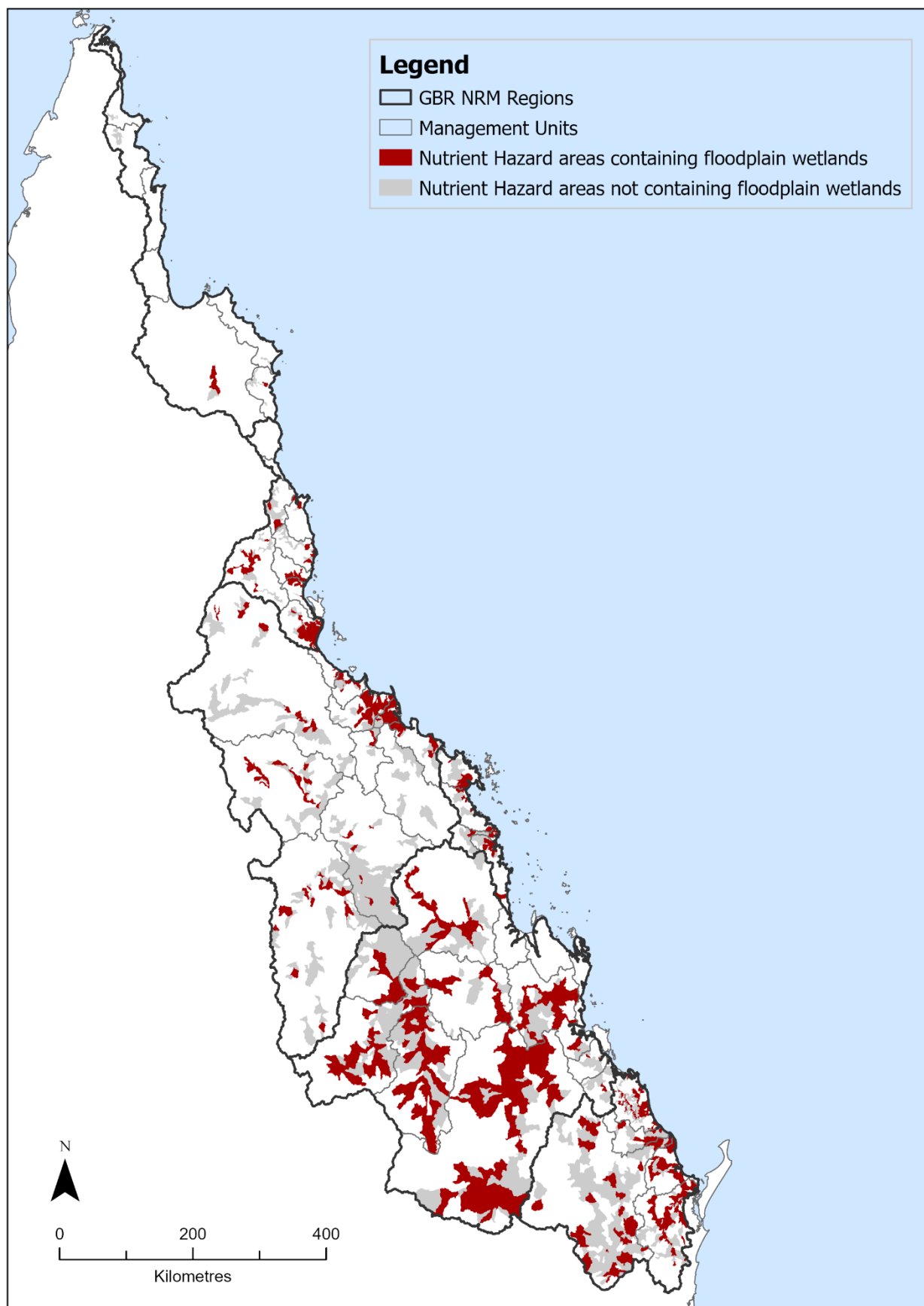


Figure 30. Nutrient hazard to freshwater floodplain wetlands in the GBR catchment area.

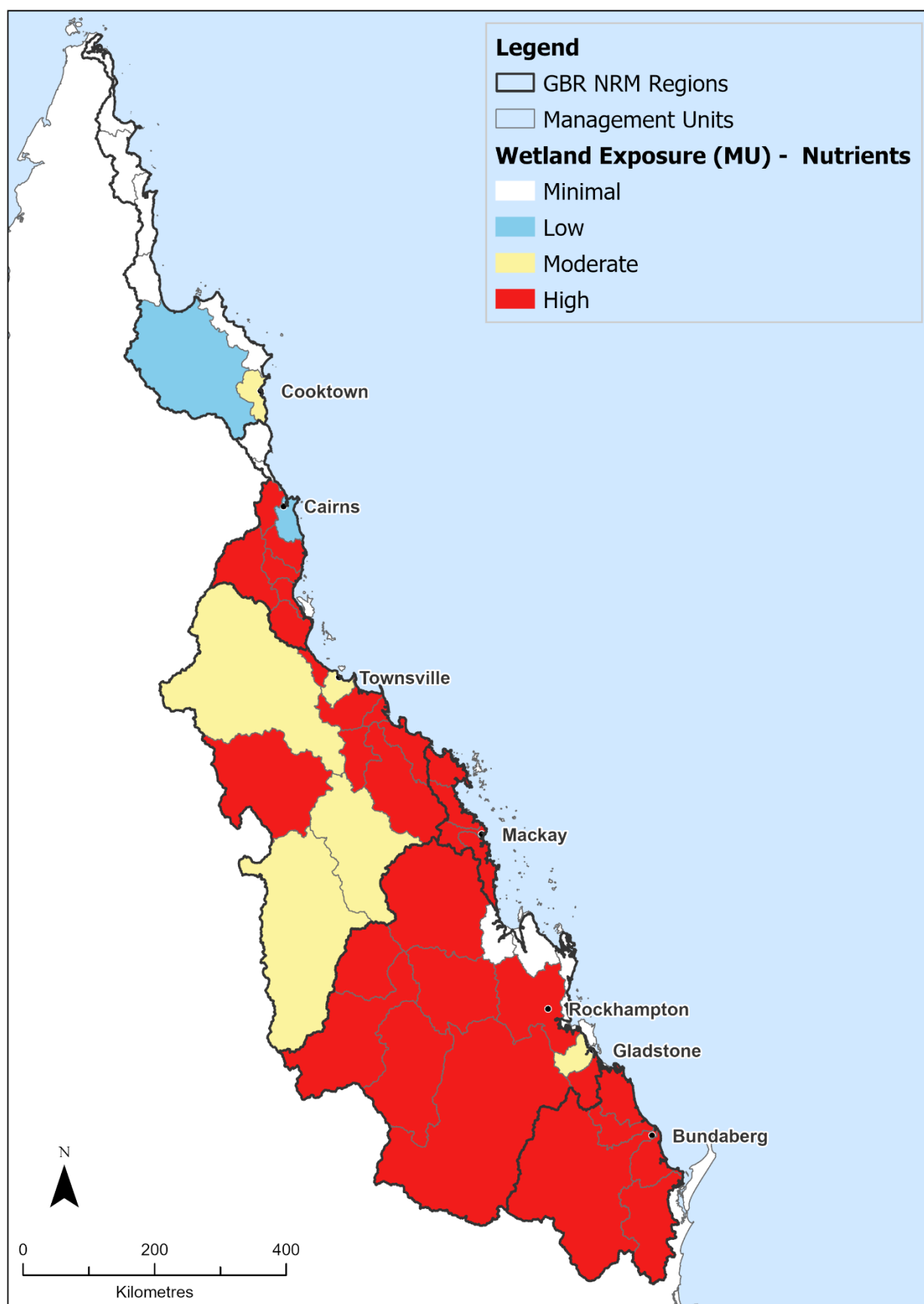


Figure 31. Exposure to nutrient hazard by management unit, where exposure is the floodplain wetland area exposed to the pollutant hazard within a management unit relative to the total floodplain wetland area in that management unit.

4.1.2 Sediments

Increased sediment inputs into wetlands can alter the wetland sediment base and cause shallowing and infilling. Over time, increased sedimentation can choke lagoons and waterways, resulting in loss of connectivity and deterioration of wetlands. A significant consequence of excess sediments is the filling of hydrologically isolated wetlands, leading to a loss of function. Increased sediment can affect plant communities by altering germination rates, reducing seedling emergence and establishment, and decreasing species richness (Wang et al. 2013; Maheny et al. 2004). These changes can impact the ecosystem's productivity, stability and sustainability (Maheny et al. 2004). In freshwater wetlands, suspended sediments can lower temperatures, reduce light, physically impact fish by clogging their gills (Ryan 1991), hinder fish foraging, decrease habitat space for some species (Ebner et al. 2016) and alter the behaviour of macroinvertebrates (Wetzel 2001; Connolly and Pearson 2007; Wallace et al. 2015) and turtles (Schaffer et al. 2015). Excess sediment can also directly increase turbidity in freshwater wetlands and indirectly introduce pollutants and nutrients attached to the sediments (Neil et al. 2002; Bainbridge et al. 2014).

4.1.2.1 Methods

The method for determining the exposure of freshwater floodplain wetlands to hazard from sediment pollutant pressures for each management unit followed that for nutrients, except that the Moderate hazard class had a wider range (> 2 to 3.5). The High (> 3.5 to 4.5) and Very High class ranges (> 4.5 to 5) were adjusted accordingly.

4.1.2.2 Sediment hazard and hazard exposure results

Very High and High hazard for sediment pressures is pervasive across most of the GBR catchment area (Figure 32; Table 11). Over 84,600 ha of floodplain wetlands within the GBR catchment area lie within or immediately downstream of Very High and High hazard areas for sediment pressures. All but five of the 48 management units (Lockhart, Stewart, Jeannie, Daintree, and Mossman) had floodplain wetlands in and/or immediately downstream of Very High or High sediment hazard (Figure 33).

Exposure (Management Unit)

Thirty-five (35) management units had more than 25% of their total wetland area exposed to High or Very High sediment hazard (Figure 34; Table 11). Thirty of these had > 50% of their wetland area exposed to High or Very High sediment hazard, with the East Burdekin, Suttor, Theresa Creek, Calliope and Boyne having 100% of their wetland area exposed. Five management units were in the moderate exposure category (> 5 to 25% wetland area exposed), two in the low exposure category (> 0.5 to 5% wetland area exposed) and the remainder (6) in the minimal exposure category (< 0.5% wetland area exposed) (Figure 34; Table 11). There were three basins where the results were adjusted in the water quality management response assessment to account for known uncertainties in the assessment:

- **Jacky Jacky:** Reduced from Moderate to Low exposure. The mapped wetlands are in grazing land use which results in a High sediment hazard rating. The area is relatively pristine and there is no evidence of high sediment hazard to wetlands in the basin.
- **Shoalwater:** Reduced from High to Moderate exposure. Of the many ACA mapping units, the Shoalwater ACA is the fourth largest (150,372 ha) within the entire GBR catchment area, and it encompasses a larger area than most ACA mapping units. The unusual configuration of this large ACA mapping unit caused locations not directly hydrologically connected to the hazard exposed areas to be given an incorrect hazard exposure rating for sediments.
- **Waterpark Creek:** Reduced from Low to Minimal exposure. There is a mapping error identified in the boundaries of the Waterpark Creek basin, which resulted in an error in the results, thus giving an incorrect hazard exposure rating for nutrients and sediments.

Exposure (GBR Catchment Area)

Relative to the total floodplain wetland area in the GBR catchment exposed to sediment hazard, floodplain wetlands in the Lower Fitzroy (13%) and Dawson (10%) management units had high sediment hazard

exposure (Table 11). Eight management units had floodplain wetlands with moderate exposure (> 4.5 to 9.5% exposed), fourteen had floodplain wetlands with low sediment pollutant exposure (> 0.5 to 4.5%) (Comet, Baffle, Haughton, Cape Campaspe, Lower Herbert, Belyando, Proserpine, Upper Burdekin) and 24 had floodplain wetlands with minimal sediment exposure (<0.5 %) relative to the GBRCA wetland area exposed.

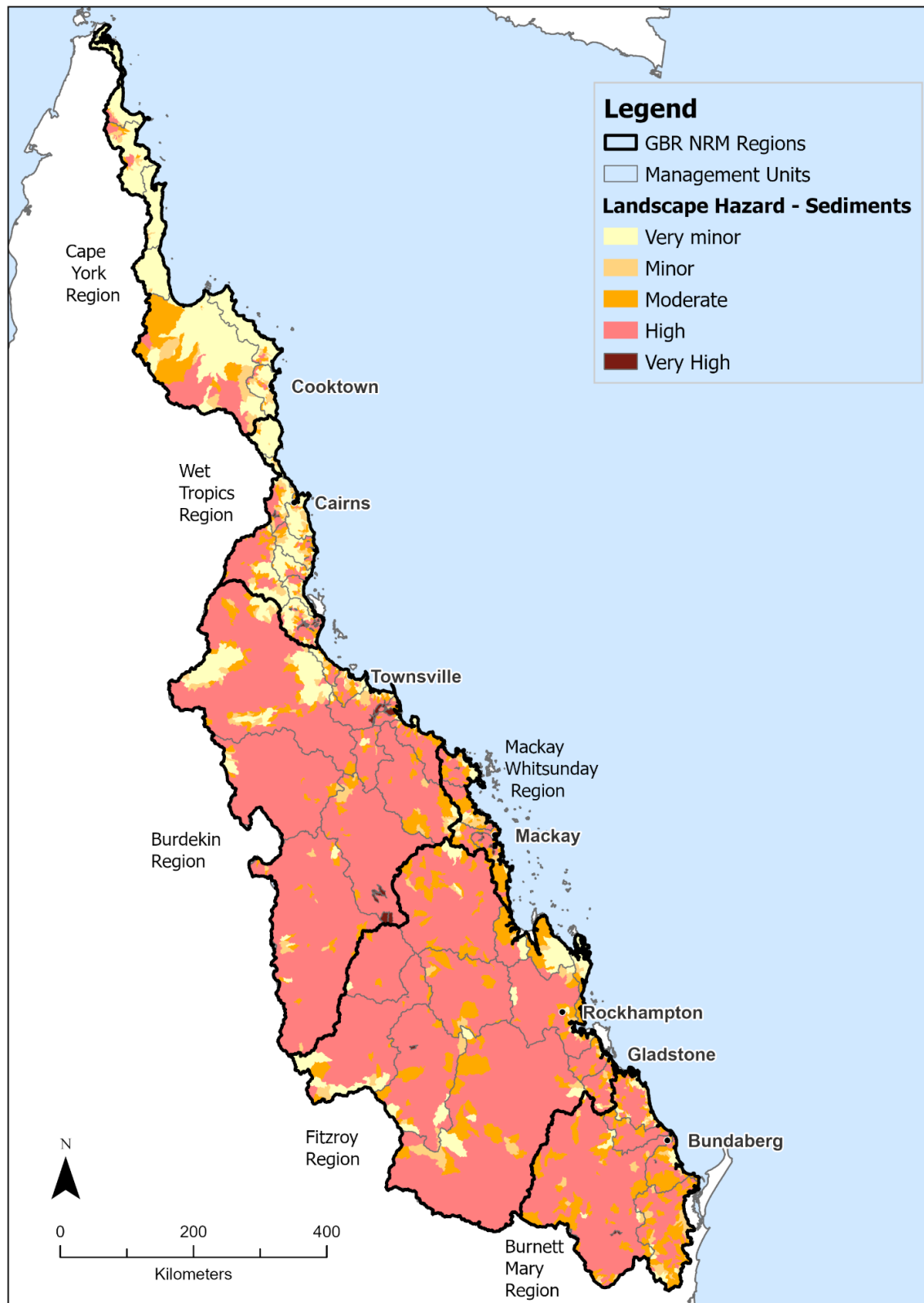


Figure 32. Hazard map for sediment pressures across the GBR catchment area.

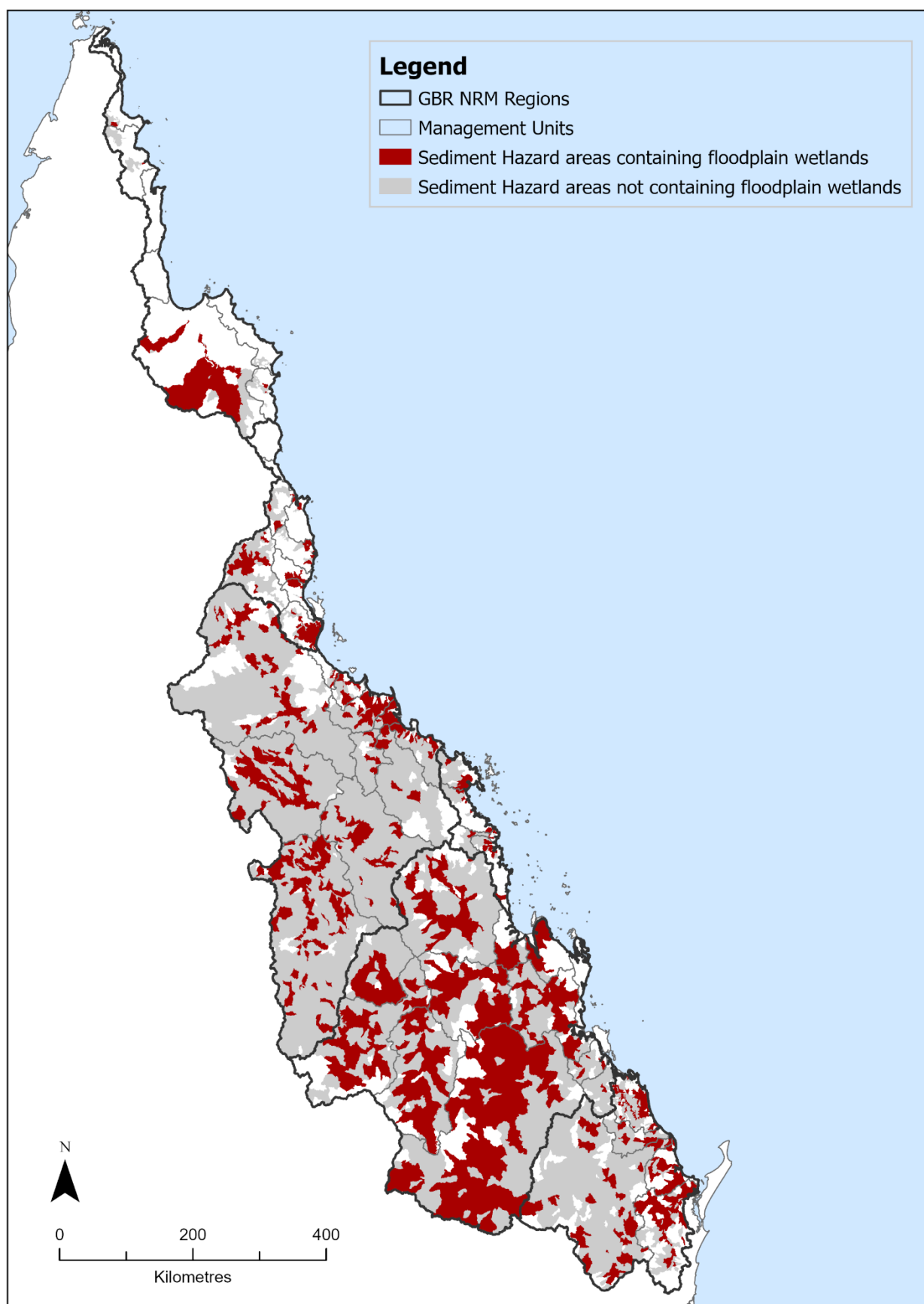


Figure 33. Sediment hazard to freshwater floodplain wetlands in the GBR catchment area.

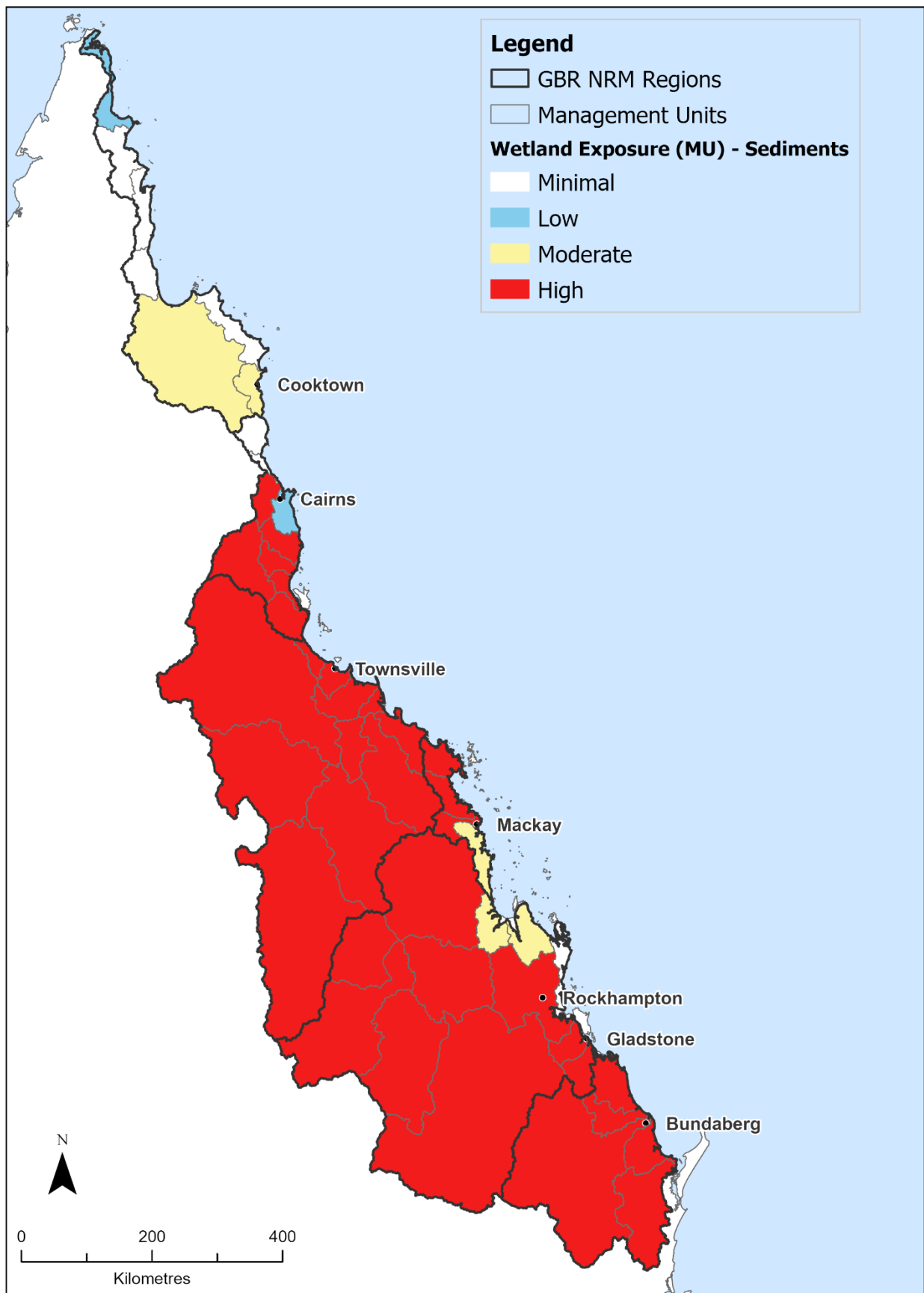


Figure 34. Exposure to sediment hazard by management unit, where exposure is the floodplain wetland area exposed to the pollutant hazard within a management unit relative to the total floodplain wetland area in that management unit.

4.1.3 Pesticides

Land use in the GBR catchment area that involves high pesticide use includes intensive cropping and animal production (Department of Science, Information Technology, Innovation and the Arts 2015). Pesticides are widespread in wetland waters throughout the GBR catchment area (Vandergragt et al. 2020), with coastal freshwater wetlands among the most affected aquatic ecosystems (Devlin et al. 2015). The most commonly reported herbicides in the GBR catchment area are PSII inhibitors, which have various impacts including reduced growth in benthic macroalgae, changes in diatom community composition, physiological disturbances in amphibians and fish, and alterations in fish population dynamics, and can cause habitat degradation (Adame et al. 2019).

4.1.3.1 Methods

The method for determining the exposure of freshwater floodplain wetlands to hazard from pesticide pollutant pressures for each management unit followed that for nutrients, with one exception. In addition to High and Very High hazard categories, the pesticide hazard and exposure assessment included the Moderate hazard category given that manufactured pesticides do not occur naturally in the environment. The more recent pesticide toxicity hazard rankings of Navarro et al. (2021) were investigated as an alternative to those outlined by the Department of Science, Information Technology, Innovation, and the Arts (2015). Rankings were highly comparable. Given the data provided in the Australia-wide assessment of Navarro et al. (2021) included a greater range of crop and production specific land uses than broadly applicable to the GBR catchment, rankings from the Department of Science, Information Technology, Innovation, and the Arts (2015) were used in the current analysis.

4.1.3.2 Pesticide hazard and hazard exposure results

Approximately 32,165 ha of floodplain wetlands within or immediately downstream of the GBR catchment area were within the Very High, High and Moderate hazard areas for pesticide pressures (Figure 35). Only eighteen of the 48 management units (Jacky Jacky, Olive-Pascoe, Lockhart, Stewart, Normanby, Jeannie, Endeavour, Daintree, Belyando, Upper Burdekin, Bowen Bogie, Cape Campaspe, Styx, Shoalwater, Waterpark Creek, Lower Fitzroy, Calliope and Boyne) had no floodplain wetlands in and/or downstream of Very High, High or Moderate pesticide hazard (Figure 36; Table 11).

Exposure (Management Unit)

Eighteen management units had more than 25% of their total wetland area exposed to Moderate, High or Very High pesticide hazard, with the Burdekin Delta having 95.5% of its wetland area exposed (Figure 37; Table 11). Nine management units were in the moderate exposure category (>5 to 25% wetland area exposed to High or Very High pesticide hazard) (Figure 37; Table 11), three were in the low exposure category (0.5 to 5% wetland area exposed) and the remainder (18) were in the minimal exposure category (< 0.5% wetland area exposed) (Figure 37; Table 11).

Exposure (GBR Catchment Area)

Relative to the total GBR catchment freshwater wetland area exposed to moderate to very high pesticide hazard, floodplain wetlands in the Tully (10%), Lower Herbert (14%), Haughton (15%) and Mary (11%) management units had high hazard exposure (>9.5%) (Table 11). Four management units were in the moderate exposure category for pesticides (Murray, Proserpine, Burdekin Delta, Mulgrave-Russell). Together this represented 50% of the floodplain wetland area in the GBR catchment lying within areas categorised as very high, high and moderate hazard (> 4.5 to 9.5%) for pesticide pressures. Twelve were in the low exposure category (0.5 to 4.5% exposed) and the remainder (28) were in the minimal exposure category (> 0.5%) relative to the GBR catchment area wetland area exposed.

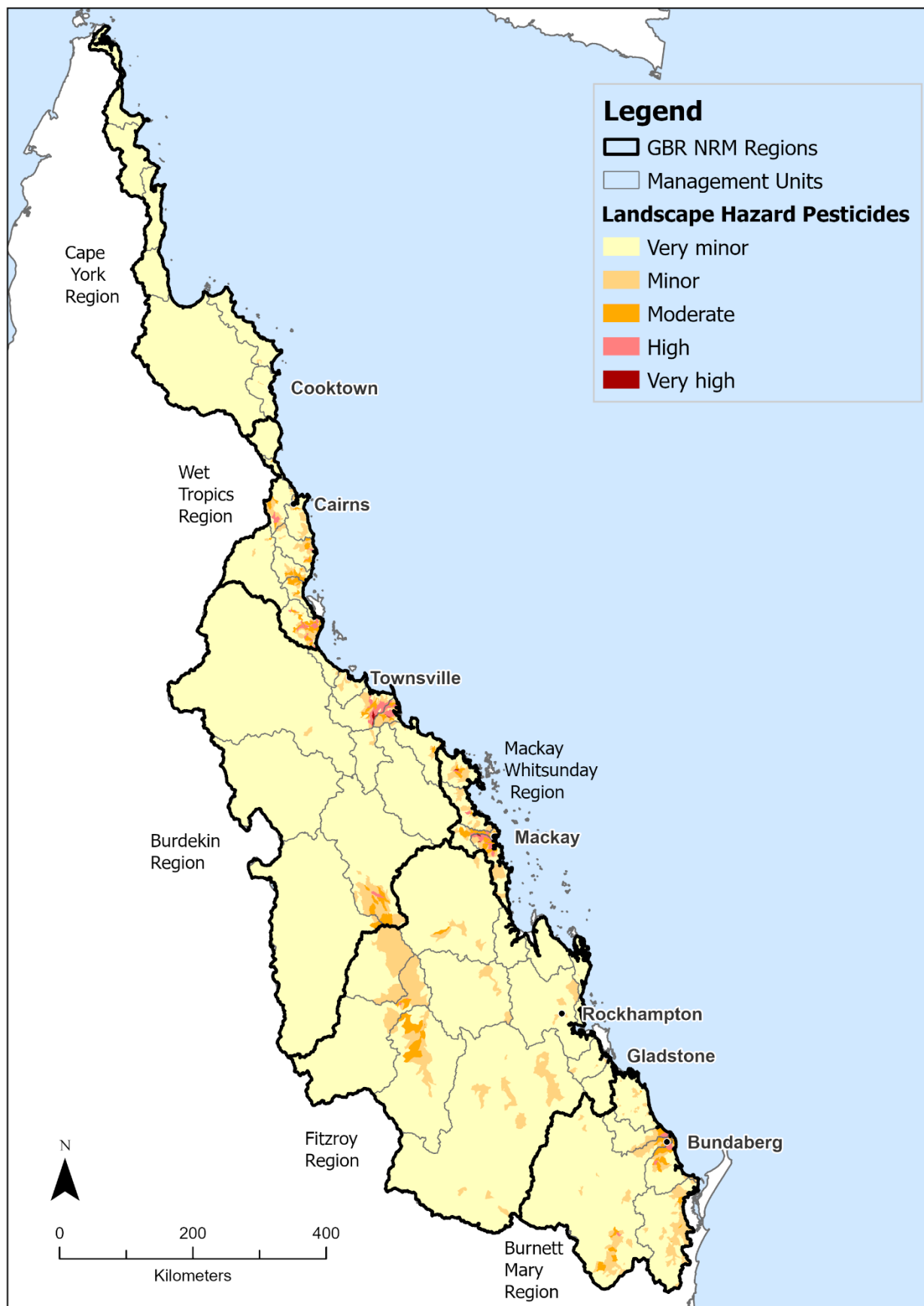


Figure 35. Hazard map for pesticide pressures across the GBR catchment area.

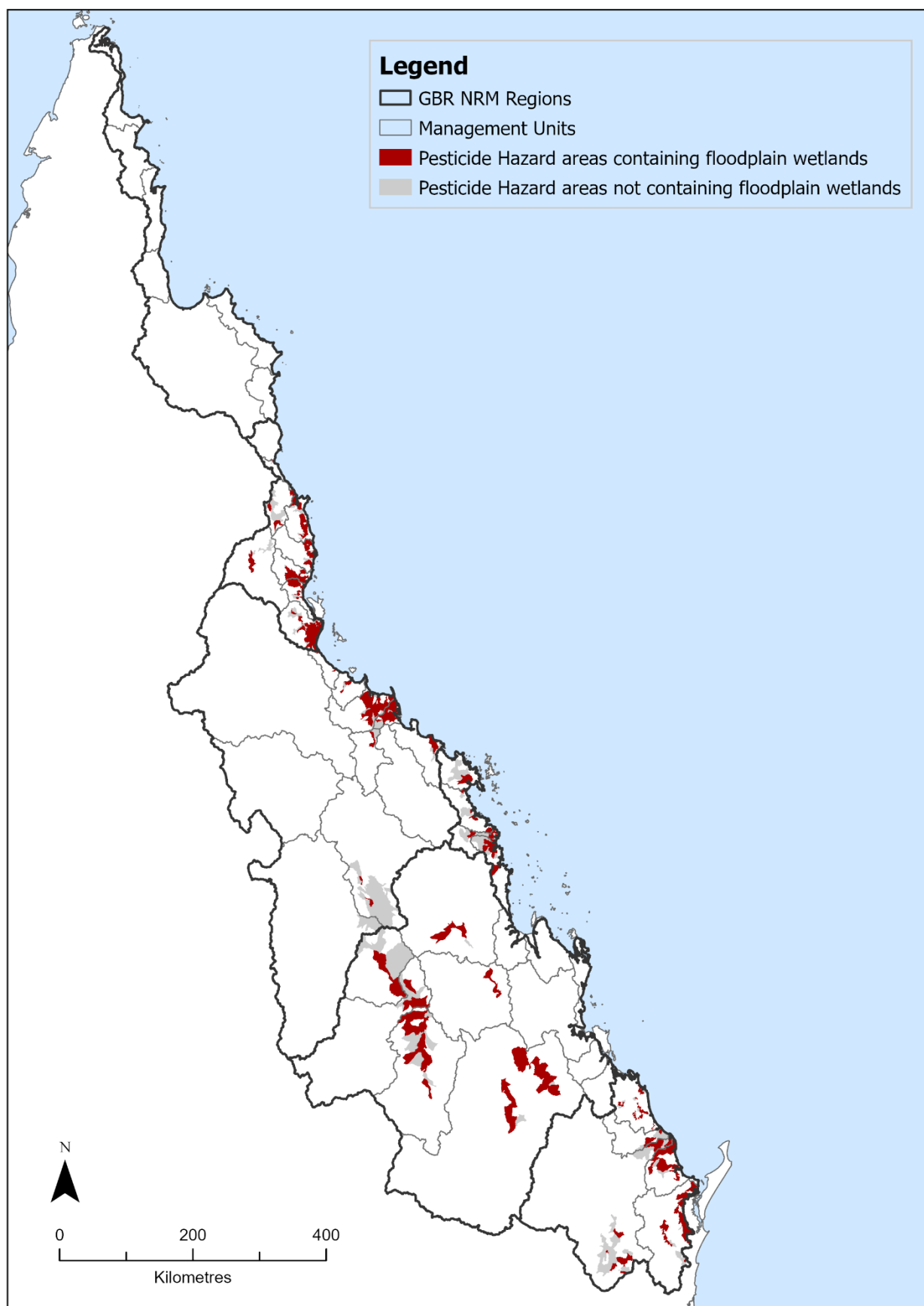


Figure 36. Pesticide hazard to freshwater floodplain wetlands in the GBR catchment area.

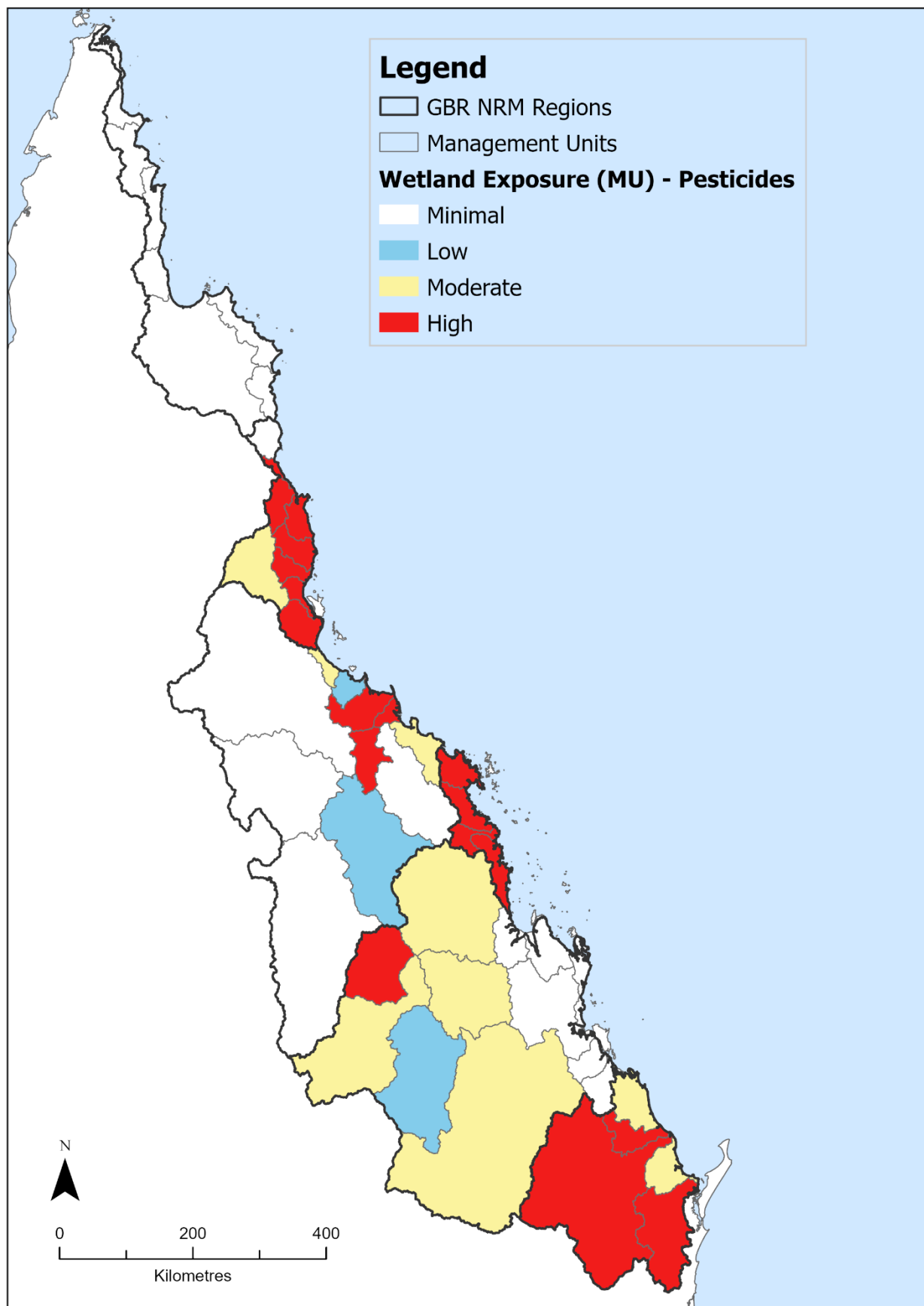


Figure 37. Exposure to pesticide hazard by management unit, where exposure is the floodplain wetland area exposed to the pollutant hazard within a management unit relative to the total floodplain wetland area in that management unit.

4.2 Marine ecosystem exposure

The exposure of marine ecosystems to degraded water quality depends on the parameter of interest, seasonal climate and weather, biogeochemical and water residence times, marine physical processes, biogeochemical transformation processes, time-dependent ecological processes and interactions with other stressors.

The frameworks from the 2017 exposure assessment (Waterhouse et al. 2017a) were reviewed to assess where the approach could be improved with the best available information. A summary of the approach for all pollutants is presented in Table 12. The methods applied were largely the same for nutrients (DIN) and sediments and are detailed in the nutrient methods Section 4.2.1.1 and Appendix 6. Any specific adjustments for sediments are described in Section 4.2.2.1.

Table 12. Summary of data used in the marine water quality exposure assessment.

	Nutrients	
	Indicator	Weight
DIN exposure	Annual average Chlorophyll- <i>a</i> (Chl- <i>a</i>) (eReefs marine model 2011–2022) difference between baseline and pre-development scenario	0.5
	Marine Monitoring Program (MMP) DIN loading, difference between baseline and pre-development scenario for wet season.	0.5
DIN Exposure Index	Area of coral reefs (weighted by exposure categories) within the river footprint for each basin	
	Sediments	
	Indicator	Weight
TSS exposure	Annual average Secchi depth (eReefs marine model 2011–2022) difference between baseline and pre-development scenario	0.5
	MMP TSS loading, difference between baseline and pre-development scenario for wet season.	0.5
TSS Exposure Index	Area of coral reefs and surveyed seagrass (weighted by exposure categories) within the river footprint for each basin	

4.2.1 Nutrients

The nature and timing of nutrient exposure in the GBR

Almost all discharge of nutrients from rivers to the GBR occurs in the wet season (typically December to April inclusive but variable between years) (Devlin and Brodie 2005; Furnas 2003; Furnas et al. 2011). Oceanic nutrient upwelling is also an important source of nutrients in the wet season in offshore areas and a potentially dominant source of new nutrients to some areas (Furnas et al. 2011; Robson et al. 2024), for example, the far northern and southern offshore GBR where few river-derived nutrients are found. As the assessment in this project is largely concerned with anthropogenic river-derived nutrients, these influences are not considered further here. The current understanding of the timing of the negative impacts of land-based nutrient inputs is that they occur almost completely during the wet season due to high levels of exposure in these months. However, there are some uncertainties about the resuspension and release of particle bound nutrients during wind and tide events which can occur year-round (Robson et al. 2024). Groundwater influences could be important but are poorly understood (Burford et al. 2024). While most nutrients are delivered to the GBR in wet season conditions, ongoing processing and availability of nutrients are also important; therefore, wet season and annual conditions are relevant in assessing the exposure of GBR ecosystems to nutrients.

It is important to acknowledge that the results have not considered the impacts of climate change on future river flows, loads or oceanographic processes which may have implications for the exposure and/or risk assessments for DIN, sediments and pesticides.

The importance of nutrient forms

Nutrients (both nitrogen and phosphorus) are discharged from rivers as a mixture of particulate and dissolved organic and inorganic forms. Dissolved inorganic and particulate forms of nutrients discharged into the GBR are both important in driving ecological effects. As shown in Section 3, most of the terrestrial nitrogen and phosphorus discharged into the GBR is in particulate form (McCloskey et al. 2021b), but this varies greatly between basins. However, dissolved inorganic forms of nitrogen and phosphorus are of greatest concern compared to dissolved organic and particulate forms of nutrients, as they are immediately and completely bioavailable for algal growth, and are transported widely across and along the shelf (Furnas et al. 2005; Garzon-Garcia et al. 2021). Measuring nutrient exposure in the GBR marine waters is therefore complicated by the large degree of processing and transformation that occurs between the river mouth and the mid-shelf and outer GBR. Increased nutrient uptake is reflected in increased Chl-*a* concentration as an indicator of phytoplankton biomass (Robson et al. 2024). It is well established that elevated Chl-*a* levels at inshore coral reefs of the GBR are linked with increased macroalgae cover, reduced hard coral richness, reduced octocoral richness and lower coral recruitment (GBRMPA 2010; Diaz-Pulido et al. 2024; Robson et al. 2024; Thompson et al. 2024; see also Section 5.1).

It is currently thought that increased nitrogen inputs are more important than phosphorus inputs, although this is still uncertain and is a point of ongoing global debate. Freshwater systems are most commonly regarded as phosphorus limited (e.g. Schindler 1977). Available nutrient data from the GBR system (reef waters, rainfall, Coral Sea, rivers) clearly show that phytoplankton biomass is constrained by the availability of readily bioavailable inorganic forms of nitrogen (Furnas et al. 2005; Furnas et al. 2011; Furnas et al. 2013). Further justification of this conclusion was provided in the 2013 SCS (drawn from Furnas et al. 2013) and there is limited new information for this report, therefore the evidence is not repeated here.

Based on the evidence above, wet season and annual conditions are therefore both relevant in assessing the exposure of GBR ecosystems to nutrients. The likelihood of exposure of marine ecosystems to nutrients focuses on annual Chl-*a* concentrations and the wet season dispersion of end-of-catchment DIN loads into the GBR (referred to as “DIN loading”). The confidence and availability of data for DIN is greater than for other nutrient forms, including phosphorus and particulate nutrients, due to the complexities in transformation and processing outlined above (this is summarised in Robson et al. 2024). Wet season and annual conditions are both relevant in assessing the exposure of GBR ecosystems to nutrients.

4.2.1.1 Method

The approach for developing the DIN Exposure Index within each River Footprint involved five major steps which were also largely followed for TSS.

1. Development of the DIN exposure spatial layer
2. Development of the River Footprints for each basin
3. Preparation of ecosystem assessment layers
4. Combining the DIN Exposure layer with the River Footprints to derive DIN Exposure for each basin
5. Calculation of the DIN Exposure Index

1) Development of the DIN exposure spatial layer

The DIN likelihood-of-exposure layer (likelihood) was assessed using two spatial layers and accounts for annual and wet season influences. The spatial layer was derived by summing the anthropogenic component of Chl-*a* from the eReefs GBR4 model and the anthropogenic component of DIN loading from the eReefs GBR1 model, as described below. A weighted normalisation, based on percentile categories, was applied to each input layer according to the reclassification table below. These layers were then summed and normalised to a scale from 0 to 1:

$$\text{DIN likelihood}_{\text{sum}} = \text{Chl-}a_{\text{anthro}} + \text{DIN loading}_{\text{anthro}}$$

$$\text{DIN likelihood}_{\text{norm}} = \frac{\text{DIN likelihood}_{\text{sum}} - \text{Min}(\text{DIN likelihood}_{\text{sum}})}{\text{Max}(\text{DIN likelihood}_{\text{sum}}) - \text{Min}(\text{DIN likelihood}_{\text{sum}})}$$

Annual influence:

- i. **Anthropogenic Chl – a(Chl_a_{anthro}):** Represents the difference between current (2011–2022) and pre-development annual average concentrations of nutrients (measured as Chl-*a*) in the water column as a measure of anthropogenic annual average Chl-*a* conditions. The Chl-*a* was extracted from the GBR4 Hindcast BGC baseline and pre-development runs, for the surface layer (*z*=42). The results were yearly averaged starting on 1 October to 30 September for years 2011 to 2022 (12 months) and from the 1 January to 30 September for 2011 (9 months) and were computed for each dataset, as well as the difference between the baseline and the pre-development runs and saved in a shapefile format for further analysis. The anthropogenic component of Chl-*a* (difference from pre-development) was converted to the standard 0.01 decimal degree (dd) grid as described below. A 2011–2022 annual average of anthropogenic Chl-*a* was used as input into the DIN exposure layer. A weighted normalisation based on percentile categories was applied to the Chl-*a* data, where each value was assigned a relative score between 0.05 and 1 ('value=0' pixels were not present for Chl-*a*) according to the reclassification in Table 13.

Wet season influence:

- ii. **Anthropogenic DIN loading (DIN loading_{anthro}):**

Represents the dispersion of end-of-catchment DIN loads during the wet season, calculated as an anthropogenic influence by comparing the difference between long-term current (2014–15 to 2022–23 wet seasons) average DIN loading with a pre-development DIN load scenario. It highlights the areas of greatest change with current land-use characteristics.

River plumes were modelled using a conservative tracer in the 1 km-resolution eReefs marine model (GBR1_H2p0_River) according to the method described in Gruber et al. (2024). The model represents the influence of 17 rivers—Normanby, Daintree, Barron, Mulgrave-Russell, Johnstone, Tully, Herbert, Haughton, Burdekin, Don, O'Connell, Pioneer, Fitzroy, Calliope, Boyne, Burnett, and Mary. In this model each river's unique tracer had a discharge concentration of 1.0 at its mouth, and the initial tracer concentration in the GBR (time = 0 for each wet season) was set to 0.

A cumulative exposure index was defined to measure the concentration and duration of exposure to tracers from individual river sources in the GBR. This index is expressed in units of Concentration × Days (Conc.Days) and calculated for cases where river water concentration exceeds a threshold of 1% in the surface layer. The index is cumulative, summing exposure events over a wet season. It provides a consistent framework for assessing relative differences in reef shelf water exposure to riverine inputs.

The mathematical formulation that expresses this concept is given below:

$$\text{Conc.Days} = \sum_{t=0}^T \text{Conc}_{\text{exceedance}}$$

where,

$$\text{Conc}_{\text{exceedance}} = \begin{cases} \text{Conc}(t) - \text{Conc}_{\text{threshold}}, & \text{where } \text{Conc}(t) > \text{Conc}_{\text{threshold}} \\ 0, & \text{where } \text{Conc}(t) \leq \text{Conc}_{\text{threshold}} \end{cases}$$

$Conc_{threshold}$ is defined here as 1% of the river concentration, $Conc(t)$ represents the time-varying tracer concentration, and t is time in days from the beginning of the wet season ($t_0 = 1$ October) and $T_{end\ of\ wet\ season} = 30$ April.

The cumulative exposure is calculated for each 1 km² grid cell in the model domain.

The end-of-catchment load for DIN was dispersed for each river assuming a direct relationship between pollutant and tracer concentration (conservative mixing). Thus, the surface load of DIN per km² was calculated as:

$$Surf.\ load = \frac{tracer}{pixel} \times \frac{[total\ load]}{[sum\ of\ tracer]} \times \frac{pixel}{km^2}$$

The total GBR surface load was calculated by summing the surface load outputs for the 17 rivers for which tracer data were available. The difference between the estimated wet season DIN loadings (tonnes km²) in the GBR for the current water year was calculated and compared to the pre-development loads derived from the Source Catchments model.

The anthropogenic component of DIN loading was converted to the standard 0.01 decimal degree (dd) grid as described below. A multiannual average for the 2014–15 to 2022–23 wet season was used as input into the DIN exposure layer. A weighted normalisation based on percentile categories was applied to the DIN loading data, where each value was assigned a relative score between 0 and 1 according to the reclassification in Table 13.

General data conversion and weighted normalisation

All spatial calculations were performed in R using the terra, sf and dplyr packages. Calculations were performed in GCS WGS84 (CRS: EPSG:4326) on a regular 0.01 decimal degree (dd) grid, with each grid cell aligned to the nearest 0.01 degree.

Vector data from the GBR1 and GBR4 models was converted to gridded data using the following method, which ensures that any data within a given 0.01 dd pixel is included. Data was smoothed to reduce local variations by applying a 21x21 pixel focal mean filter.

1. In R (sf and terra), annual shapefiles were rasterised to 0.002 dd resolution in GCS WGS84 (CRS: EPSG:4326).
2. Multiannual average was calculated and focal mean smoothing (21x21px window) applied
3. Rasters were resampled to 0.01 dd resolution by aggregating 5x5 blocks of 0.002 dd pixels, such that any data pixels were averaged to produce an output pixel (the new pixel value was the mean of all valid (non-NA) pixels in the block).
4. Rasters were masked to the GBR, extended to include the broader Burnett Mary NRM region.

Input data layers were converted to the standard 0.01 dd grid as described above. A weighted normalisation based on percentile categories was applied to the data, where each value was assigned a relative score between 0 and 1:

1. The input raster was converted into individual percentile categories (1st to 100th) across the entire GBR, with 'value=0' pixels ignored for percentile calculation.
2. Data were reclassified from percentile categories to a weighted input raster using the reclassification table in Table 13.

Table 13. Reclassification of the percentile categories for each of the spatial layers for the exposure assessment.

Percentile lower bound	Percentile upper bound	Weighted value
99	100	1.0
96	98	0.8
91	95	0.6
81	90	0.4

Percentile lower bound	Percentile upper bound	Weighted value
66	80	0.2
51	65	0.1
1	50	0.05
NA	NA	0

The areas of coral reefs, surveyed seagrass, modelled deepwater seagrass and total areas in each of the final likelihood categories in each River Footprint was calculated by overlaying the final Anthropogenic DIN Exposure map with the spatial layers for each habitat type (see Appendix 1 for data sources).

2) Development of the River Footprints for each basin

The yearly river plume cumulative extent and concentration, 1 October to 30 September, was computed for each river, from the eReefs GBR4 river tracers output then grouped in the 35 basins. The methodology to compute the yearly cumulative concentration of river water was the same as for the loading maps described in Step 1 above. The threshold concentration of 1% was used to compute the cumulative exposure index.

A second indicator was calculated to represent the accumulated number of days a grid cell would see river water over a year, which gives the river extent in term of number of days of exposure to river tracer $\geq 1\%$. The mathematical formulation that expresses this concept is given below:

$$\text{Exposure.Days} = \sum_{t=0}^T \text{Exposure}_{\text{exceedance}}$$

where

$$\text{Exposure} = \begin{cases} 1, & \text{where } \text{Conc}(t) > \text{Conc}_{\text{threshold}} \\ 0, & \text{where } \text{Conc}(t) \leq \text{Conc}_{\text{threshold}} \end{cases}$$

Combining the river cumulative exposure to river water and concentration allows the model to calculate a mean value per grid cell of exposure to concentration/day.

River plumes (“footprints”) were converted from shapefile to the standard 0.01 dd grid using the method described above, with the eReefs GBR4 data smoothed to reduce “blockiness” by applying a 21x21 pixel focal mean filter during processing. River footprints were categorised from the 2011–2022 modelled average using percentile bands 1) separately for each river (‘within-river’) method and 2) for all rivers combined (‘all-rivers’ method) according to the following table (table shows the range of exposure in days for each percentile band for the all-rivers method; these values differ for each river in the within-rivers method. The “all-rivers” method was used for this assessment, and further work will be undertaken to apply the “within rivers” method for each basin to support regional prioritisation (outside of the scope of this assessment).

Table 14. Exposure in days for each percentile band for the all-rivers method.

Percentile range	Range of exposure (days)	Weighted value
99–100	145–350	1.0
96–98	86–145	0.8
91–95	55–86	0.6
81–90	22–55	0.4
66–80	7–22	0.2
51–65	2–7	0.1
1–50	0.1–2	0.05
NA	NA	0

3) Preparation of ecosystem assessment layers

The marine ecosystems considered in the marine ecosystems assessment are coral reefs and seagrass meadows. As noted above, there is insufficient data to inform the assessment of pollutant exposure to other ecosystems and species such as mangroves, soft bottom communities, most plankton communities and fish.

However, these systems are still recognised as important to the health of the GBR and are recognised in the discussion of ecosystem condition where possible.

Coral reefs

For coral reefs, the spatial layer used was the GBRMPA Spatial Data Centre's coral reefs spatial data file (accessed 2024). For the southern GBR (from Rockhampton), an additional spatial layer mapping inshore coral and seagrass ecosystems developed by DETSI (Zann 2024) was also included.

Note that improved inshore reef mapping is currently being updated in a project commissioned by GBRMPA with the University of Queensland, however, the outputs were not available in time for this project.

Seagrass

The seagrass spatial layer used was a combination of the following datasets:

1. Collation of seagrass assessments undertaken in the Great Barrier Reef World Heritage Area (GBRWhA) from 1984 to 2014 (Carter et al. 2016; McKenzie et al. 2022).
2. Seagrass mapping of 100 km of coastal seagrass meadows from Walsh Bay to Cape Flattery and four reef-top meadows, plus additional surveys near the Starcke River mouth (Cape York) (prepared by C. Howley, see Waterhouse et al. 2016).
3. Hervey Bay and Great Sandy Straits seagrass mapping, which recognises the area of influence of the rivers in the Burnett Mary NRM region, particularly the Mary River (Rasheed et al. 2023). Hervey Bay Seagrass dataset GSMP_Meadows_2023_utm55s.shp and GBR1_GSMP_Meadows_2023.shp
4. Deepwater seagrass modelled: Represented using a statistical model of seagrass present in GBRWhA waters >15 m depth. In this model, spatial distribution is a statistically modelled probability of seagrass presence (using generalised additive models based on binomial error and smoothed terms in relative distance across and along the GBR), based on field validation points (Coles et al. 2009). Locations with seagrass bed probability >0.5 (50%) were included in the assessment.

All datasets are identified as *potential* seagrass meadows.

Each of the ecosystem shapefiles (coral reefs, potential seagrass meadows) were dissolved and reprojected to the WGS84 (EPSG:4326) and Australia Albers Equal Area (EPSG:3577) coordinate reference systems (CRS), and converted to 0.01 dd raster masks using the following methods:

- i. In R (sf and dplyr), ecosystem shapefiles were reprojected to the WGS84 coordinate system and geometries dissolved into a single multipart polygon. These polygons were later used to calculate area of exposure to river footprints, nutrients and sediments using a cookie-cutter method, with area calculated in Australia Albers Equal Area CRS.
 - ii. In R (sf and terra), shapefiles were rasterised to 0.002 dd resolution and snapped to the standard project grid described above '*General data conversion and weighted normalisation*'.
 - iii. Ecosystem raster layers were resampled to a resolution of 0.01 dd by aggregating 5×5 blocks of 0.002 dd pixels. Aggregation was performed using 'max' method to ensure any ecosystem presence was retained on resampling.
- 4) [Combining the DIN Exposure layer with the River Footprints to derive DIN Exposure to ecosystems for each basin](#)

To provide a method for linking the Anthropogenic DIN exposure back to individual basins, the categorised DIN exposure layer was overlaid with the categorised River Footprint layers, and the total area, coral reefs, potential seagrass meadows within each of the combined categories below was calculated. This approach advances from the 2017 method which defined Marine Zones for each NRM region and then attributed exposure to individual basins based on the proportional contribution of the anthropogenic DIN load to the total load contributed from the rivers that discharge into the Marine Zone. While the current method narrows down the area of influence for each basin, it is likely to lead to overestimates for rivers where there

is overlap from adjacent rivers, particularly from rivers south of the footprint due to the prevailing wind and current conditions which tend to move river plumes northwards.

Area of river footprint zones of exposure

Using R (terra), the reclassified river footprint rasters were transformed into vector polygon layers, dissolving contiguous regions of the same value, and saved as shapefiles. These were reprojected to Australia's Albers Equal Area projection (EPSG:3577) to ensure accurate area calculations. The area of each polygon was calculated in square kilometres and exported to csv. Two sets of calculations were performed to include the full extent of ecosystems in the assessment area (i.e. including the area south of the GBRWHA and extending into Hervey Bay) and an assessment of ecosystems only within the GBRWHA.

Area of coral reefs and potential seagrass meadows exposed to river plumes

Using R (terra), the river footprint shapefiles (generated as described above) were clipped using each of the three ecosystem shapefiles (generated as described above in 'General data conversion and weighted normalisation'), reprojected to the Australia's Albers Equal Area CRS, area recalculated, and attribute tables exported to csv. As above, values were compiled for the extended Burnett Mary NRM region (including Hervey Bay) and for the GBRWHA only.

Combined exposure to river plumes and DIN exposure layers

To calculate the combined exposure of ecosystems to both River Footprint and DIN exposure categories, the final re-categorised exposure rasters were added to the River Footprint using the following formula, generating a matrix of integer values corresponding to each combination of exposure and River Footprint zones as shown in Table 15.

$$\text{Cell Value} = (\text{River Footprint} \times 100,000) + (\text{Likelihood} \times 100)$$

Table 15. Values used to combine the DIN exposure and River Footprint spatial layers.

Exposure matrix		Likelihood of exposure						
		1	0.8	0.6	0.4	0.2	0.1	0.05
River footprint	1	100100	100080	100060	100040	100020	100010	100005
	0.8	80100	80080	80060	80040	80020	80010	80005
	0.6	60100	60080	60060	60040	60020	60010	60005
	0.4	40100	40080	40060	40040	40020	40010	40005
	0.2	20100	20080	20060	20040	20020	20010	20005
	0.1	10100	10080	10060	10040	10020	10010	10005
	0.05	5100	5080	5060	5040	5020	5010	5005

This process was repeated for the within-river and all-rivers footprints. The combined exposure matrix was converted to a polygon, clipped using each of the three ecosystem shapefiles, and area of exposure calculated as described above. The matrices were compiled using data.table in R and exported to csv.

5) Calculation of the DIN Exposure Index

The combined data layer was then used to calculate an index for DIN exposure, using a weighting to reflect the likely influence of the combined categories on marine water quality conditions. As described above, the DIN exposure layer was categorised into percentiles and classified into relative groupings between 1 and 0.05. For the River Footprints, the categories represent the average frequency of the presence of river water in a grid cell over the full 12-year period. The categories range from more than 5 months of the year, which is considered to be high, to less than 1 week, which is considered to be very low, and is likely to represent the extent of the very extreme discharge events in the GBR across the modelled period. The ecological relevance of these rare events is not fully understood but is assumed to be low for this assessment.

The weightings for the matrix were tested using a range of combinations. The highest categories represent high frequency of the occurrence of the influence of river footprints and the highest percentile of anthropogenic DIN exposure. Based on the logic to the categories described above, it was assumed that less than 0.1 DIN exposure was considered to very low, and the spatial extent of these areas align with the extent of GBR waters that are characterised to have either slightly elevated nutrient concentrations or ambient marine conditions during the wet season (refer to Gruber et al. 2024). Similar conditions are observed for the 0.2 DIN exposure category, with occasional influence of elevated nutrient concentrations. For the River Footprints, any occurrence of less than 3 weeks was assumed to have limited ecological relevance. The final weightings applied in the assessment are shown in Figure 38.

These weightings were applied to the categories in the combined layer and the weighted areas were summed to generate a weighted sum for each basin. These results highlighted some inconsistencies in data, most likely driven by the input catchment loads for the version of the eReefs model used in the assessment, explained further below.

		DIN exposure categories							
Average frequency per year		1	0.8	0.6	0.4	0.2	0.1	0.05	
River footprint	>5 months	1.0	0.9	0.8	0.5	0.1	0.0	0.0	
	3 to 5 months	0.9	0.8	0.5	0.5	0.0	0.0	0.0	
	2 to 3 months	0.8	0.5	0.5	0.1	0.0	0.0	0.0	
	1 to 2 months	0.5	0.5	0.1	0.0	0.0	0.0	0.0	
	3 to 4 weeks	0.1	0.0	0.0	0.0	0.0	0.0	0.0	
	1 to 3 weeks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	<1 week	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Final weighting		VH	H	HM	M	ML	L	VL	V–VL
		1.0	0.9	0.8	0.5	0.1	0.0	0.0	0.0

Figure 38. Matrix used for weighting the combined DIN exposure layer with the categorised River Footprints.

Accounting for adjustments to the DIN loads and river overlap

Many of the GBR basins generate relatively low annual average anthropogenic DIN loads, and the footprints of adjacent rivers overlap, leading to results that indicate a higher level of exposure from that river footprint than what is most likely the case. These factors were accounted for in the review of the GBR water quality targets (Waterhouse et al. 2025) by examining the anthropogenic load for each basin and the increase factor between the predicted pre-development and baseline loads to determine whether a load reduction target was required. For basins where there was a low (< 1.5) increase factor from pre-development to baseline loads, and/or the anthropogenic load was low (i.e. $< 50 \text{ t yr}^{-1}$ for DIN and $< 50 \text{ kt yr}^{-1}$ for fine sediment), it was recommended that a “prevent increased load” target be applied. This decision rule is also applied in this assessment for consistency and is further backed up by considering the total area of fertiliser-adding land uses (State of Queensland 2021)¹³ which contribute to the DIN load, illustrated by the loads by land use data presented in Section 3.2. Elevated loads of DIN are typically measured in basins that have a larger area of fertiliser-adding land use, with a large proportion from sugarcane and to a lesser extent from cropping such as bananas, horticulture, and other irrigated cropping and therefore potential scope for water quality improvement through nutrient management actions. Urban areas can also be important contributors at local

¹³ The 2021 land use mapping for GBR NRM regions is published and available for download via QSpatial: Metadata (read more at: <https://qldspatial.information.qld.gov.au/catalogue/custom/viewMetadataDetails.page?uuid=%7B35C9BBE8-5EB7-451B-B191-0650098DAC37%7D>)

scales (Prosser and Wilkinson 2024), especially where there are smaller areas of agricultural land uses (e.g. Ross and Barron basins).

As an additional consideration, the input layer for the Chl-*a* concentration data used in this project was derived from the version of eReefs marine model run in December 2023 (also used in the review of the GBR water quality targets). This model run used an earlier version of GBR Dynamic SedNet, modelled catchment loads that were generated in October 2023. An updated catchment load model run was generated for this assessment in October 2024 (presented in Section 3) which resulted in adjusted modelled loads for some basins, primarily due to differences in the way that DIN was treated in pre-development conditions. In the pre-development models, land uses including grazing lands are reverted to 'conservation' areas and therefore assigned low DIN concentrations. As there is little or no evidence that grazing produces an anthropogenic DIN load, the DIN concentration from grazing lands should not change between the pre-development and baseline scenario. In the earlier modelling, the DIN loads in grazing lands were incorrectly applied, particularly for the basins in the Fitzroy and Burnett Mary regions, thus generating a large anthropogenic load. In the updated model (used in Section 3), this was adjusted in the larger grazing/drier catchments (Cape York, Burdekin, Fitzroy and Burnett Mary). As a result, the anthropogenic load has decreased in the adjusted model and is a better reflection of the current load contributions. The differences have been assessed and show that the greatest reductions in the anthropogenic load estimates are in the Fitzroy and Mary basins. These adjustments mean that the modelled outputs for Chl-*a* in this assessment are likely to produce an overestimate of DIN exposure for the basins in the Fitzroy and Burnett Mary regions. The exclusion of the basins with anthropogenic DIN loads less than 50 t yr⁻¹ resolves this issue for most basins.

Finally, overlap between river footprints (calculated using freshwater exposure only) can account for overestimates of exposure linked to particular basins in some locations. Figure 39 shows an assessment of the spatial overlap for each of the river footprints, calculated as the median from the annual normalised concentration outputs from the eReefs marine model. For assessing the contribution from other rivers within a basin footprint, the results should be read across rows (sums to 100%), e.g. within the median Daintree basin river footprint, 8.1% is from the Mossman, 84.7% is from the Daintree and 3.0% is from the Endeavour basin. If seeking to assess the degree of influence of a particular river footprint on others, the results should be read in columns, e.g. the Daintree overlaps 6.7% with the Endeavour footprint and 13.7% with the Mossman footprint.

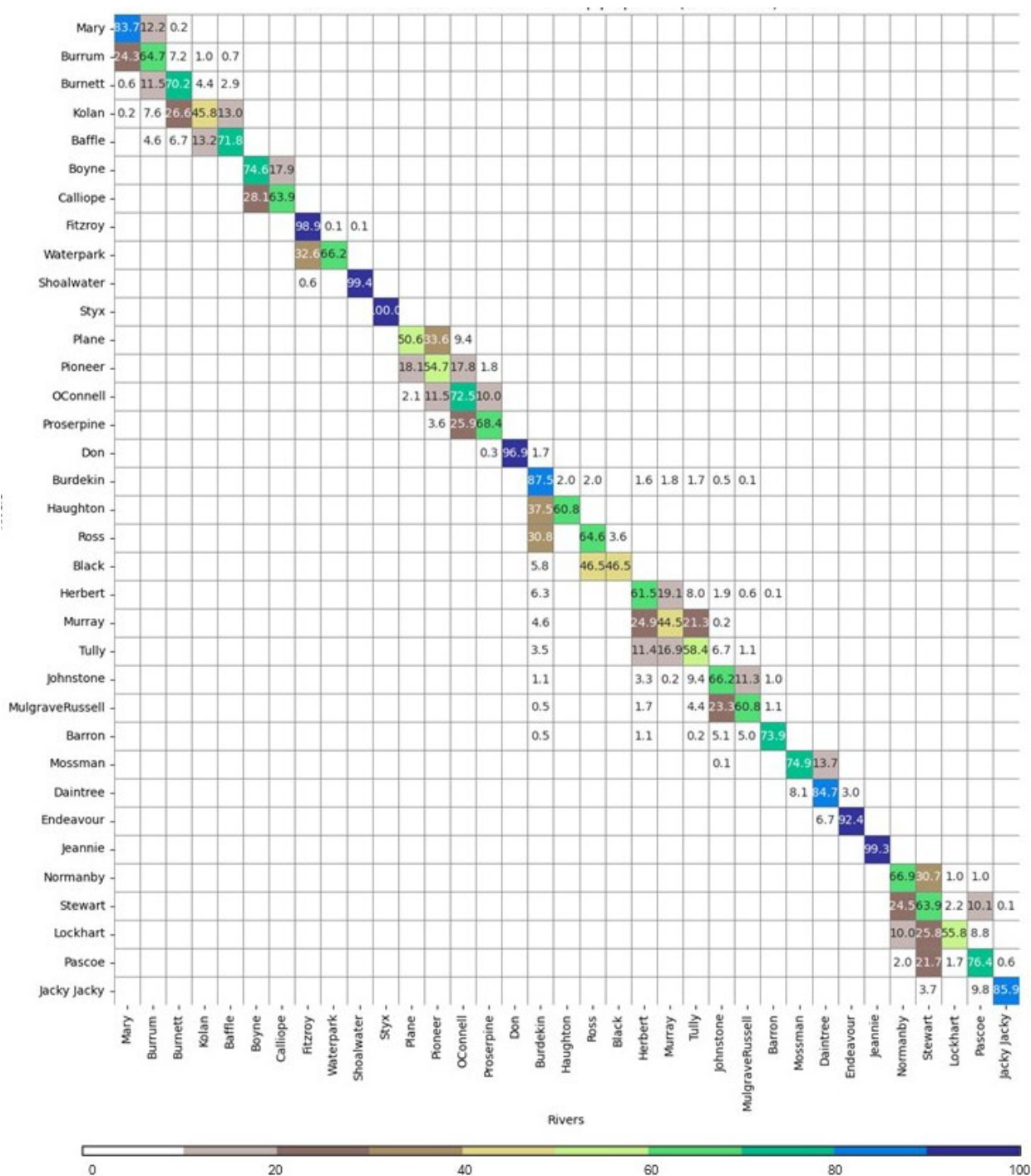


Figure 39. Proportion of spatial overlap for each of the River Footprints (in %), calculated as the median from the yearly normalised concentration outputs. Numbers show the proportion of the total River Footprint overlap as shown in the colour bar; ≤ 0 is white. For assessing the contributions within a basin footprint, the results should be read across rows (sums to 100%).

Calculating DIN Exposure Index

The final Index was calculated for coral reefs only, as although the exposure of seagrass to elevated nutrients is important, the direct effects of inorganic nutrient loading on seagrass have not been directly correlated with seagrass abundance. In part, this is because the effect of nutrient loads has so far been difficult to separate, as light limitation also caused by sediment loads, has been the primary driver of documented loss (Collier and Waycott 2009; Collier et al. 2011; Collier et al. 2012; Petus et al. 2014). From the limited number of studies in the GBR and research in other regions, it is understood that nutrient enrichment can stimulate seagrass growth, rather than impair growth (Udy and Dennison 1997; Udy et al. 1999; Mellors 2003; Collier

et al. 2015) if other factors, such as light availability are not limiting (Collier et al. 2015). Nutrients favour the growth of plankton, macroalgae and epiphytic algae, all of which attenuate light to seagrass leaves (Collier 2013). While some very high epiphyte loads have been documented on seagrass meadows of the GBR (McKenzie et al. 2012a; McKenzie et al. 2012b) and are likely to reduce light reaching seagrass leaves, to date, these have largely been seasonal blooms, and epiphyte cover has not correlated well with seagrass abundance (McKenzie et al. 2012a; McKenzie et al. 2012b). In summary, dissolved inorganic nutrients can have a direct benefit for seagrass growth to an extent, but can impact seagrass indirectly through plankton, epiphyte and microalgae blooms. The current understanding of these pathways is insufficient for a quantitative assessment. The likelihood of exposure was, however, assessed in acknowledgement that DIN exposure could be important for seagrass condition and resilience, but not included in the final exposure index.

Using the weighted sum of the coral reef exposure, the results for the basins where the anthropogenic DIN load is $<50 \text{ t yr}^{-1}$ were removed from the final index. The remaining results were then normalised to the maximum value to provide a relative index between the basins, that is, the basins with the highest summed weighted area were assigned a value of 1.0, and all other areas are expressed as a value between 0.0 and 1.0, relative to the maximum.

Final classification of the DIN Exposure Index

The final classification of the normalised results was defined by assessing four percentile categories for the dataset: Minimal (<0.01), Low (0.01 to 0.04), Moderate (>0.04 to 0.2), or High (>0.2 to 1.0).

4.2.1.1 Exposure of coral reefs to DIN

The final input layers for **anthropogenic** DIN loading, Chl-*a* and DIN Exposure are shown in Figure 39. These maps were then overlaid with the river footprints for each basin and weighted using the matrix in Figure 38.

The results are presented in Table 16 and are shown for ecosystems in the entire assessment area, and then only within the GBRWHA. The modelled annual average anthropogenic DIN load for the 35 GBR basins (tonnes per year) is shown, highlighting the basins with anthropogenic DIN loads less than 50 tonnes per year that were excluded from the final index. The weighted area of coral reefs is presented for all basins, and in a following step, basins with low anthropogenic DIN loads were excluded. The results for the final set of basins were normalised to the maximum value and ranked.

The detailed results are presented in Appendix 6: Table 22. The results for seagrass were also assessed but are not presented here as they were not included in the final index. All of the River Footprints are presented for each basin in Appendix 6. The summed and weighted exposure matrixes are not presented in this report but are available on request.

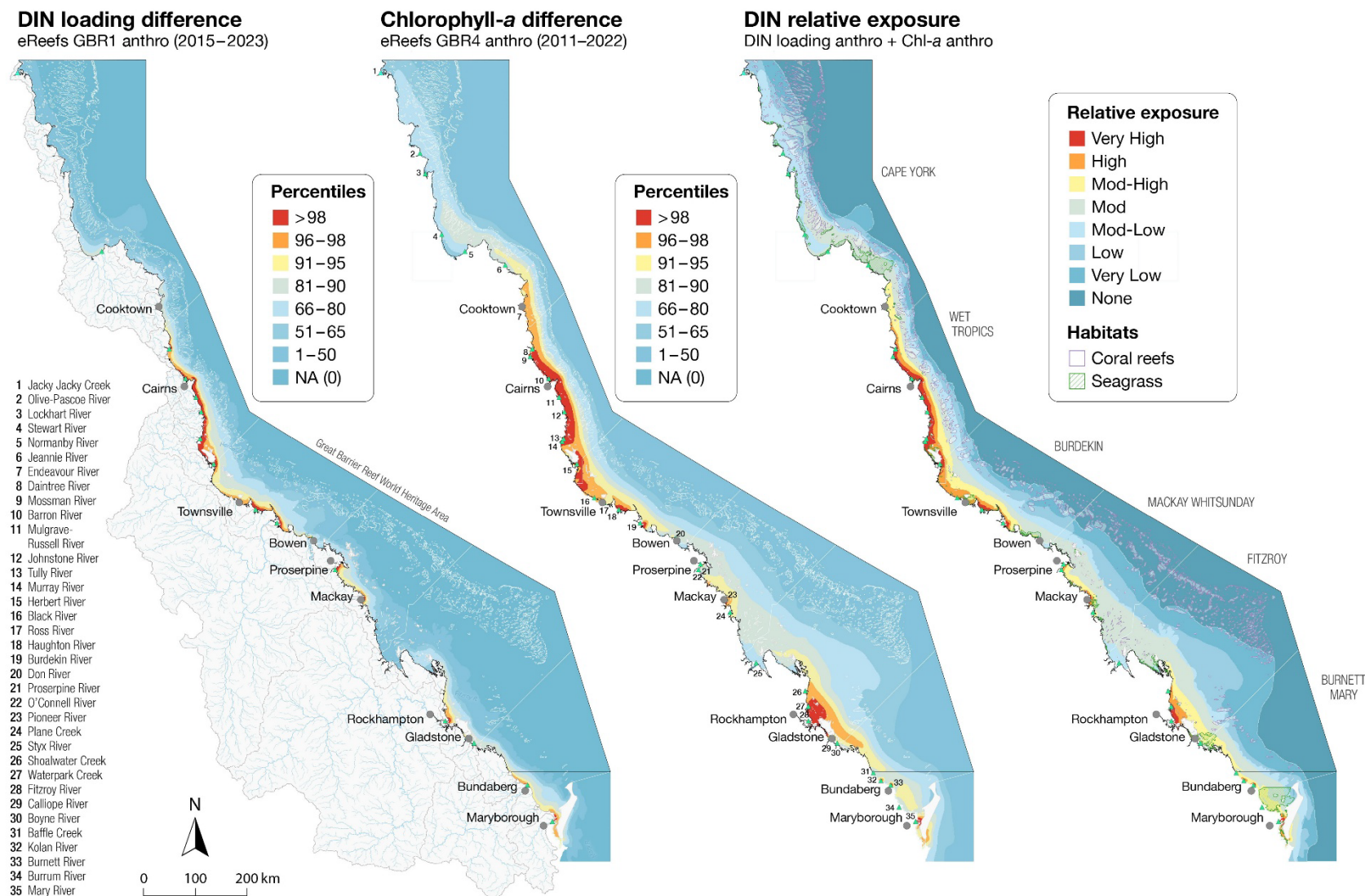


Figure 40. Inputs representing likelihood of exposure of **anthropogenic** river-derived DIN to the GBR. Left) DIN loading, difference between multi-annual average (2014–2021) calculated from current and pre-development load scenario, modelled for basins identified with grey dots; (Centre) Difference between the current annual average Chl-a (2011–2022) and the pre-development scenario calculated from the eReefs biogeochemical model; (Right) Relative DIN Exposure for the entire assessment area showing coral reef and potential seagrass meadows.

Table 16. Anthropogenic DIN Exposure Index is for all basins in the GBR catchment area. The Index is calculated for each River Footprint by summing the area of coral reefs in the weighted categories and normalising the value to the maximum result to provide a relative index between the River Footprints, that is, the River Footprint with the highest area is assigned a value of 1.0, and all other areas are expressed as a value between 0.0 and 1.0, relative to the maximum. The scores are ranked among the River Footprints, from the highest (1) to lowest score. The final DIN Exposure Index is categorised based on percentile categories of the normalised score as Minimal (<0.01), Low (0.01 to 0.04), Moderate (>0.04 to 0.2), or High (>0.2 to 1.0). Results are presented for coral reefs only within the GBRWHA, and those within the total assessment area (i.e. including Hervey Bay). Anth. = Anthropogenic; Norm. = Normalised; Exc. = excluding.

Basin	Anth. DIN load (t yr ⁻¹) (green shading shows <50 t yr ⁻¹)	Assessment of ecosystems within the GBRWHA only			Assessment of ecosystems within the entire assessment area (including Hervey Bay)		
		Norm. exc <50 t yr ⁻¹	Rank exc. <50 t yr ⁻¹	Anth. DIN Exposure Index	Norm. exc. <50 t yr ⁻¹	Rank exc. <50 t yr ⁻¹	Anth. DIN Exposure Index
Jacky Jacky	0.8	0.000	19	Minimal	0.000	19	Minimal
Olive Pascoe	2.6	0.000	19	Minimal	0.000	19	Minimal
Lockhart	0.2	0.000	19	Minimal	0.000	19	Minimal
Stewart	0.2	0.000	19	Minimal	0.000	19	Minimal
Normanby	0.3	0.000	19	Minimal	0.000	19	Minimal
Jeannie	0.9	0.000	19	Minimal	0.000	19	Minimal
Endeavour	2.0	0.000	19	Minimal	0.000	19	Minimal
Daintree	51	0.138	7	Moderate	0.138	7	Moderate
Mossman	88	0.191	6	Moderate	0.191	6	Moderate
Barron	82	0.023	14	Moderate	0.023	14	Moderate
Mulgrave-Russell	525	0.041	13	Moderate	0.041	13	Moderate
Johnstone	906	0.195	5	Moderate	0.195	5	Moderate
Tully	600	0.412	2	High	0.412	2	High
Murray	347	0.107	8	Moderate	0.107	9	Moderate
Herbert	1436	0.283	3	High	0.283	3	High
Black	20	0.000	19	Minimal	0.000	19	Minimal
Ross	57	0.023	15	Moderate	0.023	15	Moderate
Haughton	326	0.001	18	Low*	0.001	18	Low
Burdekin	390	1.000	1	High	1.000	1	High
Don	29	0.000	19	Minimal	0.000	19	Minimal
Proserpine	100	0.023	16	Moderate	0.023	16	Moderate
O'Connell	80	0.095	11	Moderate	0.095	12	Moderate
Pioneer	177	0.104	9	Moderate	0.104	10	Moderate
Plane	133	0.102	10	Moderate	0.102	11	Moderate
Styx	14	0.000	19	Minimal	0.000	19	Minimal
Shoalwater	0.0	0.000	19	Minimal	0.000	19	Minimal
Waterpark	0.0	0.000	19	Minimal	0.000	19	Minimal
Fitzroy	49	0.000	19	Minimal	0.000	19	Minimal
Calliope	2.6	0.000	19	Minimal	0.000	19	Minimal

Basin	Anth. DIN load (t yr ⁻¹) (green shading shows <50 t yr ⁻¹)	Assessment of ecosystems within the GBRWHA only			Assessment of ecosystems within the entire assessment area (including Hervey Bay)		
		Norm. exc <50 t yr ⁻¹	Rank exc. <50 t yr ⁻¹	Anth. DIN Exposure Index	Norm. exc. <50 t yr ⁻¹	Rank exc. <50 t yr ⁻¹	Anth. DIN Exposure Index
Boyne	0.2	0.000	19	Minimal	0.000	19	Minimal
Baffle	15.9	0.000	19	Minimal	0.000	19	Minimal
Kolan	54	0.001	17	Low	0.001	17	Low
Burnett	149	0.222	4	High	0.230	4	High
Burrum	31	0.000	19	Minimal	0.000	19	Minimal
Mary	372	0.046	12	Moderate	0.136	8	Moderate

*The **Haughton basin exposure category is allocated as High** in the final assessment to account for interactions with the Burdekin basin, as described below.

The final Anthropogenic DIN Exposure Index results are the same whether the ecosystem assessment is undertaken over the whole assessment area, or only within the GBRWHA. The results highlight the dominance of the Burdekin basin when considering the likely exposure of DIN to coral reef ecosystems in the GBR. The Burdekin River footprint extends over a very large area of the GBR. Basins in the **High** exposure category include the Tully, Herbert and Burnett. **Moderate** exposure categories are observed in the Daintree, Mossman, Barron, Mulgrave-Russell, Johnstone, Murray, Ross, Proserpine, O'Connell, Pioneer, Plane and Mary basins. Basins in the **Low** exposure category include the Haughton and Kolan, although based on further evidence described below, the Haughton was adjusted to High. All other basins are considered to contribute to minimal exposure of coral reefs to DIN. A significant consideration for interpreting the results is the likely overlap between river footprints, resulting in potential overestimates for some basins (see Figure 39). Using this assessment, it is likely that the results are overestimated for the Barron, Murray (overlap from Herbert and Tully) and Ross (overlap from the Burdekin).

The low results for the Haughton are not intuitive given the estimated anthropogenic DIN load from the basin, but the low results are likely due to ecosystem distribution in the modelled river footprints and interactions with the Burdekin footprint. There is very limited mapped coral reef in Bowling Green Bay which is the primary receiving area for the Haughton River footprint. This highlights a clear limitation of the method by only assessing areas of coral reefs in each footprint, and while it is recognised that other ecosystems such as seagrass meadows can be negatively affected by increased nutrient concentrations, there is limited direct and documented evidence of impacts in the GBR. The assessment using coral reefs only attempts to make the assessment more ecologically relevant than calculating total areas of river influence. There are complex interactions between the Haughton River footprint and the footprint of the Burdekin. The Haughton River typically flows around the same time as the Burdekin River, however, it often flows earlier in an event. Hydrodynamic modelling indicates that the Haughton River footprint does move north around Cape Bowling Green and into Cleveland Bay, but is often merged with the Burdekin plume within a few days. The panel in Figure 41 shows an example from the eReef Visualisation tool (e.g. <https://ereefs.aims.gov.au/gbr4/bgc/scenarios/chl-a-sum/#region=townsville-3>) over three days, illustrating how the Haughton River discharge combines with the Burdekin footprint as the plume moves further out of Bowling Green Bay. The combined plume is then typically carried north with the larger flow of the Burdekin River, making the influence of the Haughton River very difficult to disentangle in the method applied for this assessment. The Haughton has a similar anthropogenic DIN load to the Burdekin River and contains a large proportion of the sugarcane area in the Burdekin region (see Figure 14). **Therefore, as a precautionary measure, the High exposure category is applied to the Haughton basin to align with the Burdekin assessment.**

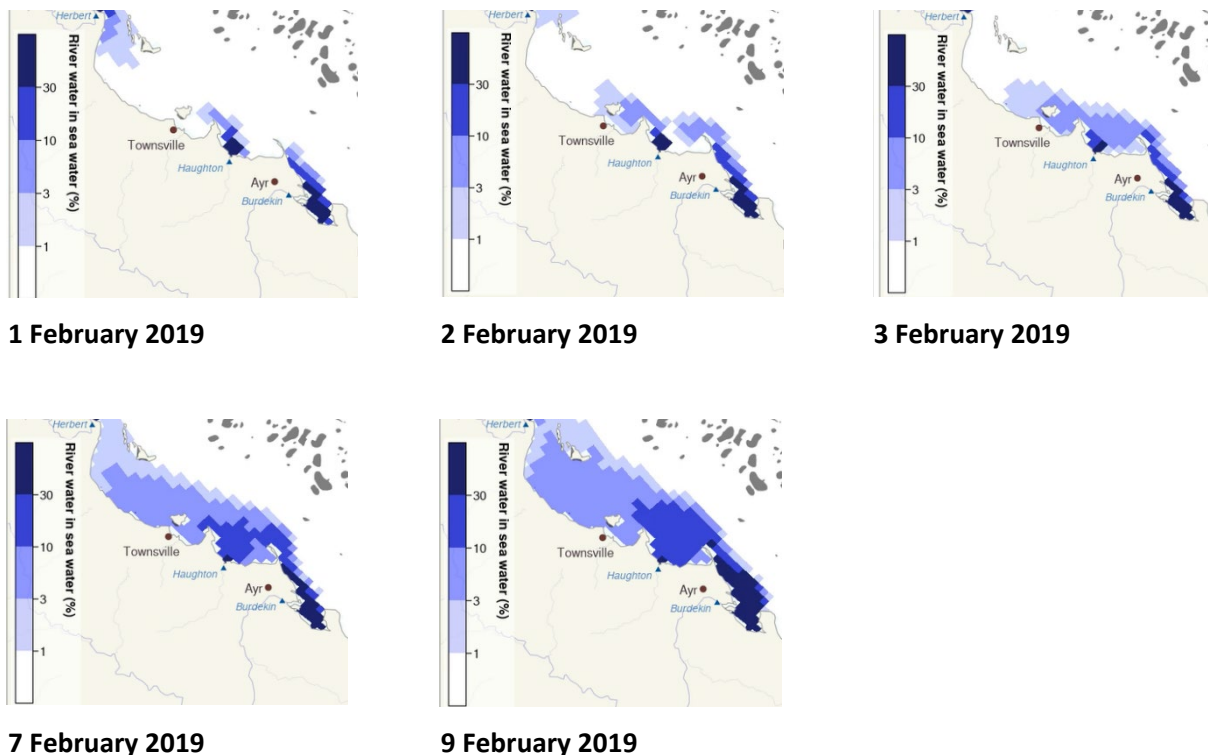


Figure 41. Percentage of river water in sea water simulated for a flood event in the Burdekin region, showing 1 to 9 February 2019. Extracted from the eReef Visualisation tool (<https://ereefs.aims.gov.au/qbr4/bqc/scenarios/chl-a-sum/#region=townsville-3>).

4.2.2 Fine sediments

The nature and timing of sediment exposure

As with nutrients, almost all discharge of sediments from rivers to the GBR occurs in the wet season (typically December to April inclusive, depending on the year) (Furnas 2003; Devlin and Brodie 2005; Furnas et al. 2011; Lewis et al. 2024a). Sediment that is transported more than 1 km offshore is generally the clay to fine silt (<20 μm) fraction (Bainbridge et al. 2018; 2021). Fine sediments have potential residence times of decades on the shallow inner shelf, during which they remain available for resuspension and can affect coastal turbidity (Brodie et al. 2012; Fabricius et al. 2013; Fabricius et al. 2014; Lewis et al. 2015; Fabricius et al. 2016). Fine sediment supply is attenuated during the year by the processes of transport into mangroves, compaction and transport offshore into deeper waters where resuspension is unlikely to occur (Brodie et al. 2012). There is clear evidence that there is year-round, wind-driven resuspension of fine terrigenous sediments on the shallow inner shelf, reducing light penetration for periods of days to weeks (Lewis et al. 2024a). The degree of resuspension appears to attenuate towards the second half of the dry season (Fabricius et al. 2016) as fine material deposited after wet season floods is moved to deeper water or coastal depositional areas (Larcombe et al. 1995). However, there is a pool of refractory fine sediments that varies depending on hydrodynamic and climate influences (Bainbridge et al. 2016).

Secchi depth is used as an indicator of water clarity. Secchi depth refers to the depth at which a white and black disc, called a Secchi disk, can no longer be seen when lowered into a body of water, essentially measuring the water clarity by indicating how far light can penetrate through the water column; a higher Secchi depth signifies clearer water, while a lower depth indicates higher turbidity (cloudiness) due to suspended particles like algae or sediment. Daily Secchi depth results are available as an output of the eReefs marine model. The use of benthic light was also considered. However, Secchi depth was chosen for

consistency with the use as the primary metric for TSS in the update of the GBR water quality targets (Waterhouse et al. 2025).

Based on the evidence above, wet season and annual conditions are therefore both relevant in assessing the exposure of GBR ecosystems to fine sediments. The likelihood of exposure of marine ecosystems to sediments in this assessment focuses on annual Secchi depth results and the wet season dispersion of end-of-catchment fine sediment loads into the GBR (referred to as 'TSS loading'), both presented as the difference between pre-development and current scenarios, i.e. anthropogenic.

4.2.2.1 Method

The approach for developing the TSS Exposure Index within each River Footprint involved five major steps and are largely the same as those described for DIN.

1. Development of the TSS exposure spatial layer
2. Development of the River Footprints for each basin
3. Preparation of ecosystem assessment layers
4. Combining the TSS Exposure layer with the River Footprints to derive TSS Exposure for each basin
5. Calculation of the TSS Exposure Index

The TSS likelihood-of-exposure layer ('likelihood') was assessed using two spatial layers and accounts for annual and wet season influences. The spatial layer was derived by summing the anthropogenic component of Secchi depth from the eReefs GBR4 model and the anthropogenic component of TSS loading from the eReefs GBR1 model, as described below. A weighted normalisation, based on percentile categories, was applied to each input layer according to the reclassification in Table 13. These layers were then summed and normalised to a scale from 0 to 1:

$$\text{TSS likelihood}_{\text{sum}} = \text{Secchi}_{\text{anthro}} + \text{TSS loading}_{\text{anthro}}$$

$$\text{TSS likelihood}_{\text{norm}} = \frac{\text{TSS likelihood}_{\text{sum}} - \text{Min}(\text{TSS likelihood}_{\text{sum}})}{\text{Max}(\text{TSS likelihood}_{\text{sum}}) - \text{Min}(\text{TSS likelihood}_{\text{sum}})}$$

Annual influence:

- i. **Anthropogenic Secchi depth (Secchi_{anthro}):** Represents the difference between current (2011–2022) and pre-development light measured as Secchi depth in the water column as a measure of anthropogenic annual average Secchi depth conditions. The anthropogenic change in Secchi depth from pre-industrial (ΔSecchi) was converted to the standard 0.01 dd grid as described in Section 4.2.1.1. A 2011–2022 annual average of ΔSecchi was used as input into the TSS exposure layer. A weighted normalisation based on percentile categories was applied to the ΔSecchi data, where each value was assigned a relative score between 0 and 1 according to the reclassification in Table 13.

Wet season influence:

- ii. **Anthropogenic TSS loading ($\Delta\text{TSS}_{\text{load}}$):** Represents the dispersion of end-of-catchment fine sediment loads during the wet season, calculated as an anthropogenic influence by comparing the difference between long-term current (2014–2022) average TSS loading with a pre-development TSS load scenario. It highlights the areas of greatest change with current land-use characteristics. This layer was produced using the same method as described for DIN loading in Section 4.2.1.1.

All other methods followed the same steps as for the DIN assessment described in Section 4.2.1.1 with the exception of the consideration of the TSS anthropogenic loads.

Accounting for adjustments to the TSS loads and river overlap

Many of the GBR basins generate relatively low annual average anthropogenic TSS loads, and are subject to overlap of the footprints of adjacent rivers, leading to results that indicate a higher level of exposure from

that river footprint than what is most likely the case. The method for excluding these rivers from the assessment was conceptually the same as that described for DIN but for TSS, using a cut off 50 kt yr⁻¹. However, there are two exceptions to this approach with the Normanby and Endeavour basins. This is related to the availability of long-term monitoring data from the Cape York Water Monitoring Partnership indicating that the end-of-catchment loads for both basins is underestimated when compared to the catchment loads that went into the eReefs marine model run (Howley and Shellburg, unpublished).

4.2.2.1 Exposure of coral reefs and seagrass to fine sediment

The final input layers for anthropogenic TSS loading, Secchi depth and final TSS Exposure are shown in Figure 42. The maps clearly show the coastal areas of naturally high turbidity, from Mackay southwards, and specific areas such as Broad Sound. These maps were then overlaid with the river footprints for each basin and weighted using the matrix in Figure 38.

The results are presented in Table 17 and are shown for ecosystems in the entire assessment area, and then only within the GBRWHA. The modelled annual average anthropogenic TSS load for the 35 GBR basins (kilotonnes per year) is shown, highlighting the basins with anthropogenic TSS loads less than 50 kilotonnes per year that were excluded from the final metric. The weighted area of coral reefs and surveyed seagrass are presented for all basins, and then excluded for the basins with low anthropogenic TSS loads. The final set of basins was normalised to the maximum value and ranked. The final TSS exposure categories are aligned with the categories for DIN: Minimal (<0.01), Low (0.01 to 0.04), Moderate (>0.04 to 0.2), or High (>0.2 to 1.0).

The detailed results are presented in Appendix 6: Table 23. All of the River Footprints are presented for each basin in Appendix 6. The summed and weighted exposure matrixes are not presented in this report but are available on request.

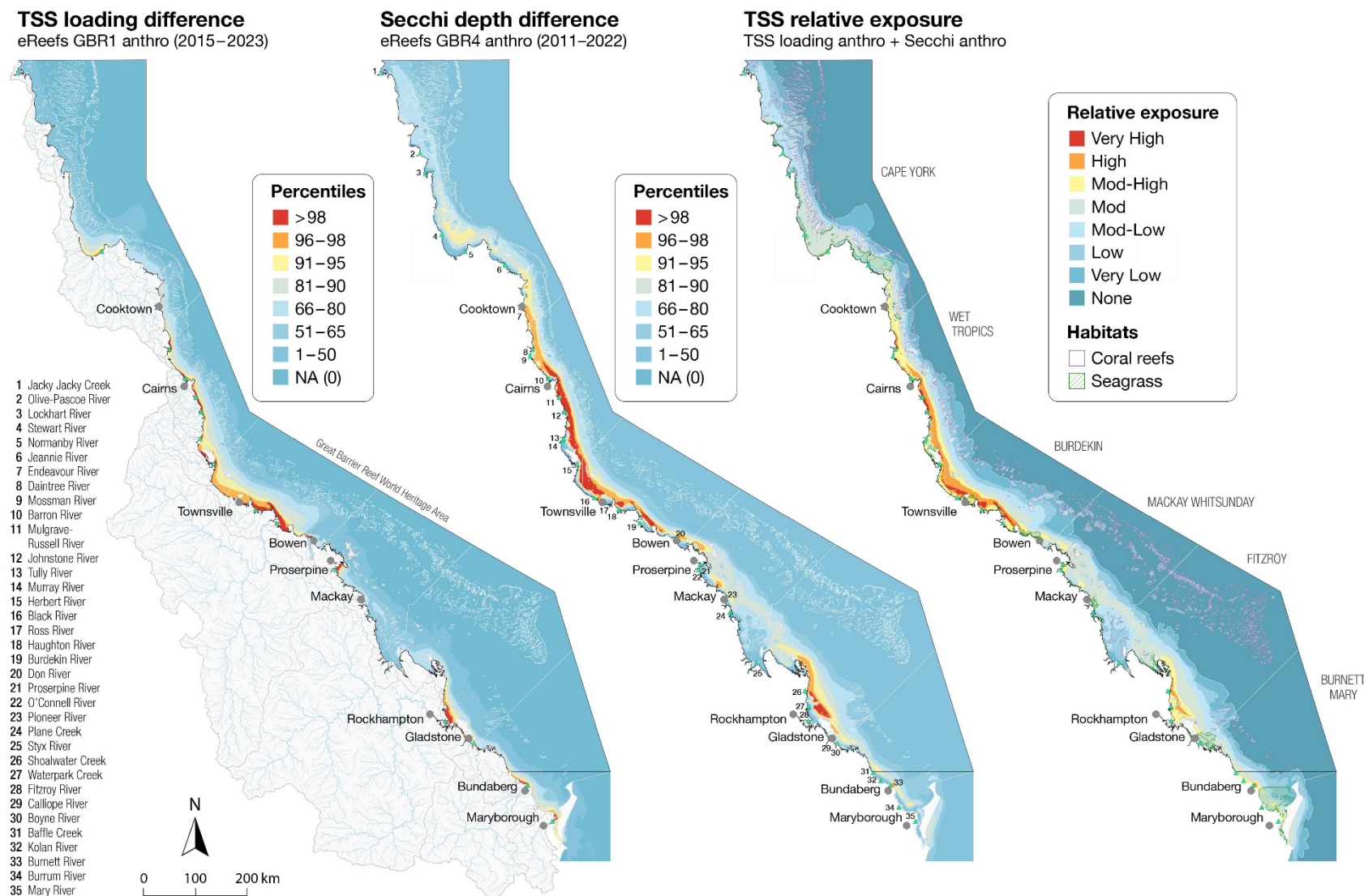


Figure 42. Inputs representing likelihood of exposure of **anthropogenic** river-derived TSS to the GBR. Left) TSS loading, difference between multi-annual average (2014–2021) calculated from current and pre-development load scenario, modelled for basins identified with grey dots; (Centre) Difference between the current annual average Secchi depth (2011–2022) and the pre-development scenario calculated from the eReefs biogeochemical model; Right) Relative TSS Exposure for the entire assessment area showing coral reef and potential seagrass meadows.

Table 17. Anthropogenic TSS Exposure Index is for all basins in the GBR catchment area. The TSS Exposure Index is calculated for each River Footprint by summing the area of coral reefs and seagrass in the weighted categories and normalising the value to the maximum result to provide a relative index between the River Footprints. The scores are ranked among the River Footprints, from the highest (1) to lowest score. The final TSS exposure categories are ranked to align with TSS as Minimal (<0.01), Low (0.01 to 0.04), Moderate (>0.04 to 0.2), or High (>0.2 to 1.0). Results are presented for coral reefs and seagrass within the GBRWHA, and those within the total assessment area (i.e. including Hervey Bay). Anth. = Anthropogenic; Norm. = Normalised; Exc. = excluding. *The anthropogenic loads for the Normanby and Endeavour basins are considered to be an underestimate, and these basins were included in the assessment.

Basin	Anth. TSS load (kt yr ⁻¹) (green text shows <50 kt yr ⁻¹)	Assessment of ecosystems within the GBRWHA only			Assessment of ecosystems within the entire assessment area (including Hervey Bay)		
		Norm. exc. <50 kt yr ⁻¹	Rank exc. <50 kt yr ⁻¹	Anth. TSS Exposure Index	Norm. exc. <50 kt yr ⁻¹	Rank exc. <50 kt yr ⁻¹	Anth. TSS Exposure Index
Jacky Jacky	0.6	0.000	17	Minimal	0.000	17	Minimal
Olive Pascoe	3.8	0.000	17	Minimal	0.000	17	Minimal
Lockhart	1.8	0.000	17	Minimal	0.000	17	Minimal
Stewart	2.5	0.000	17	Minimal	0.000	17	Minimal
Normanby	34*	0.512	3	High	0.256	4	High
Jeannie	9.3	0.000	17	Minimal	0.000	17	Minimal
Endeavour	15*	0.009	14	Low	0.005	14	Low
Daintree	21	0.000	17	Minimal	0.000	17	Minimal
Mossman	5.6	0.000	17	Minimal	0.000	17	Minimal
Barron	91	0.029	8	Moderate	0.015	9	Moderate
Mulgrave Russell	50	0.006	16	Low	0.003	16	Low
Johnstone	220	0.027	9	Moderate	0.013	10	Moderate
Tully	60	0.165	5	Moderate	0.083	6	Moderate
Murray	22	0.000	17	Minimal	0.000	17	Minimal
Herbert	207	0.230	4	High	0.115	5	High
Black	13	0.000	17	Minimal	0.000	17	Minimal
Ross	16	0.000	17	Minimal	0.000	17	Minimal
Haughton	114	0.012	13	Moderate	0.006	13	Low
Burdekin	2969	1.000	1	High	0.501	2	High
Don	251	0.024	10	Moderate	0.012	11	Moderate
Proserpine	41	0.000	17	Minimal	0.000	17	Minimal
O'Connell	156	0.041	7	Moderate	0.020	8	Moderate
Pioneer	61	0.021	11	Moderate	0.011	12	Moderate
Plane	67	0.006	15	Low	0.003	15	Low
Styx	37	0.000	17	Minimal	0.000	17	Minimal
Shoalwater	18	0.000	17	Minimal	0.000	17	Minimal
Waterpark	7.6	0.000	17	Minimal	0.000	17	Minimal
Fitzroy	1270	0.566	2	High	0.283	3	High
Calliope	30	0.000	17	Minimal	0.000	17	Minimal
Boyne	5	0.000	17	Minimal	0.000	17	Minimal
Baffle	21	0.000	17	Minimal	0.000	17	Minimal
Kolan	14	0.000	17	Minimal	0.000	17	Minimal
Burnett	117	0.041	6	Moderate	0.026	7	Moderate
Burrum	13	0.000	17	Minimal	0.000	17	Minimal
Mary	188	0.013	12	Moderate*	1.000	1	High

*The Mary basin exposure category is allocated as High in the final assessment as described below to account for the extensive seagrass meadows in the Hervey Bay region that provide critical and connected habitat for dugong populations that are associated with the GBRWHA.

The final Anthropogenic TSS Exposure categories were different when the ecosystem assessment was undertaken over the whole assessment area compared to only within the GBRWHA. This is due to the very large area of seagrass meadows located in Hervey Bay and in particular the area of influence from the Mary basin (and Burrum but this was excluded from the final metric as it has a low anthropogenic TSS load). There are approximately 285,147 ha of mapped seagrass in the total river footprint for the Mary River, however, when this assessment is constrained to the GBRWHA only, the area of seagrass meadows within the footprint that overlaps with the GBRWHA is 52,522 ha. Furthermore, within the GBRWHA, a large proportion of the footprint is in the Moderate or lower exposure categories, in comparison to the assessment over the whole area where there are 66,359 ha of seagrass meadows in the highest river footprint category, and the Moderate-High or Moderate TSS exposure category due to the relatively close proximity of the Mary River mouth to the seagrass meadows. As described in Section 1.3, the seagrass meadows in Hervey Bay provide important habitat and foraging grounds for mobile species that range in and out of the GBRWHA. For example, the area supports the highest density dugong habitat south of the Torres Strait (Grech et al. 2011; Coppo et al. 2014; Sobotzick et al. 2017; Rasheed et al. 2023). However, it is recognised that in considering relative spatial priorities for the GBRWHA, seagrass areas located directly within the GBRWHA may take priority from a GBR management perspective. Accordingly, the results for the ecosystem assessment within the GBRWHA is applied here, but in recognition of the high value of the Hervey Bay seagrass ecosystems and the connectivity to the GBR (highlighted in Rasheed et al. 2023), **the High exposure category is maintained for the Mary basin.**

The results for the remaining basins also highlight the dominance of the Burdekin basin when considering likely exposure of fine sediment to coral reef and seagrass ecosystems in the GBR. The Burdekin River footprint extends over a very large area of the GBR. Basins in the High exposure category include the Normanby, Herbert, Fitzroy and Mary. Moderate exposure categories are observed in the Tully, O'Connell and Burnett basins. Basins in the Low exposure category include the Barron, Johnstone, Haughton and Pioneer. All other basins are considered to contribute to minimal exposure of coral reefs and seagrass to fine sediment.

4.2.3 Pesticides

4.2.3.1 Method

Marine Monitoring data

Pesticide marine monitoring is conducted by the MMP as part of the P2R program. Pesticide concentrations have been monitored at 11 fixed inshore locations using grab and passive samplers from the Wet Tropics to the Fitzroy region. For a summary of methods see for example Gallen et al. (2019) and Grant et al. (2018).

Marine modelling

In 2023, Skerratt et al. published the first results of the eReefs 1 km resolution hydrodynamic modelling of diuron exposure in the GBR's inshore marine zone, providing the most spatially comprehensive assessment of pesticide exposure beyond river mouths (Skerratt et al. 2023). Prior to this, understanding of pesticide exposure in the inshore marine zone has been informed by marine monitoring results from a limited number of inshore locations, presenting spatial and temporal snapshots of potential exposure and risk. This report marks the first use of this marine modelling as part of the risk assessment informing the Reef 2050 WQIP's priority areas for management. However, this data needs to be used with recognition of its limitations: it only models diuron (one of 23 pesticides detected in the inshore marine area; Negri et al. 2024) and covers just two wet seasons (2016–2017 and 2017–2018). Despite these constraints, the modelled assessment delivers a significantly improved visual and quantitative understanding of the spatial extent of exposure. In addition, by examining additional lines of evidence (marine and catchment monitoring data) the model's limitations can be better understood and gaps infilled to generate a more complete picture of pesticide risk to the inshore marine ecosystems.

Methods are described in Skerratt et al. (2023). In summary, the Paddock to Reef's marine modelling program used the eReefs GBR1 hydrodynamic model coupled with the GBR Dynamic SedNet model (GBR-SedNet) to simulate dispersal of diuron loads (i.e. modelled load estimates from GBR-SedNet). The GBR

SedNet loads entered the GBR at 21 river locations, with dispersal modelled using freshwater inputs for 16 of these rivers and as a surface flux for the other minor rivers. Diuron loads are modelled with freshwater (where applicable) from the river entrance boundary, and these are advected and diffused by the hydrodynamic model throughout the grid and eventually mix with seawater. Transformation processes of diuron are incorporated into the model: a simple exponential decay function simulating the diuron half-life (and other non-transport processes) in marine conditions was used and a half-life set at 40 days based on the results of a calibration simulation. Validation of the eReefs diuron modelling with the results from the MMP is covered in Skerratt et al. (2023) and further reviewed in Negri et al. (2024) and therefore will not be addressed here.

For this assessment, the outputs from the eReefs diuron modelling were converted to percent species affected by applying a Burr Type III equation to the simulated diuron concentrations.

$$\% \text{ Species Affected}_{\text{diuron}} = \frac{1}{(1 + (\frac{B}{C_{\text{diuron}}})^c)^K} \times 100$$

Where:

B=0.0454, C=0.5055559, K=8.002525, C_{diuron} is the modelled diuron concentration $\mu\text{g L}^{-1}$.

This equation fits the species sensitivity distribution for estimating diuron toxicity to multiple species (see King et al. 2017 and Warne et al. 2020). The same equation is used to convert diuron concentrations to percent species affected for the Pesticide Risk Metric (Bezzina et al. 2022). The percent of species affected was estimated for the modelled diuron concentrations over a 6-month exposure window (as is done for the Pesticide Risk Metric) that covered the period when pesticide exposure is most likely to occur with wet season runoff events. For 2016–2017 and 2017–2018, that period was from 15 October to 15 April.

4.2.3.2 Pesticide risk

Marine ecosystem exposure to diuron 2016–2018

Spatial extent

The hydrodynamic model visually depicts the likely dispersal of diuron in the inshore marine zone over the wet season, highlighting regions from the Mackay Whitsunday, Burdekin and southern parts of the Wet Tropics as most likely to be exposed (Table 18 and Figure 43, Appendix 4). There are hot spots within these regions, shaded blue to aqua, that indicate where the highest concentrations of diuron are likely to accumulate (Figure 43). In general, these areas are located close to the coast and the river mouths from where they are discharged and include seagrass and inshore coral habitats (Table 18, Figure 44).

Table 18. Hot spot areas of diuron exposure (>1% species affected wet season average), including seagrass and coral habitats. Based on marine hydrodynamic modelling of the 2016–2017 and 2017–2018 wet seasons.

Hot spot area	Flood plume source	Seagrass habitat exposure	Inshore coral reef exposure	Figure references
Inshore areas adjacent to the northern region of the Plane basin (e.g. Plane and Sandy creeks), Pioneer and O'Connell basins	Pioneer River, Sandy Creek and Plane Creek*	Inshore and deep seagrass habitats adjacent to Plane, Pioneer and O'Connell basins, as well as Repulse Bay and Whitsunday Islands during some events	Inshore coral reefs adjacent to Plane, Pioneer and O'Connell basins, as well as Repulse Bay and Whitsunday Islands during some events	Figure 43 and Appendix 4 (Figures 1–3)
Repulse Bay	O'Connell, Proserpine, Pioneer rivers	Inshore and deep seagrass habitats in Repulse Bay and Whitsunday Islands during some events	Inshore coral reefs in Repulse Bay and Whitsunday Islands during some events	Figure 43 and Appendix 4 (Figures 1–3)

Hot spot area	Flood plume source	Seagrass habitat exposure	Inshore coral reef exposure	Figure references
Inshore coastal areas north of Bowen	Don River	Inshore seagrass habitats between Bowen and Cape Upstart	Small area of inshore coral reef in Abbott Bay	Figure 43 and Appendix 4
Bowling Green Bay and Cleveland Bay	Haughton River and Barratta Creek.	Inshore seagrass habitat in Cleveland Bay	Small area of inshore coral reef south of Magnetic Island	Figure 43 and Appendix 4
Lucinda and Hinchinbrook Channel	Herbert River	Inshore seagrass habitat in Hinchinbrook Channel and Hinchinbrook Island and at Lucinda.	Small area of inshore coral reef at Hinchinbrook Island. Low level of exposure for other inshore reefs in the area.	Figure 43 and Appendix 4

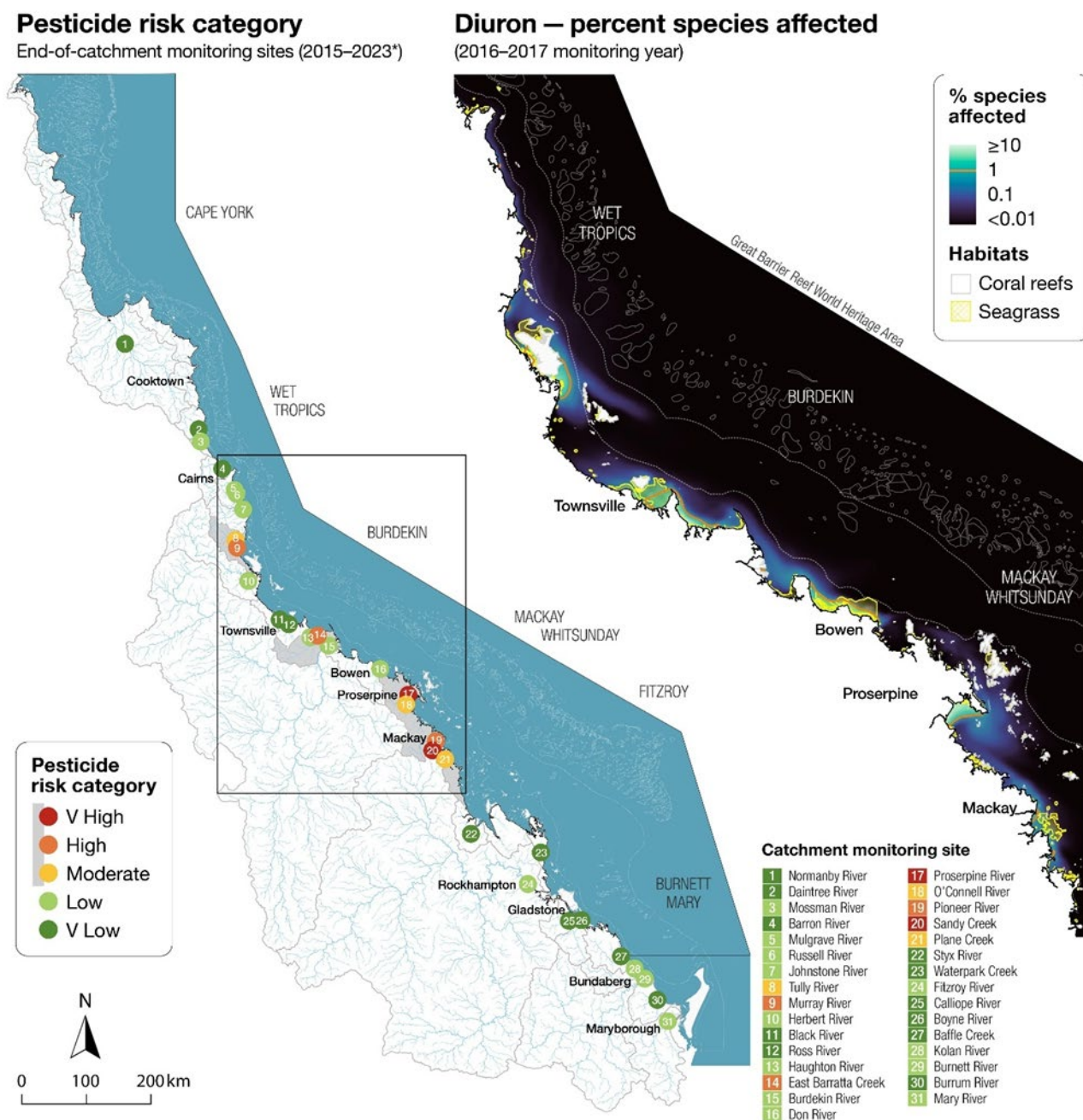
*Other small catchments in the northern area of the Plane Basin are also likely to contribute but are not included in the marine modelling.

The results from the marine modelling show similarities with pesticide risk levels at the end-of-catchment (Figure 43, left side), which indicate the highest risk areas are Mackay Whitsunday and lower Burdekin, Murray and Tully basins. End-of-catchment monitoring was not available for the Murray River during the marine modelling period (2016–2018), however monitoring data from 2018–2023 indicates a high risk and substantially higher than the Herbert River; a trend that is not reflected in the marine modelling. End-of catchment monitoring in Fitzroy catchments shows a generally lower risk, which is mirrored in the marine modelling. On the other hand, the marine modelling showed no diuron exposure in coastal regions adjacent to the Burnett Mary region, whereas end-of-catchment monitoring indicated up to Moderate risk for some rivers in this region in 2017–2018 (*Table 6* and Appendix 4).

Results from the marine monitoring passive sampler sites reflects a similar relative trend across regions and catchments (Appendix 4: Table 18). For the same years, diuron was detected across all 11 passive sampler sites, from the Fitzroy to the Wet Tropics, demonstrating the ubiquitous presence of diuron along the coast. The highest levels were detected in sites adjacent to the Mackay Whitsunday region and lower Burdekin, followed by the Wet Tropics. Low levels of diuron were even detected at sites adjacent to the Fitzroy region areas where catchment monitoring indicates a low level of diuron delivered to the inshore marine environment (Figure 47). This ubiquitous nature of diuron in the inshore marine zone is potentially the result of longer half-lives of diuron in marine waters (139–185 days; Mercurio et al. 2015; 2016; 2018). Importantly, the marine monitoring demonstrates that diuron was only one of 23 pesticides detected in these inshore areas (Negri et al. 2024), therefore, similar spatial exposure patterns are likely for mixtures of pesticides.

Our understanding of pesticide risk in the inshore marine ecosystem has been significantly enhanced by the hydrodynamic modelling, which reveals a more comprehensive picture than previously available through limited monitoring sites (Skerratt et al. 2023). The model demonstrates that diuron generally disperses northward along the coast, with tides and currents playing an important role in plume dynamics (Skerratt et al. 2023; for examples see Appendix 4). Localised variations may concentrate pesticides in embayments (which is also where seagrass tend to establish) rather than dispersing them along the coast, and in other cases, disperse them beyond the original catchment area into northern regions and embayments (Skerratt et al. 2023). This concentration effect is particularly evident in the hotspot areas identified in Table 18, where seagrass and inshore coral habitats experience the highest exposure levels. Shallow inshore seagrass meadows appear most at risk, with diuron concentrations frequently exceeding both the 99% and 95% species protection thresholds (Figure 44, Appendix 4). Importantly, even these exposure patterns are likely to underestimate the true risk, as they account for only diuron rather than the complete mixture of pesticides present. Given that diuron typically contributes only 30–40% (Figure 27) of the total pesticide risk

in end-of-catchment monitoring, the spatial extent of habitats experiencing threshold exceedances from the full mix of pesticides is most likely greater than what the diuron-only modelling indicates.



*includes the years within this range where monitoring data is available, not all catchments have monitoring data for all years between 2015 and 2023.

Figure 43. End-of-catchment pesticide risk (left side) averaged across years from 2015–2023, and diuron exposure in the inshore marine zone (inset) based on marine modelled diuron concentrations presented as the wet season average percentage species affected computed on the near surface for the 2016–2017 wet season (15 October to 15 April). Marine modelling demonstrates potential exposure areas of seagrass and coral ecosystems. The pesticide risk category of each catchment monitoring site is listed north to south.

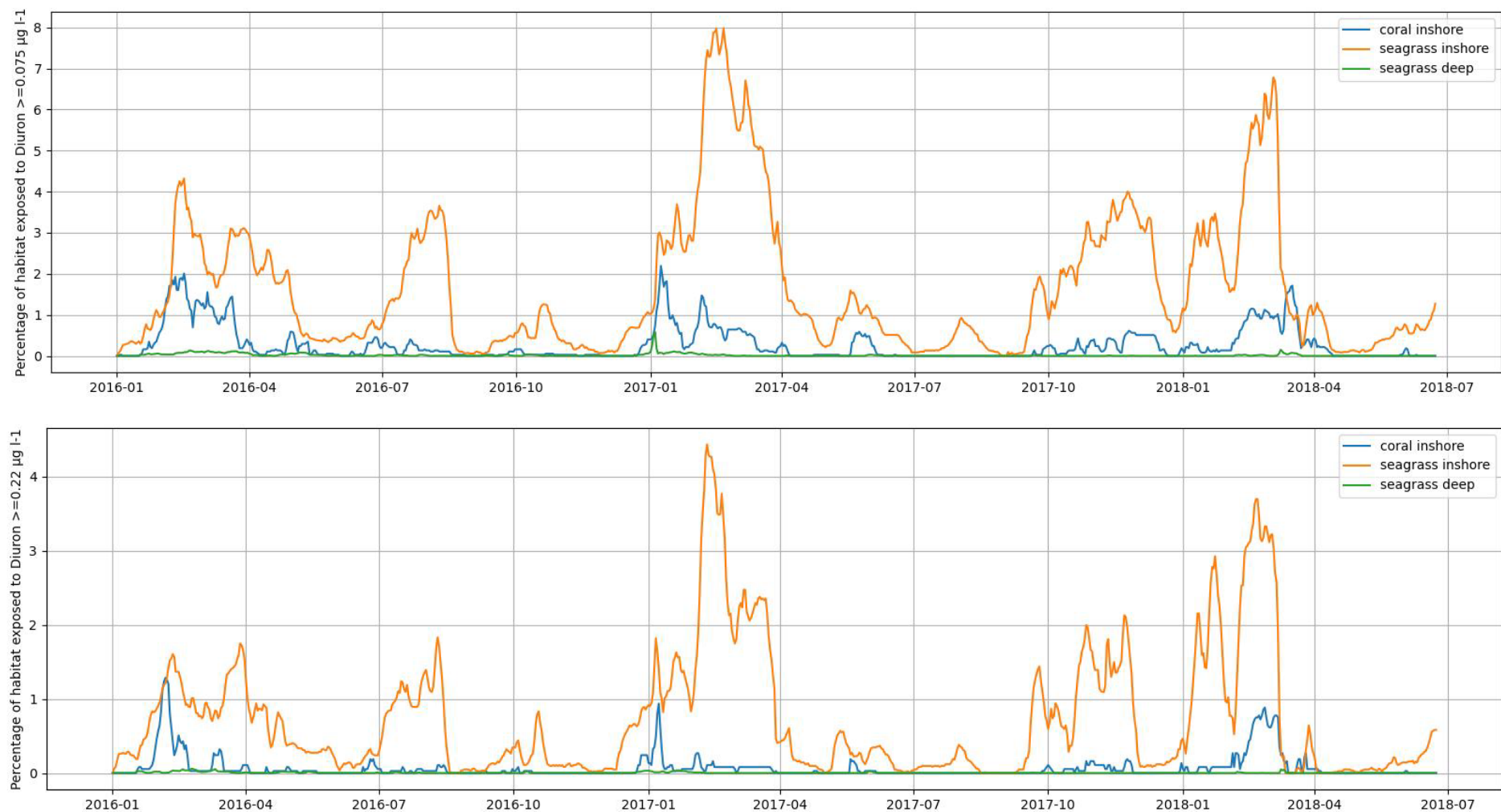


Figure 44. The estimated proportion of coral (inshore) and seagrass habitats exposed to diuron threshold concentrations from January 2016 to July 2018, where the top figure shows the proportion exposed to $\geq 0.075 \mu\text{g L}^{-1}$ (the diuron 99% species protection threshold) and the bottom figure shows the proportion exposed to $\geq 0.22 \mu\text{g L}^{-1}$ (the diuron 95% species protection threshold).

Temporal extent

The hydrodynamic model also helps to infill gaps in our understanding of temporal exposure patterns. Figure 46 maps areas where diuron concentrations exceeded the 1% species affected threshold, displaying the number of days that exceeded that threshold (noting that these are not consecutive days). Most areas between Mackay Whitsunday and Wet Tropics indicate diuron concentrations occurred above threshold levels between 1 and 20 days, with some areas reaching up to at least 50 days. These results accord with marine monitoring data that has found diuron in 96% of passive samplers deployed across the 11 fixed sampling sites (Negri et al. 2024). Those areas with a longer temporal exposure align with the hotspot areas in Figure 43 and further suggest that these are areas where pesticides accumulate over time rather than dispersing further along the coast. Given the long half-life of diuron, which is set to 40 days in the hydrodynamic model based on scenario sensitivity analysis with the marine monitoring data (Skerratt et al. 2023), an accumulation of 50 days of exposure in some areas is not surprising.

Exposure patterns presented in Figure 46 represent the average percent of species affected over a six-month exposure window, which is considered a chronic level of exposure. However, our knowledge of the temporal dynamics of pesticide concentrations would suggest that higher, acute levels of exposure are also likely to occur in these inshore habitats (Negri et al. 2024 and references within). Indeed, the passive sampler monitoring demonstrates maximum (~ monthly time-integrated) concentrations do exceed those represented in Figure 45, reaching up to 14 and 18% species affected from diuron exposure alone (0.58 and 0.778 $\mu\text{g L}^{-1}$ of diuron, respectively) at Round Top Island (Appendix 4). These results demonstrate that some inshore marine ecosystems have chronic levels of exposure to diuron above threshold levels along with more acute¹⁴ periods of much higher concentrations. When considering all pesticides together, the number of days above threshold levels are likely to be longer as diuron contributes only a portion of the total pesticide risk. For example, passive samplers deployed at Round Top Island estimated 34% of species affected from 15 pesticides, with diuron contributing approximately half (Appendix 4).

The marine modelling indicates some year-to-year variations in exposure, but the general trends and hot spots remain the same (Figure 45 and Figure 46). The main variations indicate a larger area exposed to diuron off the coast from the Pioneer and Plane basins in 2017–2018 compared to the previous year, whereas the spatial exposure area adjacent to the Herbert River was higher in 2016–2017. These trends are also reflected in the end-of-catchment monitoring (Figure 45) where Pioneer and Sandy catchments show a higher % species affected in 2017–2018 compared with 2016–2017, and this difference is less pronounced for the Proserpine and O'Connell rivers. Conversely, the end-of-catchment % species affected for diuron in the Herbert River was higher in 2016–2017 than 2017–2018. Figure 45 also demonstrates that diuron has continued to present a risk (>1% species affected) in the years beyond what the hydrodynamic modelling has been able to demonstrate to date, highlighting the need for the hydrodynamic model to continue to expand its temporal coverage of pesticide exposure. In addition to this, recent long-term (14 years) trend analysis has indicated a significant increase in PSII herbicides at a number of the fixed marine monitoring sites (Taucare et al. 2022).

¹⁴ In ecotoxicology, acute and chronic exposure periods are based on the life cycle of an organism and therefore vary depending on the organism. As an example, the chronic period for assessing the toxicity of a pesticide on a phototrophic species is ≥ 72 hours (for microalgae) to ≥ 7 days (for macrophytes), with acute periods being any time less than that. Thus, the ~monthly time-integrated concentrations of passive samplers would be considered representative of chronic levels of exposure. Assessing acute peaks in diuron concentrations using the hydrodynamic modelling is not as reliable at this stage of its development and therefore has not been included as part of this assessment.

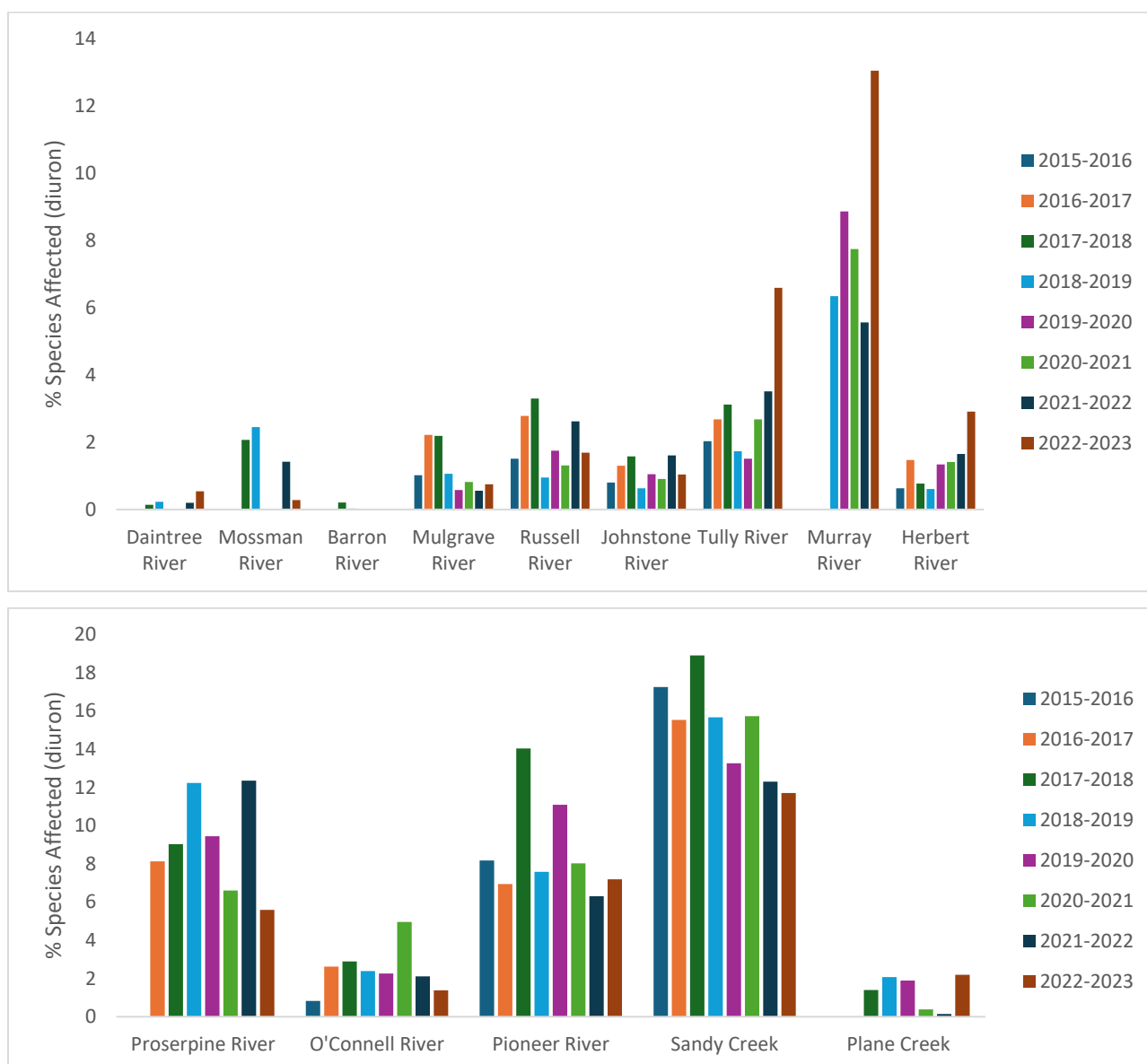


Figure 45. Average percent species affected by diuron over each wet season from 2015–2023 (estimated using the Pesticide Risk Metric). Estimates are based on monitoring data collected at the end-of-catchments for Wet Tropics (top) and Mackay Whitsunday (bottom) catchments.

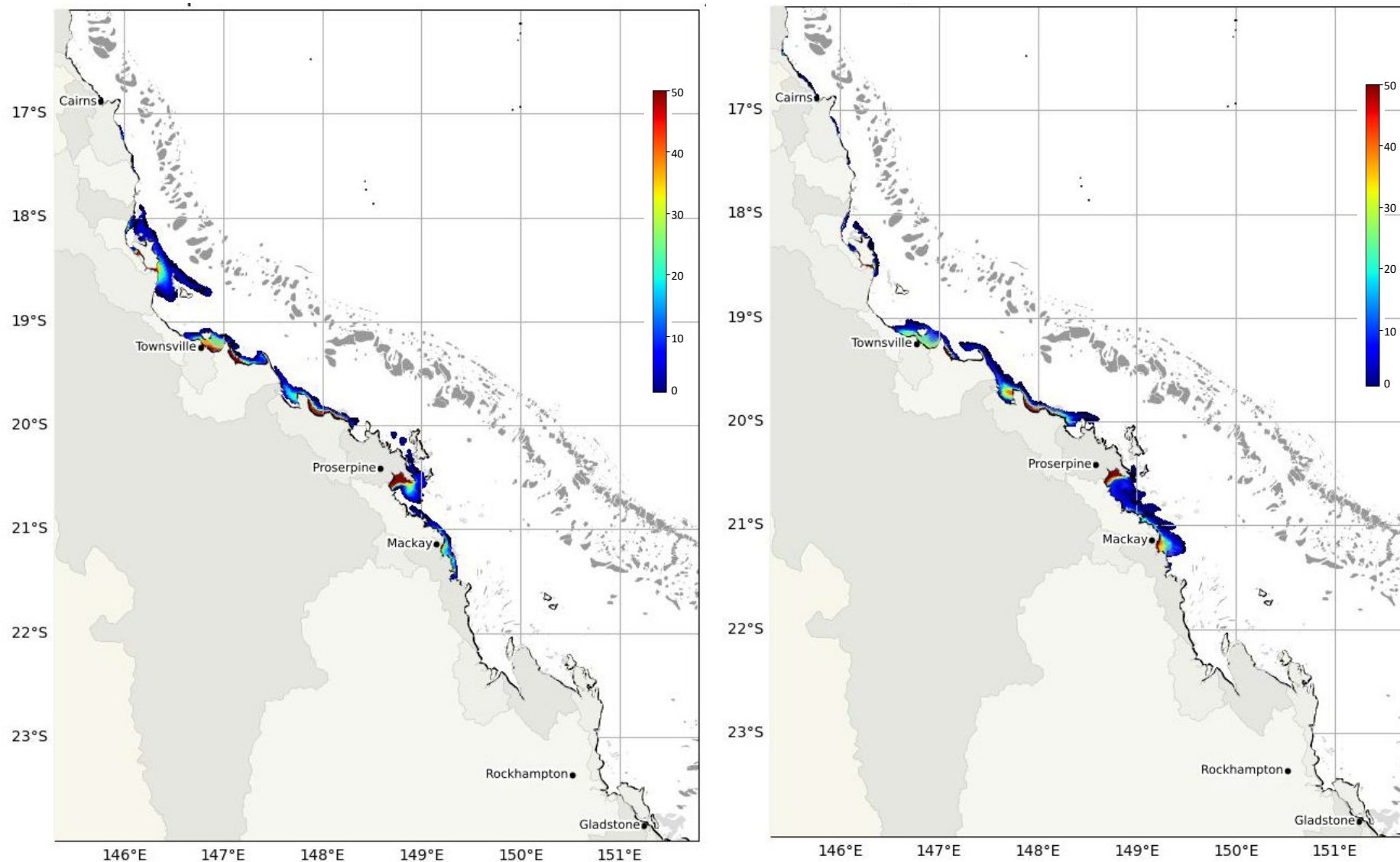


Figure 46. Number of days during the wet season that areas are exposed to concentrations of diuron that exceed the 1% species affected threshold in 2016–2017 (left) and 2017–2018 (right). Colours represent the number of days over the wet seasons starting on the 15th of October (2016, 2017) and finishing on 15 April (2017, 2018).

Ecological risk

Ecological risk of pesticides is determined by spatial and temporal exposure patterns, as well as the magnitude of pesticide concentrations, mode of action and organism sensitivity. While Skerratt et al. (2023) previously compared modelled diuron concentrations to ecological thresholds, a more nuanced approach was taken here by expressing risk as percent species affected. This helps to quantify the magnitude of impact above threshold levels, while accounting for temporal exposure (i.e. the average over the wet season) and species sensitivity (Warne et al. 2020). Converting diuron concentrations to percent species affected enables direct comparisons with other pesticides on a common risk scale, allowing comparisons with other lines of evidence and gauging how much the risk might be underestimated when focusing just on diuron. End-of-catchment monitoring indicates that diuron typically contributes 30–40% of the total percent species affected, suggesting the marine modelling could underestimate total pesticide risk by 60–70% on average (Figure 27). There is substantial variation across catchments of this underestimation (error bars Figure 27), with diuron contributing more than 70% in some locations and much less in others (Appendix 4: Table 18). Additionally, different pesticide half-lives may alter their spatial and temporal accumulation patterns in marine habitats. These variations highlight the importance of considering full pesticide mixtures when assessing ecological risk to inshore marine ecosystems.

Repulse Bay provides a good case study for examining pesticide risk through multiple lines of evidence (modelling, plus end-of-catchment and marine monitoring). The bay receives discharge from the Proserpine and O’Connell rivers, with additional influence from the Pioneer and Plane basins (Appendix 4: Table 18). Passive samplers have been deployed in Repulse Bay (south of the O’Connell River) as one of the Marine Monitoring Program’s fixed monitoring sites. A seagrass habitat is located on the northeastern side of the bay and south of the O’Connell River. End-of-catchment monitoring detected all 22 pesticides included in the Pesticide Risk Metric between 2016–2018 (Water Quality & Investigations 2024b), while passive samplers detected 17 of those 22 pesticides. The pesticides included diuron, 8 other PSII inhibiting herbicides, other herbicides and insecticides (including imidacloprid). Total percent species affected was estimated as 27% and 29.4% for Proserpine River and 12.4% and 7.9% for O’Connell River for the 2016–2017 and 2017–2018 wet seasons, respectively (Appendix 4: Table 18), with diuron contributing between 21–37% of this risk. Unfortunately, the passive sampler deployments were incomplete over these wet seasons with sampler deployments missing key periods of discharge over the wet season, making our comparisons of total PAF and diuron contributions with this dataset difficult (and also highlighting one of the issues with monitoring in the inshore marine areas; Gallen et al. 2019). The marine model estimated wet season average diuron exposure at 5.8% and 1.9% species affected for 2016–2018 in Repulse Bay.

The Repulse Bay example reveals not only an underestimation of risk in these marine habitats from the marine modelling but also demonstrates the potential for impacts on diverse organisms given the mixtures of pesticides discharging to these ecosystems. Herbicides, in general, dominate the catchment risk profiles, with various modes of action directly targeting different physiological pathways in phototrophs. PSII inhibiting herbicides (like diuron) have well-documented effects on the photosynthesis in marine phototrophs, including phytoplankton, seagrass and corals (Negri et al. 2024). The ecological impacts of other herbicide types are less well studied, but based on their modes of action that target other functions of phototrophic species (e.g. growth hormones), they can contribute to a combined impact on phototrophs and exert their toxic impacts in different ways (e.g. affecting different species to different degrees and their speed of recovery). Additionally, the presence of insecticides such as imidacloprid and chlorpyrifos introduces entirely different risks, with documented effects on marine invertebrates (see Negri et al. 2024 and references therein). The complex mixture of these pesticides, along with other water quality pollutants and stressors (e.g. heat stress), likely creates ecological consequences more severe and widespread than what is predicted here. For instance, sub lethal and indirect impacts are possible for other organisms such as fish, including metabolic impacts and endocrine disruption. Sublethal impacts causing stress on an organism could affect their resilience to other co-occurring stressors such as other water quality pollutants (Hook et al. 2023). In addition, a moderate sediment exposure from the O’Connell and Pioneer rivers (Table 17) indicates there is potential for additive or synergistic impacts from photosystem II inhibiting herbicides (e.g. diuron).

combined with the shading effects from sediment on phototrophic species (Negri et al. 2020; King et al. 2022).

Pesticide exposure assessment for Management Response

Given the spatial and temporal limitations in assessing pesticide exposure to marine ecosystems, a multi-evidence approach was used to inform management responses. Three complementary lines of evidence have been considered: end-of-catchment monitoring data, basin-level risk assessments, and marine modelling case studies.

End-of-catchment monitoring data provides the most robust primary evidence, capturing contributions from up to 22 pesticides that account for the majority of pesticide risk (Spilsbury et al. 2020), with temporal coverage of up to eight years for some catchments¹⁵. This data offers a comprehensive view of what is observed being transported to the marine environment from monitored areas.

Basin-level risk assessments complement the monitoring data by accounting for areas not captured at monitoring sites, particularly downstream land uses that may contribute additional pesticide inputs. These data help address spatial gaps in the monitoring network and provide a more complete picture of risk across the entire basin, which is particularly important where:

- Monitoring sites are located further upstream, missing downstream contributions (e.g. Herbert).
- Additional land uses exist that are not represented in the monitored catchment.
- Land use proportions differ substantially between the monitored catchment and the broader basin.

Marine modelling provides a spatial visualisation of pesticide dispersion and fate in the marine environment, showing how catchment-derived pesticides affect marine ecosystems. While more limited in temporal coverage and pesticide types, these studies offer valuable insights into exposure patterns beyond the river mouth.

When comparing these lines of evidence, there was general alignment in patterns of risk, though with some notable exceptions. For example, the percent species affected estimated for diuron at the end-of-catchments (Figure 47) showed similar patterns to marine modelling hotspots in most areas (Table 18). A notable exception to this was that the marine model indicated a diuron hotspot from Herbert River discharge, however, the end-of-catchment data indicated low risk at the end-of-catchment. This discrepancy is potentially resolved through the basin-level assessment, which indicated there is likely a higher risk from pesticides once agricultural land uses downstream of the monitoring site were accounted for (Table 10). In another example, the marine modelling indicated Repulse Bay as a hotspot for diuron, with seagrass and inshore coral ecosystems exposed to discharge from the Proserpine and O'Connell rivers. For both rivers, the end-of-catchment and basin level risk did not match completely; the Proserpine had very high risk at the end-of-catchment but only moderate risk at the basin level, while the O'Connell showed moderate risk at the end-of-catchment but high risk at the basin level. For the O'Connell, this discrepancy was attributed to a greater proportion of sugarcane land use at the basin scale (13%) compared to the monitored area (6%).

¹⁵ The temporal coverage of pesticides in GBR catchments covers more years than what is presented in this report for some catchments, the earliest monitoring occurring in 2009 up to the most recent wet season as monitoring is ongoing.

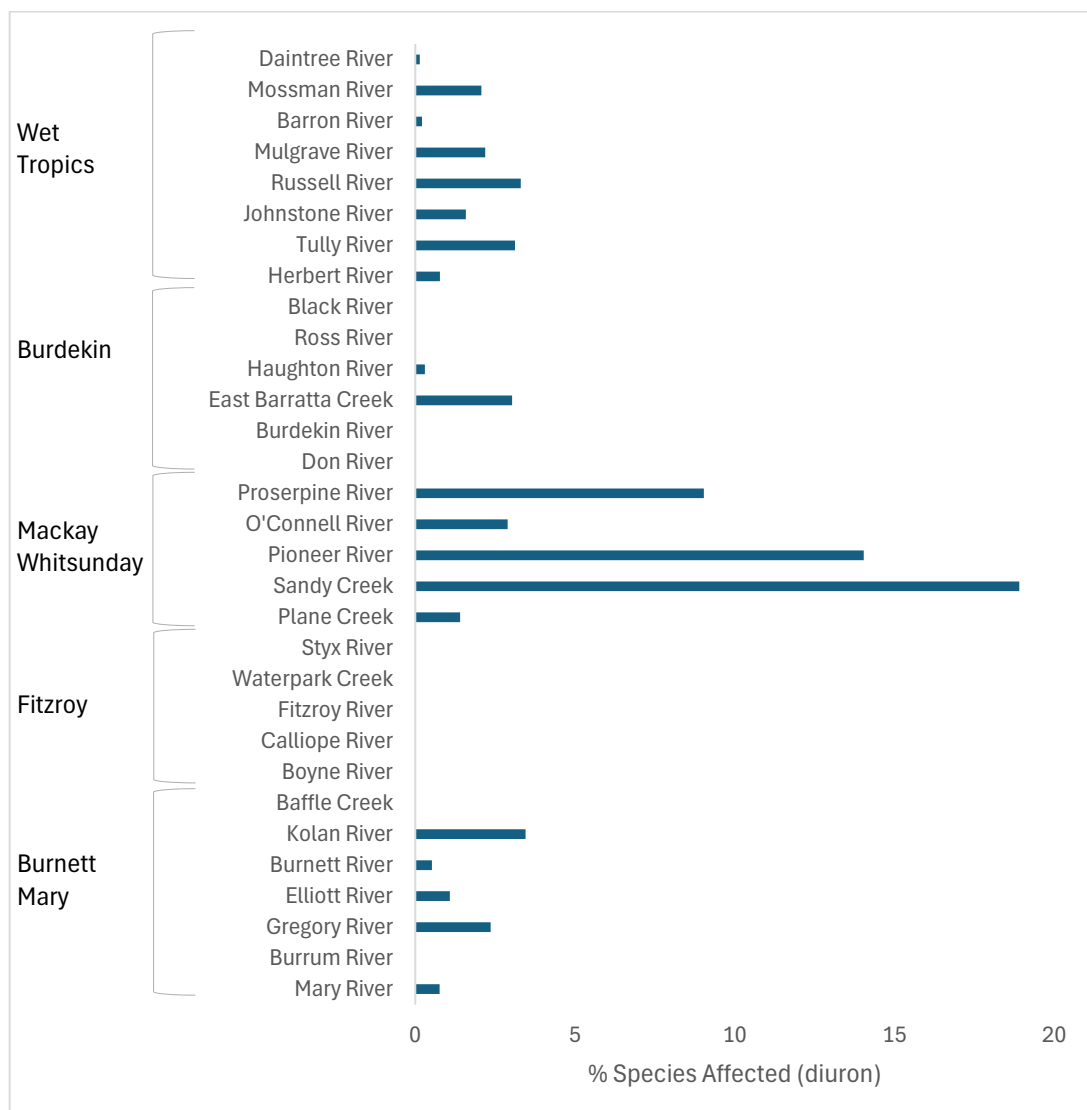


Figure 47. Percent species affected from diuron (as estimated using the Pesticide Risk Metric) at end-of-catchments for the 2017–2018 wet season.

For determining pesticide exposure levels for the Management Response Framework, the end-of-catchment monitoring data was used as a basis and confirmed or adjusted using evidence from the basin-level risk assessments, the marine modelling trends and, when required, other evidence such as land use proportions (e.g. Appendix 4 and Warne et al. 2020). The results are presented in Table 19.

The pesticide risk levels were converted from the five-point grading system (Table 5) to the four-point grading system used to describe the pollutant exposure levels for the Management Response Framework:

Management response exposure	Equivalent pesticide risk	Equivalent % species affected
Minimal	The pesticide risk is Very Low on average	The yearly (wet season) average % species affected is $\leq 1\%$ for all years monitored.
Low	The pesticide risk is Low on average for all years monitored	The yearly (wet season) average % species affected is between 1 and 5% species affected
Moderate	The pesticide risk is Moderate on average for all years monitored	The yearly (wet season) average % species affected is between 5 and 10% species affected
High	The pesticide risk is High or Very High on average for all years monitored	The yearly (wet season) average % species affected is $>10\%$ species affected.

Table 19. Evidence and reasoning for the assigning of pesticide exposure levels for the Management Response Decision Support Framework. Land uses with the potential for higher pesticide risk ('higher-risk land uses') include sugarcane, bananas, horticulture, dryland & irrigated cropping.

Region	Catchment/ Basin	End-of- catchment risk level (Table 6)	Basin risk level ^A	Flood plume source of marine diuron hotspots (Table 18)	Exposure level (Management response framework)	Reasoning
Cape York	Jacky Jacky	No Data	Very Low		Minimal	Only basin value available
	Olive-Pascoe	No Data	Very Low		Minimal	Only basin value available
	Lockhart	No Data	Very Low		Minimal	Only basin value available
	Stewart	No Data	Very Low		Minimal	Only basin value available
	Normanby	Very Low	Very Low		Minimal	Evidence aligns
	Jeannie	No Data	Very Low		Minimal	Only basin value available
	Endeavour	No Data	Very Low		Minimal	Only basin value available
Wet Tropics	Daintree	Very Low	Very Low		Minimal	Evidence aligns
	Mossman	Low	Moderate		Low	Catchment value was used as the basin has a smaller proportion of higher-risk land uses than the catchment.
	Barron	Very Low	Very Low		Minimal	Evidence aligns
	Mulgrave	Low	Moderate		Moderate	Basin value was used as there are areas of land use missed in monitored area ^A and proportions of higher-risk land uses in the basin is around mid-level (12.8%). ^B
	Russell	Low				
	Johnstone	Low	Moderate		Moderate	Basin value was used as there is a higher proportion of higher-risk land uses in basin ^B .
	Tully	Moderate	Moderate		Moderate	Catchment and basin evidence aligns
	Murray	High	Moderate		High	Catchment value was used as there is lower confidence in basin-level estimate ^C , and this basin has the third highest proportion of sugarcane of all the basins. ^B
	Herbert	Low	Moderate	Yes	Moderate	Basin estimate was used as there is land use missed below monitoring site ^A , and it is a potential source of a marine hotspot
Burdekin	Black	Very Low	Very Low		Minimal	Evidence aligns
	Ross	Very Low	Low		Minimal	Catchment value used as there is lower confidence in basin-level estimate ^C and very low proportion of higher risk land uses. ^B
	Haughton	Low	High	Yes	High	Barratta Creek estimate was used as it aligns with basin level estimate, the basin has a relatively large proportion (17%) of higher-risk land use (relative to all other basins) ^B and there is a potential marine hotspot.
	Barratta	High		Yes		
	Burdekin	Low	Very Low		Low	Catchment value was used as the Burdekin has the second largest spatial area of land uses with higher pesticide risk relative to all other basins. ^B

Region	Catchment/ Basin	End-of- catchment risk level (Table 6)	Basin risk level ^A	Flood plume source of marine diuron hotspots (Table 18)	Exposure level (Management response framework)	Reasoning
	Don	Low	Very Low	Yes	Low	Catchment value was used as a conservatory approach as the marine modelling results indicate a potential hotspot and exposure of large seagrass areas.
Mackay Whitsunday	Proserpine	Very High	Moderate	Yes	High	Catchment value was used as a conservatory approach as it is a source of a potential marine hot spot.
	O'Connell	Moderate	High	Yes	High	Basin value was used as there is a greater proportion of sugarcane land use at basin scale (13%) compared to the monitored area (6%) ^{AB} , and a source of a potential marine hotspot.
	Pioneer	High	Very High	Yes	High	Evidence aligns
	Sandy	Very High	Very High	Yes	High	Sandy Creek value was used as it aligns with basin level estimate, the basin has the largest proportion of higher risk land use (relative to all other basins) ^B and a source of a potential marine hotspot.
	Plane	Moderate				
Fitzroy	Styx	Very Low	Very Low		Minimal	Evidence aligns
	Shoalwater	No data	Very Low		Minimal	Basin value was used as no monitoring data was available for this basin ^C .
	Waterpark Creek	Very Low	Very Low		Minimal	Evidence aligns
	Fitzroy	Low	Low		Low	Evidence aligns
	Calliope	Very Low	Low		Minimal	Catchment value was used as there is lower confidence in basin-level estimate ^C and very low proportion of higher-risk land uses. ^B
	Boyne	Very Low	Very Low		Minimal	Evidence aligns
Burnett Mary	Baffle	Very Low	Very Low		Minimal	Evidence aligns
	Kolan	Low	Low		Low	Evidence aligns
	Burnett	Low	Low		Low	Evidence aligns
	Gregory	Low	Moderate		Moderate	Basin value was used as there are areas of land use missed in monitored area ^A and the proportions of higher-risk land use is around mid-level (10.42%). ^B Note - the estimate for pesticide risk may increase in this region with inclusion of more horticulture-relevant pesticides in the expansion of the pesticide risk metric.
	Elliott	Low				
	Burrum	Low				
	Mary	Low	Low		Low	Evidence aligns

^A Warne et al. 2020; ^B Appendix 4; ^C Monitoring data was not available for this catchment at the time when land use relationships were developed (Warne et al. 2020).

4.2.4 Other pollutants

In addition to nutrients, sediments, and pesticides, numerous other pollutants can enter GBR waterways and potentially impact GBR ecosystems. These 'other pollutants' include metals, persistent organic pollutants (POPs), per- and poly-fluoroalkyl substances (PFAS), plastics, pharmaceutical and veterinary products (PVPs), coal and fly ash, and sunscreens. These pollutants were not included in the formal spatial prioritisation assessment due to significant data limitations. Available evidence for marine and coastal ecosystems is largely constrained to specific locations, particularly near industrialised and urban centres. The following information has been summarised from the 2022 SCS Question 6.1 on other pollutants (Chariton and Hejl 2024).

Most studies have focused on a few areas including Port Curtis (Gladstone), Townsville, Cairns and Mackay. Routine monitoring programs for these pollutants in the GBR is limited, with the exception of some monitoring as part of the Regional Report Cards (e.g. Gladstone, NQ Dry Tropics and Mackay Whitsunday) (Chariton and Hejl 2024). This limited spatial coverage and lack of temporal data constrains the ability to assess the distribution, concentration trends and ecological risks of these contaminants.

From the information available, elevated concentrations of metals have been recorded in waters and sediments adjacent to industrialised areas. For example, copper concentrations above guideline values have been recorded in parts of the Fitzroy basin associated with legacy mining, mercury has been reported around the Tully catchment associated with sugarcane, while aluminium and zinc from acid sulphate soils in Trinity Bay (Cairns) significantly exceed guideline values. Elevated concentrations of manganese and nickel in Port Curtis, copper, nickel and zinc in Townsville Harbour and cadmium from acid sulphate soils in Trinity Bay have been recorded in sediments. Although limited data exists, there is evidence that biota found inshore (e.g. turtles, seagrass, corals, algae) accumulate higher concentrations of metals than offshore organisms, for example metal concentrations are higher in crabs from catchments with operational and legacy mines (e.g. Normanby and Fitzroy).

POPs are associated with industrial activities, oil spills, coal and urbanisation. POPs are detectable in GBR sediments, typically below guideline values, and generally decrease across an inshore to offshore gradient. Experimental studies indicate POPs can affect fish physiology behaviour, coral reproduction and trophic food webs, though the extent of these impacts in the field remains unclear.

Microplastics and fibres are widespread throughout GBR coastal and marine environments. In coastal locations, their presence is influenced by surrounding land use, river and stormwater inputs. Plastics have been documented in a wide variety of marine organisms including plankton, fish, birds and turtles, with ecological risks varying by species, feeding behaviour, and life stage.

There is insufficient data to assess the spatial and temporal patterns of PFAS, pharmaceutical and veterinary products, coal dust and sunscreens in the GBR. The limited evidence suggests that PVPs are more concentrated near wastewater overflows and stormwater discharges, while polycyclic aromatic hydrocarbons (PAHs) derived from coal have been detected in coastal sites near Hay Point (Mackay). As the threat of these 'other pollutants' is likely to increase with increasing population, it was highlighted in the 2022 SCS as a priority area for future monitoring programs in the GBR and its catchments (Waterhouse et al. 2024b).

5. Ecosystem condition

The Paddock to Reef program results were the primary source of data for assessing **ecosystem condition** for freshwater and marine ecosystems in the River Footprints and management units. Table 20 aids to specify the components of those ecosystems and the end-points or metrics relevant for assessing the influence of water quality on their condition.

Table 20. The components of the ecosystems and the metrics relevant to assessing condition and water quality exposure on these values.

Domain	Ecosystem	Ecosystem Components	End-point/metric
Freshwater	Floodplain wetlands	Floodplain palustrine and lacustrine wetlands in the GBR catchment area	Wetland Condition Monitoring Program pressure and state indicators (Johns et al. 2022; Sutcliffe et al. 2022) <i>See Table 21 for full list</i>
Marine	Coral	Inshore and midshelf coral reef habitats in the GBR World Heritage Area	MMP Coral Index (Thompson et al. 2024) <i>Coral cover, juveniles, macroalgae, cover change, composition</i>
Marine	Seagrass	Intertidal seagrass meadows and deepwater seagrass meadows in the GBR World Heritage Area and Hervey Bay/Great Sandy Straits	MMP Seagrass Index (McKenzie et al. 2024b) <i>Abundance, resilience</i>

5.1 Links between poor water quality and ecosystem condition

Links between water quality, pollutants and ecosystem processes and condition were summarised briefly in Section 4 as an introduction to the exposure assessments. The sensitivity of corals and seagrass to degraded water quality is documented in the 2022 SCS for sediments (Collier et al. 2024), nutrients (Diaz-Pulido et al. 2024) and pesticides (Negri et al. 2024). There was limited direct evidence about the impacts of pollutants on GBR wetland ecosystems, so the information below was drawn from DES (2023e).

In summary:

- While the 2022 SCS concluded that ‘There is limited evidence of the impact of dissolved inorganic nutrients on GBR wetland ecosystems’ (Diaz-Pulido et al. 2024), impacts of nutrient contamination on wetland environmental values were reviewed as part of the design of the Wetland Condition Monitoring Program (DES 2023e). The main ecological responses to nutrients in the systems included in the P2R Wetland Condition Monitoring Program are increased plant production, weed infestation, increased hypoxia and plankton blooms (Pearson et al. 2013; Davis et al. 2017). Weed infestations typically make minor contributions to aquatic food webs despite their high biomass and starve the productive bed of light and prevent reoxygenation of the water column (Verhoeven et al. 2006). Flow on effects to fauna include decreased macroinvertebrate and fish diversity (Arthington et al. 2015; Adame et al. 2019). As nutrient loads persist and increase, wetland systems can tip from stable states with low turbidity and abundant submerged macrophytes to eutrophic, turbid states with prolonged phytoplankton dominance. However, Pearson et al. (2010), in a Wet Tropics case study, highlight the complexity of predicting the impacts of land use generated contaminants on freshwater systems and biota. For example, hypoxia from nutrient contamination may not occur if the water is turbid enough from sediment inputs to limit phytoplankton growth.
- Excessive amounts of dissolved inorganic nutrients can have detrimental effects on GBR ecosystems. In coral reefs, the most severe impacts may be indirect, for instance, excess nutrient availability on inshore reefs is generally (but not always) positively correlated with increased fleshy macroalgal

abundance which can reduce coral settlement and recruitment, outcompete corals, reduce coral cover and negatively affect coral calcification. Excess nutrients might also contribute to coral-eating crown-of-thorns starfish outbreaks (see below). Direct effects of elevated nutrients include reduced coral calcification, negative impacts on coral reproduction, and potentially reducing thermal tolerance to bleaching. (Source: Diaz-Pulido et al. 2024).

- There is no clear evidence of direct negative impacts of increased dissolved inorganic nutrients on seagrass ecosystems, and although elevated nutrients may be beneficial for mangrove growth, they can interact with climate stressors such as drought (low rainfall and low humidity) causing mangrove decline. (Source: Diaz-Pulido et al. 2024).
- During high river discharge events, elevated nutrient levels cause phytoplankton blooms that sometimes coincide with developing crown-of-thorns starfish larvae. These blooms increase the amount of food available for larvae which can increase survival, growth, and development rates, though it has not yet been shown that crown-of-thorns starfish outbreaks are limited by larval supply. Crown-of-thorns starfish outbreaks in the GBR typically start on midshelf reefs between Cairns and Lizard Island – the crown-of-thorns starfish ‘initiation area’, which occasionally receives nutrient-enriched flood plumes from rivers. Although land-based nutrient runoff may contribute to outbreaks, other factors such as marine upwelling, life history traits including high fecundity, and the effect of predator removal (e.g. fishing, shell collecting) may also be important. Combining evidence from these different factors will contribute to a more complete understanding about when, where and how population outbreaks will occur. (Source: Caballes et al. 2024).
- Increased sediment loads to wetlands have several impacts including a reduction of available light, increased nutrient and contaminant loads and alterations to the soil substrate. Sediments that flow into wetlands can transform the structure of sites from being topographically heterogeneous into flatter plains that support reduced biodiversity and encourage weeds (Zedler and Kercher 2004). Sediment loads entering wetlands can have substantial impacts on the growth and abundance of vegetation within wetlands. For example, Reid et al. (2007) note that an increase in nutrient levels and change in transparency and substrate would likely have resulted in aquatic plant loss on a large scale in billabongs of the Murray-Darling River system.
- Increases in the loads of fine sediments and particulate nutrients affect the quantity and quality of light (i.e. modified light spectrum towards ‘less usable’ light) reaching coral reefs, seagrass and other benthic organisms and can influence the behaviour and condition of animals including fish, particularly in inshore areas. This has resulted in persistent impacts on reef composition (including changes in the abundance and diversity of species at different depths, and increases in macroalgal growth), and variability in the distribution, abundance and composition of seagrass meadows. These direct effects can result in indirect effects on other taxa including seagrass-dependent dugong which can extend across the whole GBR. The greatest impacts of fine sediments and particulate nutrients occur in the inshore central and southern GBR (Wet Tropics to Burnett Mary Natural Resource Management regions). (Source: Collier et al. 2024).
- Sedimentation, the settling of sediments and particulate nutrients onto surfaces, can have negative direct effects on a variety of taxa including corals, causing tissue damage, reducing growth rates and altering microbial communities. Importantly, settled and suspended particulate matter can suppress recovery from other disturbance events (e.g. heatwaves, cyclones) and affect recruitment and early life stages of corals and fishes. (Source: Collier et al. 2024).
- Pesticides are designed to control agricultural pest species, and virtually all tested pesticides are potentially harmful to non-target aquatic species of the GBR region. For example, photosystem II herbicides consistently impact all photosynthetic marine organisms of the GBR that have been tested, including corals and seagrass. Other simultaneous pressures, including heatwave conditions and variation in light were shown to increase the sensitivity of GBR species to pesticides, indicating that guideline values applied under some conditions in the field are likely to underestimate the risk to aquatic ecosystems. (Source: Negri et al. 2024).

It is outside the scope of this assessment to analyse the consequence of pollutant exposure in the context of all of the factors outlined above, and for many factors there are limited quantified data to complete the assessment.

5.2 Freshwater (floodplain) wetland condition

5.2.1 Method

The GBR Wetland Condition Monitoring Program has been reporting on the condition of natural, freshwater wetlands found in major aggregations on floodplains within the GBR catchment area since 2016 (Wetland Condition Monitoring Team 2024). ‘Natural’ freshwater wetlands are those areas that existed as freshwater wetlands before European occupation in Australia and that still meet the definition of wetlands in Queensland-wide wetland mapping (Tilden and Vandergragt 2022). The program uses an augmented, serially alternating panel design whereby a subset of wetlands is monitored every year, while other subsets of wetlands are monitored on a rotational basis every four years. Wetland condition, the overarching term used to describe the pressures on and the state of wetland environmental values, is assessed annually using a suite of pressure and state indicators (Table 21, Tilden and Vandergragt 2022; Tilden et al. 2023). Indicators can attain scores from 1 to 5, where 1 indicates the score that would have been achieved prior to impacts associated with European settlement. Scores of 5 represent levels of state and anthropogenic pressure most removed from the pre-European settlement condition (Johns et al. 2022; Sutcliffe et al. 2022). Composite indices, which represent different types of pressure (e.g. pollutant inputs) and state (e.g. biotic integrity), are then calculated from suites of individual indicators. Break points are used to classify condition as follows: index scores < 1.5 are considered indicative of very low pressure or very good state; scores ≥ 1.5 but < 2.5 as low pressure or good state; scores ≥ 2.5 but < 3.5 as moderate pressure or state; scores ≥ 3.5 but < 4.5 as high pressure or poor condition; and scores ≥ 4.5 as very high pressure or very poor state.

Table 21. GBR Wetland Condition Monitoring Program uses a suite of 24 indicators to monitor the condition of natural, freshwater floodplain wetlands in the GBR catchment area. Type: D, desktop; F, field; FV, field verified. WL, wetland.

Indicator	Description	Type	Area of interest
P1	Land use associated with the introduction or perpetuation of pest plant and/or animal species	D	WL & 1 km buffer
P7	Wetland pest plant cover	F	WL
P8	Wetland pest plant cover	F	200 m buffer
P2	Modification of native vegetation	D, FV	200 m buffer
P20	Native vegetation cleared	D	WL & 5 km buffer
P21	Loss of wetland regional ecosystems	D	WL & 5 km buffer
P14	Altered surface water flow due to vegetation cleared	D	1 km buffer
P16	Change in landscape hydrological integrity	D	WL & 1 km buffer
P19	Water abstraction, or consumption by livestock or feral animals	F	WL & 200 m buffer
P3	Land use associated with pesticide residue inputs	D	WL & 1 km buffer
P4	Land use associated with nutrient inputs	D	WL & 1 km buffer
P5	Number of septic systems per hectare of mapped wetland	D	WL & 200 m buffer
P10	Sediment supply (modelled)	D, FV	WL & 1 km buffer
P12	Number of stormwater or other point inflows per hectare of wetland	F	WL & 200 m buffer
S1	Floristic composition and vegetation structure	F	WL & 200 m buffer
S3	Exotic plant cover	F	WL & 200 m buffer

Indicator	Description	Type	Area of interest
S7	Direct disturbance by humans, livestock or feral animals physically impacting soil	F	WL & 200 m buffer
S8	Soil surface deformation from ungulates	F	WL
S9	Drainage modifications and artificial structures altering natural surface flows	F	WL & 200 m buffer
S12	Hydrological modifier code	D, FV	WL
S15	Modified and artificial wetlands	D	1 km buffer
S16	Altered surface flow due to linear transport infrastructure	D	WL & 1 km buffer
S13	Landscape vegetation connectivity	D	WL & 32 km buffer
S14	Native vegetation	D, FV	200 m buffer

For this report, indicator scores from the program were used to estimate wetland condition in management units (specifically, in the monitored wetland aggregations within management units), using each wetland's most recent survey data. For example, if a wetland was surveyed in 2020 and then again in 2024, the 2024 data alone was included for that wetland in the analysis. This ensured all wetlands were singly and equally represented in the condition assessment (one data point per indicator per wetland) and that sample sizes per management unit remained as large as possible. Twenty seven of the 48 management units contained at least one wetland monitored at least once as part of the GBR Wetland Condition Monitoring Program. As such, wetland condition was only assessed for those management units.

For each management unit containing at least one monitored wetland, the mean score for each indicator was calculated. The resulting data were used to estimate an overall condition (poor, moderate or good) for each management unit, as informed by the index score break points used by the wetland monitoring program. For each management unit, the stepwise decision process was as follows:

- (1) if $\geq 40\%$ of indicators had a mean score < 2.5 , AND $\leq 10\%$ of indicators had a mean score ≥ 3.5 , then wetland condition was considered good (unless one or more indicators had a mean score of 5.0, then wetland condition was considered moderate);
- (2) otherwise, if $\geq 40\%$ indicators had a mean score < 2.5 , AND $> 10\%$ but $\leq 20\%$ of indicators had a mean score ≥ 3.5 , then wetland condition was considered moderate (unless one or more indicators had a mean score of 5.0, then wetland condition was considered poor);
- (3) otherwise, if $\geq 40\%$ indicators had a mean score ≥ 2.6 but < 3.5 , AND $\leq 20\%$ of indicators had score ≥ 3.5 , then wetland condition was considered moderate (unless one or more indicators had a mean score of 5.0, then wetland condition was considered poor);
- (4) otherwise, if $\geq 40\%$ indicators had a mean score ≥ 3.5 , then wetland condition was considered poor;
- (5) otherwise, if $> 20\%$ indicators had a mean score ≥ 3.5 AND the proportion of indicators with mean scores ≥ 2.5 was greater than the proportion with mean scores < 3.5 , then wetland condition was considered poor;
- (6) otherwise, if $> 20\%$ indicators had a mean score ≥ 3.5 AND the proportion of indicators with mean scores < 3.5 was greater than or equal to the proportion with mean scores ≥ 2.5 , then wetland condition was considered moderate (unless one or more indicator had a mean score of 5.0, then wetland condition was considered poor).

The condition assessment can be considered conservative as it penalises for higher pressures and poorer states (i.e. higher indicator scores).

5.2.2 *Current freshwater (floodplain) wetland condition*

Out of the 27 management units with wetland aggregations that were assessed for condition based on mean indicator scores (Appendix 5: Table 20), wetlands in the aggregations located in four management units were in good condition, 12 in moderate condition and 11 in poor condition (Figure 48).

Wetlands located in the monitored aggregations in the Normanby, East Burdekin, Cape Campaspe and Burrum management units were all assessed as being in good condition. Those in the Mulgrave-Russell, Tully, Upper Herbert, Ross, Upper Burdekin, Don River, Waterpark Creek, Dawson, Isaac, Mackenzie, Baffle and Mary were assessed as being in moderate condition. Wetlands in the monitored aggregations in the Johnstone, Murray, Lower Herbert, Haughton, Burdekin Delta, Proserpine, Plane Creek, Lower Fitzroy, Nogoa and Burnett management units were assessed as being in poor condition. Wetlands in this latter group tended to score more poorly overall in terms of their indicator scores, particularly for indicators based on vegetation metrics, such as landscape vegetation connectivity and native vegetation clearing within 5 km of wetlands (Appendix 5: Table 20). A similar but less extreme tendency was observed in management units where wetlands in monitored aggregations were in moderate condition.

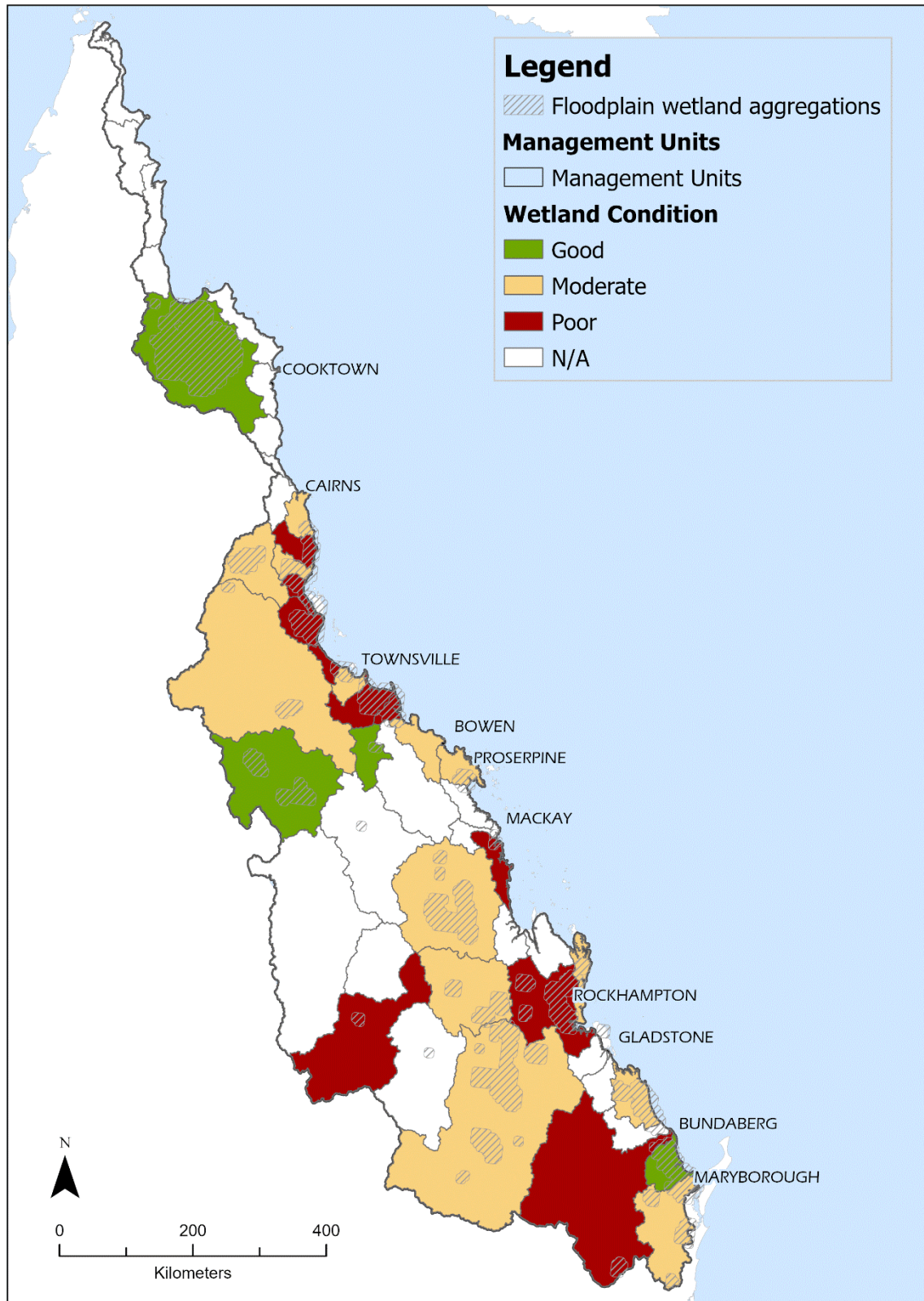


Figure 48. Freshwater wetland condition for aggregations within management units. Note that the condition assessment is based on analysis of data on wetlands in major aggregations monitored by the GBR Wetland Monitoring Program.

5.3 Marine condition

As described above, the scope of this assessment is not specifically limited to GBR coral reefs and seagrass ecosystems, however the ability to incorporate other ecosystems is limited by data availability, particularly at the necessary spatial scales.

The MMP has been assessing the condition of inshore coral reefs and seagrass since 2005. Condition is reported annually in conjunction with water quality data. The current status reported in the 2022–23 annual reports was used for this assessment, and the methods are fully described for coral reefs in Thompson et al. (2024) and seagrass in McKenzie et al. (2024b). Information from the 2022 SCS and GBR Outlook Report are referenced where appropriate.

5.3.1 Coral and seagrass distribution across the GBR

The extent and distribution of ecosystems in proximity to the River Footprints for each basin is variable across the GBR (Moran et al. 2022) and has an important influence on the results in this spatial prioritisation exercise. Figure 49 shows the regional distribution of coral reefs in the GBR for each marine NRM region, including the extent within each waterbody. This highlights that the area of coral reefs is by far the largest in the Cape York NRM region, followed by the Fitzroy, Mackay Whitsunday, Burdekin, Wet Tropics and Burnett Mary regions. The largest areas of coral reefs located in the inshore waterbody are in the Cape York and Mackay Whitsunday regions.

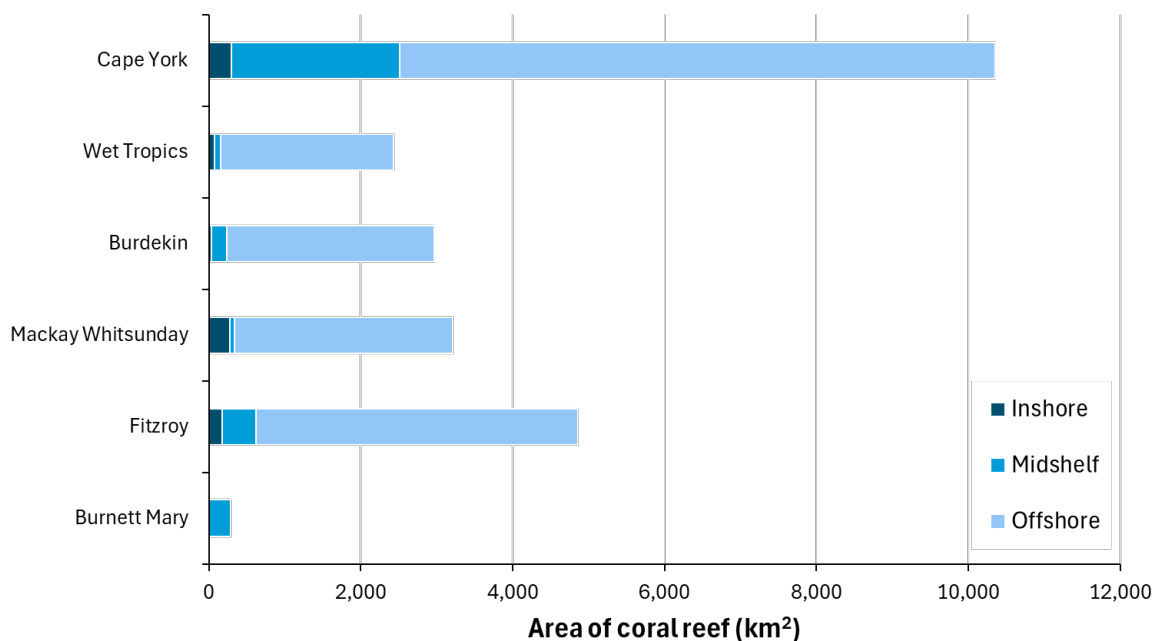


Figure 49. Coral reef area across the six NRMs of the GBR (Moran et al. 2022).

Figure 50 shows the regional distribution of seagrass meadows in the GBR for each marine NRM region, including the extent within each waterbody. Approximately 3,464 km² of inshore seagrass meadows have been mapped in the GBRWHA, and approximately 32,000 km² occur in deeper waters. Seagrass meadows provide shelter and nursery habitat for small fish, prawns, and other invertebrates, which provide food for both resident and migratory fish species, facilitating connectivity and productivity of fisheries. They can improve water clarity, stabilise sediments and reduce coastal erosion, and sequester carbon (Gribben et al. 2022). Deepwater meadows can support larger-bodied fish and invertebrates, although are not as productive as inshore meadows for fisheries resources. Seagrasses are an essential food source for dugongs and green turtles, which play critical roles in structuring and connecting seagrass meadows and are important for First Nation communities (GBRMPA 2024).

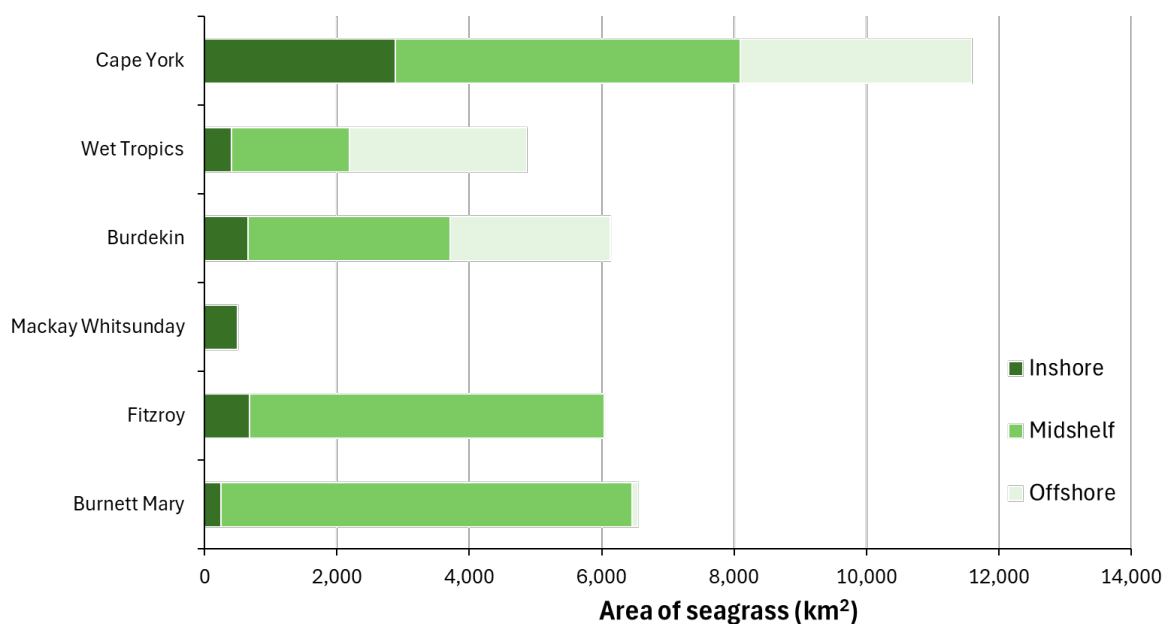


Figure 50. Seagrass area across the six NRMs of the GBR (Moran et al. 2022).

5.3.2 Current condition of GBR coral reefs and seagrass meadows

The 2022 SCS summarised the current (2021) status and trend of the MMP coral reef and seagrass condition data since 2017. The condition of GBR inshore coral reef ecosystems from the Wet Tropics to the Fitzroy region has declined marginally since 2017 and was categorised as ‘Poor’ condition in 2020 to 2021¹⁶ (based on a multi-indicator resilience index) with regional differences. Hard coral cover on shallow mid- and outer shelf reefs has increased overall since 2017, showing fast recovery from Cooktown to Bundaberg after experiencing losses from repeated mass coral bleaching and/or crown-of-thorns starfish between 2016 and 2019¹⁷.

Inshore seagrass meadows across the GBR declined from ‘Moderate’ abundance and resilience in 2017 to ‘Poor’ in 2020⁶, and while overall condition improved in 2021 (to Moderate), there were continuing declines in the Fitzroy and Burnett Mary regions. These declines were primarily a consequence of above-average discharges from some rivers and disturbance from tropical cyclones (McKenzie et al. 2024a).

The results for the most recently reported marine condition (2022–2023) are summarised in Table 22, with additional detail in Appendix 7. Further explanation and interpretation of the data is provided in the annual reports (McKenzie et al. 2024b, Thompson et al. 2024). Data is not collected as part of the MMP for coral reefs in the Cape York and Burnett Mary NRM regions. However, the AIMS Long Term Monitoring Program reports status for several midshelf and offshore locations in these regions. These are considered to be less relevant for this report. For the Burnett Mary region, information has been drawn from a recent assessment by Hillyer and Moss (2025) which summarises four years of coral monitoring data in the region.

For coral reefs, the Cape York condition information is low confidence for the inshore areas as a majority of the sites monitored are in midshelf and offshore areas. In these areas, hard coral cover has increased, and these areas are identified as being in good condition for the Management Response Assessment in Section 7. Coral reefs in the Wet Tropics and Burdekin regions are identified as being in moderate condition showing slight improvement since 2020–21, and those in the Mackay Whitsunday and Fitzroy remain in poor condition. The data for the Burnett Mary is low confidence as it assesses a limited set of indicators over a limited time, but indicates coral cover, while highly variable among reefs was regionally moderate from 2020 to 2022. The trend in the long-term datasets is variable for the Wet Tropics and Burdekin regions but shows

¹⁶ Reef Water Quality Report Card 2020

¹⁷ AIMS Long Term Monitoring Program

concerning patterns of a long period of poor condition in the Mackay Whitsunday and Fitzroy regions (Appendix 7: Table 24).

For seagrass meadows, the Cape York, Burdekin and Mackay Whitsunday regions have remained in moderate condition, while the Fitzroy and Burnett Mary regions remained in poor and very poor condition respectively. Seagrass condition in the Wet Tropics regions varies between good in the northern Wet Tropics (adjacent to the Daintree, Mossman and Barron basins) and poor in the southern Wet Tropics (adjacent to the Mulgrave-Russell, Johnstone, Tully, Murray and Herbert basins). The trend in the long-term datasets is variable for all regions except the Fitzroy which shows a long-term declining trend, and a similar pattern in the Burnett Mary region since 2018–19.

*Table 22. Summary of coral reef and seagrass condition results primarily from the Marine Monitoring Program (largely inshore areas) linked to river basins based on proximity to the river mouth and knowledge of the extent of river footprints. Refer to Appendix 7 for further detail and explanation. Sources: Coral reef condition - Thompson et al. (2024), Gladstone Healthy Harbour Partnership (2023), *based on coral cover only AIMS Long Term Monitoring Program, **based on Region score for coral cover only presented in Hillyer and Moss (2025); Seagrass - McKenzie et al. (2024b). The Lowest Score is based on the lowest score for either coral or seagrass linked to each basin. N/A = not assessed.*

Basin	Coral reef		Seagrass meadows		Lowest score
	Subregion	2022–23 Condition	Relevant site	2022–23 Condition	
Jacky Jacky		*Condition not reported Increase in hard coral cover 2017–2022	Shellburne Bay/Margaret Bay	Good	Mod
Olive Pascoe			Shellburne Bay	Good	Mod
Lockhart			Lloyd Bay	Good	Mod
Stewart			Cape York regional score	Mod	Mod
Normanby			Flinders Group/Bathurst Bay/St Stanley Island	Mod	Mod
Jeannie			Flinders Group/Bathurst Bay/St Stanley Island	Mod	Mod
Endeavour			Archer Point	Mod	Mod
Daintree	Barron-Daintree	Mod	Low Isles	Mod	Mod
Mossman	Barron-Daintree	Mod	Yule Point	Good	Mod
Barron	Barron-Daintree	Mod	Yule Point	Good	Mod
Mulgrave-Russell	Johnstone-Russell Mulgrave	Mod	Green Island	Mod	Poor
Johnstone	Johnstone-Russell Mulgrave	Mod	Green Island	Mod	Poor
Tully	Herbert-Tully	Mod	Mission Beach/Dunk Island/Missionary Bay	Poor	Poor
Murray	Herbert-Tully	Mod	Mission Beach/Dunk Island/Missionary Bay	Poor	Poor
Herbert	Herbert-Tully	Mod	Mission Beach/Dunk Island/Rockingham Bay/Missionary Bay	Poor	Poor
Black	Burdekin	Mod	Magnetic Island/Townsville	Poor	Mod
Ross	Burdekin	Mod	Townsville	Mod	Mod
Haughton	Burdekin	Mod	Magnetic Island/Bowling Green Bay	Poor	Mod
Burdekin	Burdekin	Mod	Magnetic Island/ Bowling Green Bay/Bowen	Mod	Mod
Don	Burdekin/Mackay Whitsunday	Mod	Bowen	Mod	Mod

Basin	Coral reef		Seagrass meadows		Lowest score
	Subregion	2022–23 Condition	Relevant site	2022–23 Condition	
Proserpine	Mackay Whitsunday	Poor	Lindeman Island/Repulse Bay/Hamilton Island/Shoal Bay/Pioneer Bay	Mod	Poor
O'Connell	Mackay Whitsunday	Poor	Lindeman Island/Repulse Bay/Hamilton Island/Cid Harbour/Tongue Bay/Whitehaven Beach/St Helens Bay/Newry Islands	Mod	Poor
Pioneer	Mackay Whitsunday	Poor	Mackay Whitsunday regional score	Mod	Poor
Plane	Mackay Whitsunday	Poor	Lindeman Island/Repulse Bay/Hamilton Island/Llewellyn Bay/Clairview	Mod	Poor
Styx	Fitzroy	Poor	Fitzroy regional score	Poor	Poor
Shoalwater	Fitzroy	Poor	Shoalwater Bay/Keppel Islands	Poor	Poor
Waterpark	Fitzroy	Poor	Fitzroy regional score	Poor	Poor
Fitzroy	Fitzroy	Poor	Shoalwater Bay/Keppel Islands	Poor	Poor
Calliope	Fitzroy	Very Poor	Gladstone Harbour	Poor	Poor
Boyne	Fitzroy	Very Poor	Gladstone Harbour	Poor	Poor
Baffle	Burnett Mary	Mod**	Rodds Bay	Very poor	Very poor
Kolan	Burnett Mary	Mod**	Burnett Mary regional score	Very poor	Very poor
Burnett	Burnett Mary	Mod**	Burnett Mary regional score	Very poor	Very poor
Burrum	Burnett Mary	Mod**	Burrum Heads	Poor	Very poor
Mary	Burnett Mary	Mod**	Hervey Bay	Very poor	Very poor

5.4 Other ecosystems

The 2024 GBR Outlook Report provides an up-to-date account of the status of the condition of other ecosystems in the GBR.

Based on the report, the condition of other coastal ecosystems including mangroves, islands, and mainland beaches and coastlines is currently good or very good across the GBR region. However, these habitats are expected to be particularly vulnerable to future sea level rise as climate change progresses (GBRMPA 2024).

Mangrove forests within the GBR catchment area continue to occupy most of their historical extent, despite pressures from coastal development and natural processes that have resulted in both losses and gains over time (State of Queensland 2023). Coastal developments including dams, ponded pasture and roads can lead to mangrove loss or degradation (Chamberlain et al. 2020). Since 2019, major cyclone impacts on mangrove forests have been relatively low, though damage from severe cyclones in late 2023 and early 2024 has yet to be assessed (McKenzie et al. 2024a). Advances in monitoring, including the incorporation of a satellite-derived canopy cover index into national reporting frameworks, have enhanced understanding of mangrove condition, which is currently considered good across the GBR (GBRMPA 2024).

Monitoring of algal cover typically occurs in conjunction with coral reef monitoring activities. Reef-wide monitoring from 1995 to 2021 shows that the cover of upright fleshy macroalgae is higher closer to the mainland and increases with increasing latitude and towards shallow depths (< 3 m) (Fabricius et al. 2023;

Waterhouse et al. 2024a). Overall, on inshore GBR reefs, the relative proportion of large fleshy macroalgae has increased or remained stable over the past five years in most regions (Thompson et al. 2024). Some recent increases are likely in response to major events such as Severe Tropical Cyclone Debbie in the Mackay Whitsunday region. The level of macroalgae on inshore reefs is highly variable and is positively related high concentrations of Chl-*a* and suspended sediment (Thompson et al. 2024).

Saltmarshes occur discontinuously along the GBR coastline, forming part of an interconnected habitat mosaic with mangroves and seagrass meadows (Waterhouse et al. 2024b). These ecosystems are valued for their carbon sequestration potential and their role in supporting commercial fishery species (GBRMPA 2024). However, saltmarshes have been historically affected by drainage, infrastructure development, and hydrological modifications, including the construction of bund walls and ponded pastures (Abbott et al. 2020). Although statewide regulatory controls have limited new developments, existing infrastructure continues to alter saltmarsh hydrology in some areas (Department of Natural Resources and Mines 2001). No significant changes in saltmarsh extent have been recorded since 2019, but their condition is not systematically monitored across the GBR. As with mangroves, saltmarshes' ability to accrete sediment and adapt to rising sea levels is limited, posing long-term risks (GBRMPA 2024).

Dugong populations in the GBR region remain of concern, with significant historical declines attributed to habitat degradation, seagrass loss, and human-related threats such as boat strikes, bycatch, and extreme weather events. The urban coast dugong population, particularly in southern and central GBR regions, has shown long-term decline with recent declines corresponding to seagrass areas that were lost in the 2022 floods in the Burnett Mary region. Numbers recorded in Bowling Green Bay have increased, and dugong numbers north of Hinchinbrook near Cardwell were the highest they had been since 2005. Populations in more remote areas, such as Cape York, are believed to be more stable (GBRMPA 2024).

6. Management options

The water quality management response assessment introduced in Section 1.2 requires the identification of management options for each of the pollutants across a range of land uses. The assessment draws on several lines of evidence to identify priority management options relevant to water quality improvement in the GBR:

- The 2022 SCS and additional research outputs relevant to the specific pollutant or land use of interest.
- P2R Water Quality Risk Frameworks and the recent review of the P2R Management Practice Adoption targets (Review of Land Management Targets, DPI 2024).
- *Gully and Stream Bank Toolbox. A technical guide for gully and stream bank erosion control programs in Great Barrier Reef catchments* (Wilkinson et al. 2022).
- Queensland Wetlands Program and *WetlandInfo* specifically, and the *Synthesis of evidence of the effectiveness of wetlands in water quality improvement, costs and cost-drivers in the GBR catchment area* (Waterhouse et al. 2024c).
- Draft report *Identifying Options for Targeted Investment in Urban Water Management within the Great Barrier Reef Catchment* (DETSI, 2025) for urban management options.
- Additional expert input on all aspects including management options for non-agricultural land uses.

Management options for water quality improvement in the GBR have primarily focused on agricultural land uses and have typically been grouped into management practices and landscape remediation (including systems repair and engineering options). There is also a range of supporting or enabling actions including engagement, extension and education; monitoring, evaluation and applied research; and planning and institutional arrangements which form part of a ‘whole-of-system’ management approach.

Whole-of-system management is an integrated approach that goes beyond focusing on management components in isolation and instead considers management more holistically by encompassing all the components, interactions, and stakeholders within a system. Traditional whole-of-system management would consider the full range of direct and indirect drivers and pressures on a system, which is beyond the scope of this project. However, the key principles of a whole-of-system, values-based framework (DESI 2022) can still be used as a guide for implementing water quality-focused management options, which include:

- Consider system connections when developing and implementing management interventions, including connections between the biophysical environment, the beneficiaries of the services provided by that ecosystem and their values.
- Use a values-based, holistic management approach to achieve outcomes that consider the biophysical environment alongside social, economic and cultural outcomes.
- Engagement - involve all relevant groups (including Traditional Owners) of the system to ensure their needs and values have been considered and incorporated into the design of management interventions, including knowledge sharing.
- Foster integration - Break down silos between groups, stakeholders, and sectors to foster collaboration and coordinated action.
- Make decisions based on the best available knowledge at several scales; that is, at the site, catchment, and system-scales (e.g. how can the knowledge about the broader system be used to inform site-specific management interventions?).
- Select management interventions for the appropriate spatial and temporal scales.
- Incorporate adaptive management by embracing flexibility and continuous learning, allowing strategies to evolve based on new information and changing conditions.

A synthesis of the management options within the scope of the project is presented here to demonstrate how the management options identified in the water quality management response assessment (Section 7) were derived. While these are presented here as components, the implementation of these management

options should be considered in context of the principles of the Whole-of-System, Values-Based Framework described above.

6.1 Agricultural management practices

The agricultural management practice adoption component of the P2R program defines management practice frameworks and practice benchmarks, for each major agricultural industry (sugarcane, grazing, bananas, grains and horticulture) to report on the progress towards 90% of land being managed using best practice system; this target is currently being reviewed. The management practices are currently defined in the P2R Water Quality Risk Management Frameworks¹⁸ which are being reviewed. These are described further in Section 6.1.1.1.

In addition to these management practice frameworks, engineered solutions targeted to managing erosion including streambank and gully erosion, are among the most effective options for improving water quality in the GBR. These are discussed in Section 6.2.

6.1.1 Current management frameworks

6.1.1.1 2017 P2R Water Quality Risk Frameworks

The P2R Water Quality Risk Frameworks identify management practices based on their potential to decrease pollutant loads leading to a moderate to low water quality risk.

- **A Management Practices**—Lowest Risk for poor water quality outcomes. These are described as innovative management actions with cutting-edge technology and tailored farm nutrient plans.
- **B Management Practices**—Moderate-Low Risk for poor water quality outcomes. These are described as Best Practice Practices that reduce risks but may not be optimised.
- **C Management Practices**—Moderate-Risk for poor water quality outcomes. These are described as minimum standard management actions with some risk-reducing strategies.
- **D Management Practices**—Highest Risk for poor water quality outcomes. Superseded or outdated practices with high pollutant runoff risk.

Uptake of the Moderate–Low Risk (B) range of management practices is used to report progress towards the P2R program’s Management Practice Adoption targets. These management practices are grouped into farming systems actions such as nutrient management, soil management and herbicide management. The Reef Water Quality Report Cards have reported varied rates of adoption of improved management practices across basins and actions with the majority being lower than the target of 90% of land in priority areas using best management practice systems (Section 6.1.1.3 and Appendix 8).

During 2024, a review of the approach to the targets for management practice adoption was undertaken (see Section 6.1.1.2), and specific land management targets have been proposed and are currently being finalised (as at May 2025). In many instances, these practices are still linked to the 2017 P2R Water Quality Risk Framework management practices and provide the underpinning changes to management practices for water quality outcomes. These frameworks are presented in Appendix 8 and were considered in the development of the water quality management response assessment for each of the pollutants and land uses.

6.1.1.2 Revised management practices as part of the review of the Management Practice Adoption targets

The P2R Management Practice Adoption team in the Queensland Department of Primary Industries (DPI), led the process to review the approach to the management practice adoption targets at a regional and catchment scale (DPI 2024). DPI formed expert Technical Working Groups by Management Practice Area for each of the main agricultural industries in the GBR catchment area—bananas, grains, grazing, horticulture and sugarcane, in each of the NRM regions (or where relevant, e.g. bananas were only considered in the Wet

¹⁸ <https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef/management-practices>

Tropics region). The intent of the process was to document regionally relevant management practice adoption characteristics, rather than generic GBR wide management practice frameworks.

The project team conducted 61 workshops, engaging more than 80 technical experts in 15 regional technical working groups. These Technical Working Groups were comprised of industry organisations and local specialists including consultants, agronomists, extension officers, landholders, scientists, and industry and government researchers. Members were invited for their technical, specialist, or scientific expertise, knowledge, and experience, at the regional or local level. An extensive regional consultation process was conducted with these groups using ADOPT (Adoption and Diffusion Outcome Prediction Tool; <https://adopt.csiro.au/>), a method that allows users to assess and predict the likely peak level of adoption of specific agricultural innovations with a particular target population in mind. The method is based on the criteria affecting adoption which includes convenience, risk exposure, environment, future profit, annual profit, upfront cost, existing skills, use advisors, complexity, and trialability. The Technical Working Groups were encouraged to respond from the target population's perspective, focusing on how they believed the landholder population *would* respond, not how the Technical Working Group thought the population *should* respond.

Technical experts identified and described key characteristics of practices and the landholders most requiring support; landholder orientation towards profit, environment, and risk; factors influencing the ability to learn about the practice change; and impacts on ease and convenience from adopting the practice change. This information was used to describe the specific management practices that landholders adopt in their region and describe the specific regional landholder population's perspective of the practice. This localised focus was designed to produce more accurate predictions of potential adoption outcomes at a regional scale.

The results of the processes are presented in Appendix 8 and were considered in this project in the development of the water quality management response assessment for each of the pollutants and land uses. Practices in the Land Management Targets Review are described as 'foundational' to achieving pollutant reductions, and management practices that provide steps towards achieving them were identified as 'complementary' practices. Management practices were not revised in the review across all catchments, industries and pollutants (Table 23) and some are still being finalised at the time of preparing this report. Overall, there is close alignment between the existing P2R Water Quality Risk Frameworks and the reviewed practices, with a shift in the overall emphasis of some practices across different locations, and identification of some different practices.

Table 23. Delineation of catchment, industries and pollutants for which the revised management practices and adoption targets were identified.

Catchment Area	Industry	Pollutants
Cape York	Grazing	Fine Sediment
Wet Tropics	Bananas	Fine Sediment, DIN
Daintree, Mossman, Barron, Mulgrave-Russell and Johnstone	Sugarcane	DIN, Pesticides
Johnstone	Grazing	TSS
Tully, Murray and Lower Herbert	Sugarcane	DIN, Pesticides
Herbert	Grazing	Fine Sediment
Burdekin	Sugarcane	DIN, Pesticides
	Grazing	Fine Sediment
Mackay Whitsunday	Sugarcane	DIN, Pesticides
	Grazing	Fine Sediment
Fitzroy	Grazing	Fine Sediment
	Grains	Fine Sediment
Burnett Mary	Sugarcane	DIN, Pesticides
	Horticulture	Fine Sediment, DIN
	Grazing	Fine Sediment

6.1.1.3 Reporting adoption and cost effectiveness

Ideally, evidence of the current adoption of management practices across all industries would have been included in this report. However, with the review currently underway this information has not been reported across all management units and agricultural practices since the 2019 Reef Water Quality Report Card. Therefore, a combination of datasets has been used in the current analysis to assess management practice adoption where possible.

Large investments have occurred in agricultural management practice changes in the GBR catchments over the last 10 years. These past State and Federal investments were reviewed in program groupings and in mechanisms, e.g. incentives, extension and education, for this analysis. Cost-effectiveness is commonly used for evaluating options to improve environmental outcomes (Wätzold and Schwerdtner 2005; Claassen et al. 2008; Duke et al. 2013) including options for pollution reduction or improving environmental quality in water bodies (Lise and van der Veeren, 2002; Cools et al. 2011; Doole 2012). There are several cost elements associated with changing management practices or implementing remediation actions. Measures of cost-effectiveness may vary because of differences in the cost elements that are assessed, the period of analysis and the risks considered. In addition to the direct financial costs of proposals or management changes, other costs that may be considered include additional program costs (e.g. operation, maintenance and decommissioning costs), additional costs incurred by landholders (e.g. private capital costs, opportunity costs and transaction costs), and broader organisational costs (e.g. program and administration costs) (Star et al. 2021). There are often large non-financial costs involved, and costs may be non-linear with increases in the quantity of desired changes. The primary assessment of these costs is critical to understand the financial impacts and the adoption implications to inform management prioritisation.

Three datasets were used to provide insights into the range of costs associated with specific management actions. The datasets were obtained from both Australian and Queensland Government funding programs from 2016 to 2024. In this period, there have been many changes to the way that cost-effectiveness is assessed. The datasets have some critical differences which result in variability in the per unit cost or cost-effectiveness reported. Some programs split their reporting into multiple projects capturing only specific components of delivery e.g. monitoring or on-ground works, maintenance costs or landholder engagement. Therefore, it can be challenging to consistently quantify the overall cost effectiveness of a larger program of work. Maintenance costs when required were treated as a separate project, and the engagement of landholders equally was often treated as a separate project or included in an extension program. In conjunction with this, different methods were used to assess the effectiveness of the investment in reducing pollutant loads. Different versions of the P2R Projector Tool, a paddock-scale model which draws from Source catchment modelling to assess water quality outcomes, were applied to assess effectiveness. Therefore, ranges have been applied at a policy mechanism level as an indication of the mechanism costs.

6.1.2 Management options

6.1.3 Nutrients

Sugarcane

The most effective and profitable management practice for reducing dissolved nitrogen exports is reducing nitrogen fertiliser applications to industry-recommended rates, with consistently positive results across different land uses, climates, and management contexts. Further rate reductions can also give positive water quality benefits, but productivity and profitability can vary (Thorburn et al. 2024). The Reef Protection Regulations (DES 2022) specify fertiliser application rates for each of the regulated growing areas based on yields, for plant and ratoon sugarcane. These are shown in Figure 52 and Figure 53.

In sugarcane, other management practices include the use of Enhanced Efficiency Fertiliser (EEF), mill mud application, improved irrigation, crop residue management, improved farming systems (such as growing legumes in between sugarcane crops) and sub-surface fertiliser application. For many of these management practices, the effectiveness and profitability has not been clearly demonstrated and, for some, these vary depending on climate, soil and seasonal characteristics (Thorburn et al. 2024). The effectiveness and profitability of practices for reducing dissolved phosphorus exports are less clear (Thorburn et al. 2024).

Nutrient management plans and actions have been a critical focus of past investments in sugarcane. This includes matching nitrogen fertiliser application to crop yield to ensure optimal nitrogen use efficiency, as per the initial P2R Water Quality Risk Framework for sugarcane management (Appendix 8: Table 26). The management practice adoption data generated through the P2R program indicates considerable success in the improvement of nutrient management practices in sugarcane over the last five years (2019–24) driven by the large investment in nutrient management planning with considerable end of project reporting in the 2023–24 dataset.

The rates of N-fertiliser application and subsequent yields are reported as part of the P2R program and have recently been collated for the 2023–24 Reef Water Quality Report Card. The data was collected as part of the reporting from investment programs and therefore sub-catchments that are considered a higher priority for water quality improvement have had increased investment focus and therefore contain greater data coverage. The Burnett Mary region (specifically only reported for the Burrum and Burnett basins) had the least amount of area captured due to limited investment in nutrient management in the region. Plane Creek, the Lower Herbert, Haughton and Burdekin Delta had the largest areas of investment and therefore reporting. While this results in an unbalanced sample, management changes have been recorded for 191,941 ha representing 43% of the sugarcane growing area in the GBR catchment area (Figure 51). Different investments and programs have occurred across areas resulting in variable DIN reductions relative to the project activity in different locations.

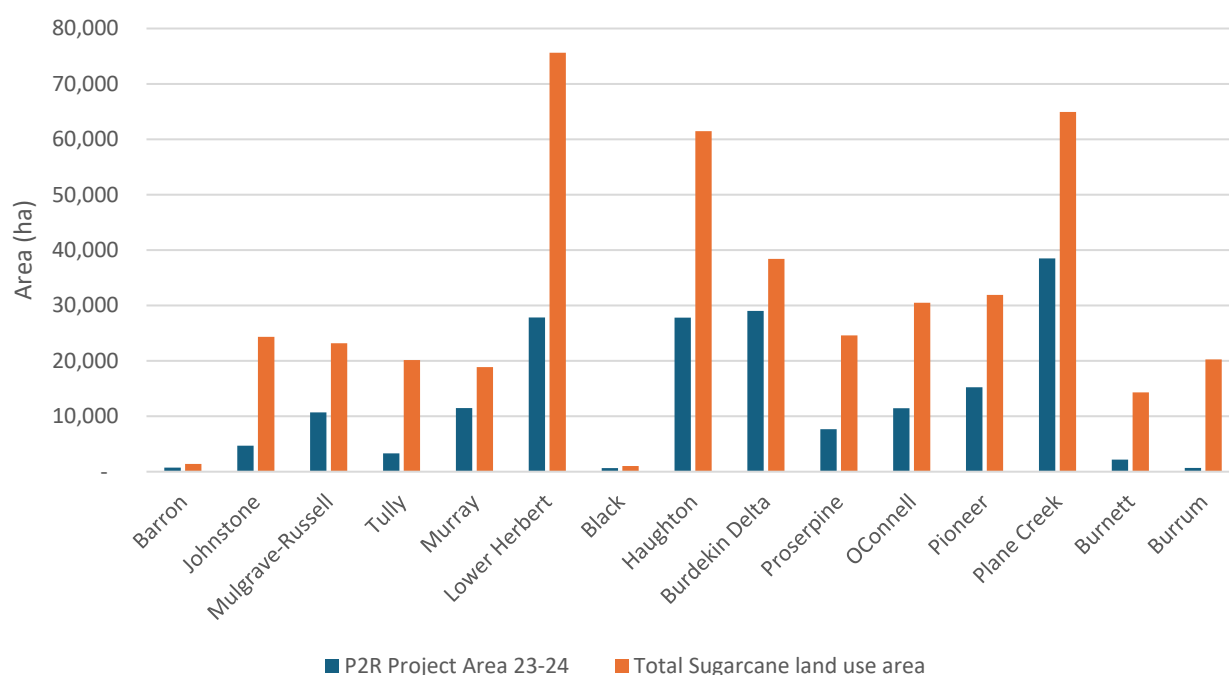


Figure 51. Area of P2R program adoption data (2023–24) recorded within each management unit to assess management practice adoption for nutrient management in sugarcane relative to the total sugarcane growing area.

The reported adoption data shows that all sub-catchments where investment reporting data was available have reduced N-fertiliser application rates for plant cane to rates that are below the regulated rate (kilo per hectare) through completing activities such as nutrient management planning. The Murray, Barron and Johnstone have reported the greatest decreases from before to after following involvement in a project (Figure 52).

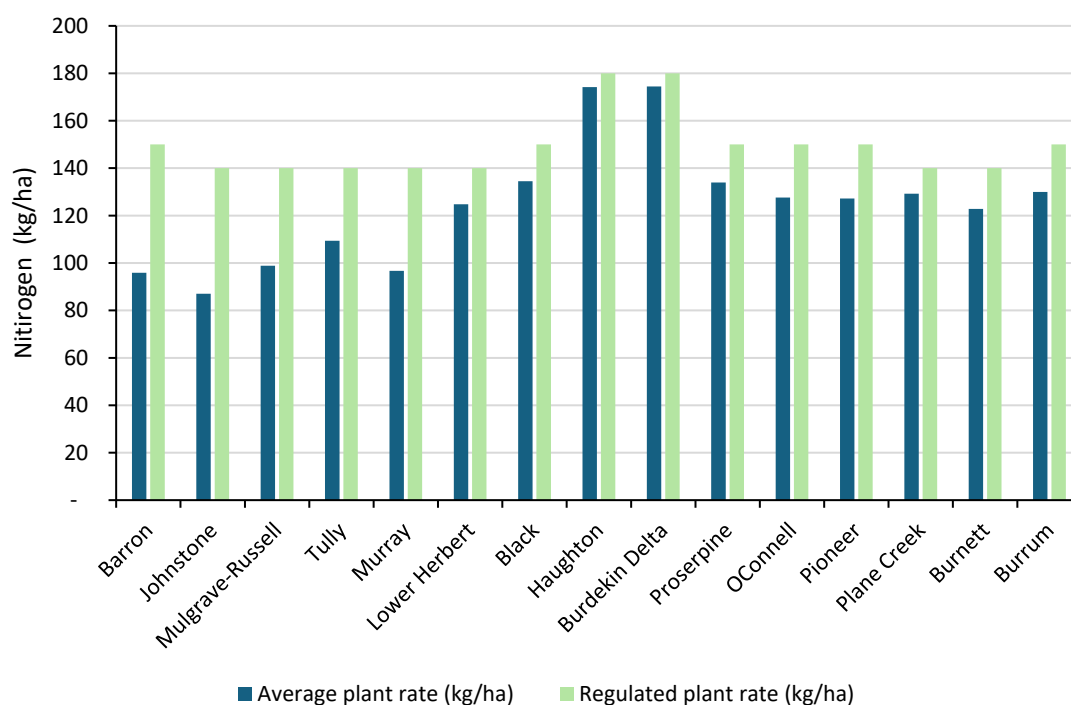


Figure 52. Average N-fertiliser application rate for plant cane crops for management unit, and the regulated application rate for plant cane.

N-fertiliser application in sugarcane ratoon crops was reduced across all sub-catchments where investment reporting data was available to rates that are below the regulated rates (Figure 53). The Black (note very limited data), Johnstone, Tully and Murray have reported the greatest decreases from before to after following involvement in a project.

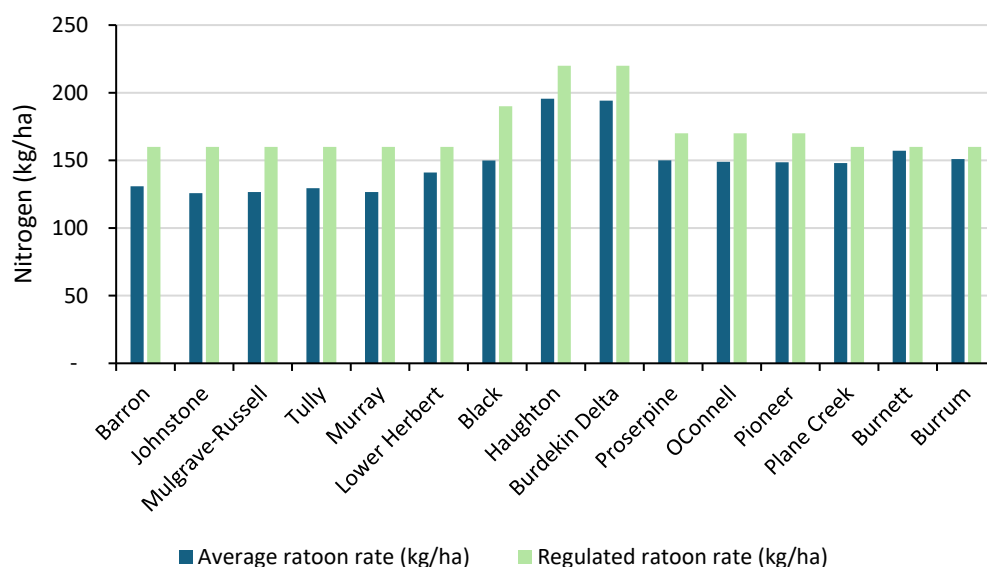


Figure 53. Average N-fertiliser application rate for ratoon cane crops for management unit, and the regulated application rate for ratoon cane.

The adoption rates shown above informed the revised management practices as part of the Review of Land Management Targets (DPI 2024). The review process took into account the population of landholders that are already operating a system such as irrigation (i.e. 60% of growers irrigate) and who have not adopted the

defined management practice (e.g. automated irrigation). These growers form the target population for management practice change. The baseline for the assessment considered those who have already adopted the practice; and the 2035 additional adoption figure is the proportion of growers adopting the practice that could be achieved in the best-case scenario above the baseline adoption (i.e. how much extra change the best-case scenario would achieve). The practices identified in the Review of Land Management Targets (DPI 2024) build on the past P2R Water Quality Risk Frameworks through increased adoption of a wider range of practices tailored to regional situations. The adoption rates presented are specific to each practice and vary based on catchment area.

The outcomes of the Review of Land Management Targets (DPI 2024) in the Wet Tropics, Burdekin and Mackay Whitsunday regions are presented in Appendix 8 and summarised below. The review highlighted consideration of regionally-specific practices, and relatively low adoption rates predicted for some practices.

The Wet Tropics region was divided into two growing areas with a northern grouping covering the Daintree, Mossman, Barron, Mulgrave-Russell and Johnstone sugarcane areas, and the southern grouping covering the Tully, Murray, and Lower Herbert sugarcane areas (Appendix 8: Table 27). The focus of the practices remains to better match the applied N-fertiliser to the plant needs and increased Nitrogen Use Efficiency (NUE). The use of EEF products at a reduced application rate was identified as a standalone practice across the region or could be used in combination with other N-fertiliser rate adjustment practices. Accounting for legume crops in rotation was identified across the region with potentially high adoption rates, in addition to the use of soil ameliorants to address yield constraints and improve crop uptake of applied nutrients. Mill mud application was identified as a relevant practice with lower adoption rates in the northern areas. Improved drainage management was highlighted in the northern areas with high adoption rates. The management practices and adoption rates are predicated on the assumption that the delivery of Nutrient Management Plans will continue. Improving drainage and use of soil ameliorants to improve yield had high adoption rates relative to the use of EEFs.

In the Burdekin region the review outcomes had a large focus on reducing water losses through automating furrow irrigation, addressing salinity and rising groundwater (e.g. dewatering where appropriate, conjunctive use and subsurface drainage), and improved disease management (Appendix 8: Table 28). Optimising nitrogen rates was also explored through accounting for legume rotation crops and mill mud, and use of ameliorants to address subsoil constraints, but with lower levels of adoption (DPI 2024).

The Mackay Whitsunday region contained a smaller proportion of growers where irrigation management applies and had a focus on addressing drainage and waterlogging problems to improve yield and nutrient use efficiency, addressing soil constraints to improve yield and mill mud application across the broader population (Appendix 8: Table 29). To a lesser extent, legume crop rotations and EEFs were considered as individual practices with varied target populations in the Review of Land Management Targets (DPI 2024).

Horticulture and bananas

There has been limited focus on horticulture and banana management for water quality improvement in the GBR most likely because the footprint for these industries is relatively small. There is also a large diversity of horticultural commodities. As a result, the current evidence about the most effective practices for nutrient reductions in bananas and horticulture is limited and requires further investigation as these inputs can be locally important (Prosser and Wilkinson 2024).

The P2R Water Quality Risk Framework for horticulture focuses on nutrient management planning, where timing and placement are critical. The outcomes of the review of the horticulture management practices in the Review of Land Management Targets are presented in Appendix 8: Table 42 and specifically pertain to the Burnett Mary region. The practices include adjusting fertiliser rates in response to leaf, sap and soil testing to match nutrient availability to crop requirements. Fertiliser placement (method or location) is a complementary practice that adds value to good nutrient management and having quality test results in practical timeframes, with trusted one-on-one agronomic decision support advice being critical. The industry best management practice framework for horticulture in Australia is Hort360 which has 108 water quality related modules and sub-modules. Hort360GBR is jointly funded by the Queensland Government's Reef

Water Quality Program and the Australian Government's Reef Trust Program and reflects the practices mentioned above.

Thorburn et al. (2024) highlights the importance of nutrient management of DIN in bananas, where lower N applications reduced N leaching (Armour et al. 2013), however the influence of different fertiliser application methods is poorly understood (Thorburn et al. 2024). The priority practices for bananas in the P2R Water Quality Risk Framework (Appendix 8: Table 31) are focused on nutrient management planning, where fertiliser optimisation (timing, placement and frequency) is critical. The Banana Best Management Practices Environmental Guideline (King 2021) highlights the importance of nutrient management for water quality outcomes. *Freshcare Environmental – Reef Assured* is an initiative between the Australian Banana Growers' Council and DETSI to gain accreditation under the *Reef Protection Regulations for Nutrient management*.

6.1.4 Fine sediments and particulate nutrients

Grazing

Grazing management practices that seek to increase groundcover are critical for water quality outcomes in the GBR. Common practices include the use of moderate and adaptive grazing stocking rates, maintenance of at least 40% groundcover (but preferably >70%), regular periods of strategic rest ('spelling') from grazing (especially in the early wet season), cattle exclusion from fragile land-types, and maintaining or reintroducing vegetation into landscapes (including pasture management and vegetation buffers) (Bartley and Murray 2024).

Mechanical rehabilitation measures, such as deep ripping, blade ploughing and targeted gully remediation (Hall 2014; Rust and Star 2018) can enhance water infiltration into soils and reduce erosion from degraded lands, improving overall land condition in land types that do not have sodic soils. These strategies work best when paired with controlled grazing, as full eco-hydrological restoration may take more than 10 years, and recovery from heavy grazing impacts can span decades (Bartley et al. 2014; Koci et al. 2020). Studies emphasise that tailoring practices to local conditions—including landscape position, soil characteristics and seasonal dynamics—is essential for achieving measurable water quality improvement.

There is high variability in the cost-effectiveness of practices at the farm/project scale which is driven by several factors including a wide range of different practices and economic returns, location within the landscape and factors relating to sediment mobilisation and delivery (Bartley and Murray 2024).

The P2R Water Quality Risk Framework for grazing management (Appendix 8: Table 33) identifies management actions related to grazing pressure, land condition, management of linear features (roads and fences) and riparian management. However, the Reef Water Quality Report Card uses groundcover as the proxy indicator for all of these management actions. Section 2.2.3 highlights the results for groundcover across all basins and management units in the GBR catchment area. The Review of Land Management Targets grouped practices according to catchment with no further delineation between basins.

The outcomes of the Review of Land Management Targets in all regions are presented in Appendix 8 and summarised below, highlighting the consideration of regionally-specific practices.

In the Cape York region, matching stocking rate to carrying capacity was identified as a critical foundational practice in this sensitive, 'high-risk' environment in the Review of Land Management Targets (DPI 2024) (Appendix 8: Table 34). A suite of components (complementary practices) is required to successfully implement this practice. Graziers may be undertaking one or more components with varying success. However, few are successfully undertaking the full suite of practices and support is required for all components of this practice to increase adoption. Additional considerations specific to the catchment such as fire management were identified as critical components of maintaining groundcover, acknowledging that timing of burning is critical to avoid further soil losses across the Cape York region. Gully management and management of linear features were highlighted as foundational practices in gully prone landscapes in Cape York, while stabilising and protecting frontage country were described as complementary practices that will add value to other practices.

In the Wet Tropics region, the Review of Land Management Targets identified matching stocking rate to carrying capacity as a foundational practice for both the Johnstone and Herbert basins, despite having very different target landholder population characteristics (Appendix 8: Table 35) (DPI 2024). The Johnstone basin has high rainfall, smaller 'hobby farms', and a tendency towards a 'landscape management' focus and the Herbert basin has variable rainfall, and larger, multi-generational grazing enterprises. A suite of complementary practices was identified to successfully achieve matching stocking rate to carrying capacity. It was highlighted that graziers may be undertaking one or more components with varying success however few were successfully undertaking the full suite of practices. Support is required for all components of this practice to increase adoption. Wet season spelling was noted as a component of matching stocking rate to carrying capacity. Stabilising and protecting creek and river frontage country and management of linear features were identified as complementary practices that will add value to other practices.

In the Burdekin region, the Review of Land Management Targets identified practices that address stocking rate management and pasture spelling highlighting that these practices are directly linked to, and enabled by, improving herd efficiency (Appendix 8: Table 36) (DPI 2024). Herd efficiency was described as needing to be part of a holistic approach to improve adoption and should not be considered in isolation of stocking rate management and pasture spelling. A lack of skilled extension advisors and underperforming (inefficient) breeder herds were identified as key barriers to adoption for all practices in the Burdekin region (DPI 2024).

In the Mackay Whitsunday region, the Review of Land Management Targets highlighted that the assessment of land condition (twice annually) and recording and monitoring land condition to address decline was a critical practice (Appendix 8: Table 37). The practices that address stocking rate management, pasture recovery, riparian management and continuous upskilling for management in this basin are directly linked to land condition. As in the Burdekin, they were described as needing to be part of a holistic approach to improve adoption. A critical point raised through the ADOPT process was that there is a large population of landholders who have relocated to the region with little to no knowledge of the region-specific management required for this area. As a result, a large area of the region is poorly managed. This could be rectified through focusing on continuous upskilling for management.

In the Fitzroy region, the Review of Land Management Targets identified adjusting stocking rates to ensure that residual pasture is maintained until the 'green date'¹⁹, with additional residual built in (to buffer for drought or late rainfall) as a foundational practice (Appendix 8: Table 38). The Fitzroy basin consists of highly productive land types that have historically supported high numbers of grazing animals and a productive broadacre cropping industry. In recent years the productivity and resilience of these land types have declined. Landholders still stock these land types according to historical productivity measures and as a result overstocking and overgrazing is now common practice. The practices of wet season spelling, herd efficiency, landscape hydration, managing of stock in creeks and vulnerable areas using watering points and/or fencing, and managing degraded areas were identified as supporting practices for managing stocking rate. The Review of Land Management Targets identified the limitation of trained and skilled extension staff in the region to implement all of these practices (DPI 2024).

In the Burnett Mary region, the Review of Land Management Targets identified matching stocking rate to carrying capacity as a foundational practice (Appendix 8: Table 39) (DPI 2024). It was recognised that the ability to balance wet season spelling and carrying capacity provides opportunities to adopt further practices and allow for landscape recovery. The remaining practices focused on improving landscape health and condition. The ADOPT process highlighted that the availability of trained and skilled soil conservation officers is a significant barrier to adoption in this region (DPI 2024).

Grains

Grains are predominantly grown in the Fitzroy region, and the 2022 SCS highlighted the importance of practices such as tillage and contour banks (Bartley and Murray 2024). Contour banks are recognised as a

¹⁹ Defined by when there has been sufficient rainfall e.g. 50 mm rainfall over three days, day length and temperature to produce active pasture growth.

key management practice to reduce sediment runoff by capturing sediments before they enter waterways (Murphy et al. 2013).

The Review of Land Management Targets focused on grains in the Fitzroy region (Appendix 8: Table 41). Cropping was broken into two areas: Fitzroy West which consists of Theresa Creek, Nogoia, Comet, Mackenzie, and Fitzroy East which consists of the Dawson. The foundational management practices were associated with zero tillage and active management of weeds to ensure that tillage is not used as a method for weed control (DPI 2024).

Horticulture and Bananas

For sediment management in bananas, Rasiah et al. (2009) found that inter-row grass covers were effective at reducing compaction and improving infiltration caused by wheel traffic stress. However, the study did not directly measure the influence of management practices on sediment and nutrient loss. Roebeling et al. (2007) applied the Land Use Crop Technical coefficient generatOR (LUCTOR) crop growth model to generate input-output data for different management practices in banana production in the Tully and Murray basins. SedNet and ANNEX were used to model the water quality response of these practices. The modelling indicated that maintaining cover on inter-rows leads to a 60% decrease in fine suspended sediment delivery, however, these results may not be transferable to other systems. Zonal tillage is when only the row area is cultivated in preparation for planting and the inter-row area remains undisturbed. The reduced cultivation as a result of zonal tillage was predicted by the model to reduce suspended sediment from the industry by 65% from 5,700 t yr⁻¹ to 2,000 t yr⁻¹.

The management practices for sediment management in bananas and horticulture in the Review of Land Management Targets also focused on increased groundcover between rows and reduced wheel ruts (DPI 2024).

The Review of Land Management Targets for horticulture specifically applies to the Burnett Mary region. The foundational practices identified focused on adjusting fertiliser rates in response to leaf, sap and soil testing to match nutrient availability to crop requirements. Fertiliser placement (method or location) was identified as a complementary practice that adds value to good nutrient management, and having quality test results in practical timeframes, with trusted one-on-one agronomic decision support advice was considered critical in achieving this (Appendix 8: Table 43) (DPI 2024).

6.1.5 Pesticides

Pesticides are applied across a range of land uses (See Section 3.4.2.3) and application should be managed across all of these. Managing pesticide risk to ecosystems involves both preventative actions that aim to avoid unnecessary pesticide use and risk-reducing actions that minimise risk to ecosystems when pesticides are necessary (Figure 54). Managing pesticide risk is distributed across different hierarchical scales of management from institutional to landscape to farm to paddock levels, with preventative actions largely occurring at the institutional, landscape and farm levels, and risk reducing actions at the farm and paddock-scale. Key to the success of reducing pesticide risk is engagement, extension and agronomic advice, as has been demonstrated through the Project Bluewater 2 case study (Sluggett 2024).

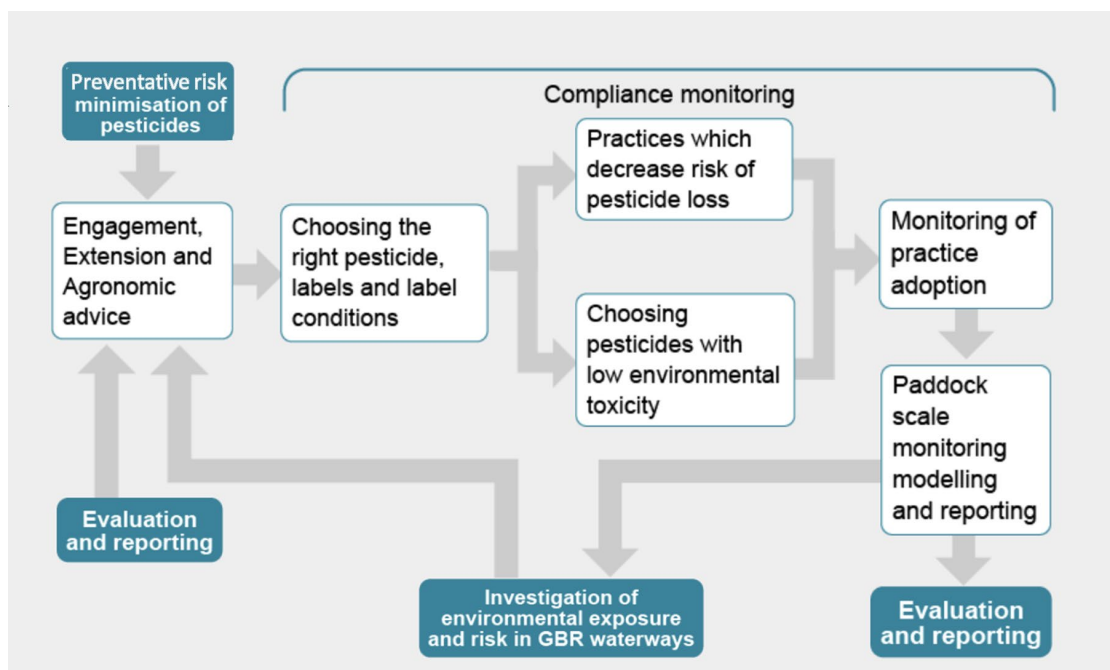


Figure 54. Management steps for reducing pesticide risk to ecosystems (white boxes) and the complementary activities (blue boxes) that support risk reduction including preventative actions, compliance monitoring, and adaptive improvement (monitoring, evaluation and reporting). Figure is adapted from the National Environmental Science Program (NESP) Tropical Water Quality Hub Synthesis.

Preventative Actions

Preventative actions focus on longer-term effective pest control that reduce the need for pesticide applications and establish institutional frameworks that support responsible use. At the institutional level, the first steps for managing pesticide risk for ecosystem protection are preventative actions undertaken by the Australian Pesticide and Veterinary Medicines Authority (APVMA) as part of the registration and regulation process for pesticide products. Compliance with the regulatory standards for pesticide use in Queensland is in accordance with the [Chemical Usage \(Agricultural and Veterinary\) Control Act 1988](#), which enforces adherence to the use of pesticide products according to the registered label instructions. General, regional or seasonal restrictions might appear on the label of a pesticide product to guide its responsible use so that the product is not applied in situations with unacceptable risks (APVMA 2020). Pesticides are not included in the Reef Protection Regulations (which only apply to nutrients and sediments).

The 2022 Scientific Consensus Statement (Question 5.3; Davis et al., 2024) reviews the most up-to-date literature on the most effective management practices for reducing pesticide risk from the Great Barrier Reef catchments, and the following provides a short summary of that review on preventative and risk-reducing actions.

At the landscape-scale, effective and strategic pest control is applied through area-wide management approaches that target pest populations across a defined geographic area rather than field-by-field. These collaborative approaches involve multiple landholders working together to manage mobile pests or to slow the evolution of pesticide resistance. Pesticide resistance poses a challenge for the future viability of entire farming systems, and its knock-on effects for water quality, which is an important consideration to ensure practices recommended for improved water quality do not contribute further to pesticide resistance (Davis et al. 2024). Fortunately, area-wide management strategies for pesticide resistance align closely with those for controlling pests: “clearly defining the boundaries of the area in which herbicide-resistant weeds will be managed; having land managers within that area agreeing to a shared goal; providing support to land managers who have fewer resources for managing herbicide-resistant weeds; and building strong working relationships among land managers” (Davis et al. 2024, p.30).

A range of non-chemical pesticide control measures (integrated pest management (IPM), cultural controls that modify the pest's growing environment) hold considerable potential for reducing reliance on chemical control measures, but most are yet to be trialled in the GBR catchment area with respect to long-term pesticide use reductions, efficacy and economic outcomes (Davis et al. 2024). The 2022 Scientific Consensus Statement noted that while *"a diverse range of IPM tactics were noted as being used by farmers, few industries in the GBR catchment area consistently or comprehensively use IPM"* (Davis et al. 2024).

Many elements of broader farm management (e.g. crop planting density, varietal selection, crop row spacing, habitat management) hold considerable promise for reducing pest pressure and reducing long-term pesticide applications. Cultural control for pest management is a broad concept, encompassing practices that manipulate the broader crop production system across a farm to reduce pest establishment, reproduction, dispersal, competitiveness and/or survival (minimising the need or scale of subsequent chemical or physical control of an established pest presence) (Davis et al. 2024). It includes practices such as paddock-field layout and orientation, fallow management, crop rotation, timing of planting, harvesting and field operations, resistant crop varieties, crop planting density, seed or plant quality, and management of adjacent environments (Davis et al. 2024).

Risk-reducing actions

As highlighted in the 2022 SCS, practices that demonstrably reduce pesticide risk from agricultural land uses have remained relatively consistent through time, and across climatic regimes and farming systems of the GBR catchments (Davis et al. 2024). These include:

- i. **Reducing application rates.** Improving application methods to reduce the total amount of pesticide applied through lower application rates (within label recommendations), e.g. banded/shielded/spot spray applications (Davis et al. 2024). Project Bluewater 2 found that using appropriate nozzles, pressure settings, and application technologies such as dual herbicide sprayers can improve efficacy while reducing off-target movement. Project Bluewater 2 in the Burdekin found that changes to nozzles and tracking legs cost approximately \$2,750 for a large farm (250 ha) but provided significant reductions in herbicide losses. Pesticide runoff load reductions are typically directly proportional to application rate reductions (e.g. 50% reduction in area applied results in approximately 50% reduction in load loss).
- ii. **Timing of application** in relation to weather risk periods. Pesticide losses can be reduced by >90% for some pesticides by avoiding runoff events, from rainfall or irrigation, within several weeks of application (Davis et al. 2024). The first flush events of the wet season typically carry the highest concentrations of pesticides, exposing organisms to acute periods of very high pesticide concentrations in some areas, followed by chronic levels of exposure for the remainder of the wet season.
- iii. **Switching to pesticide products with lower environmental risk.** Selecting pesticides with shorter persistence, greater sorption, lower mobility, and lower toxicity can significantly reduce environmental risk (Davis et al. 2024). The Pesticide Decision Support Tool (Warne et al. 2023) was developed to assist growers in making informed choices about alternative pesticides with improved risk profiles. The Pesticide Decision Support Tool has been redeveloped as the [Pesticide Projector](#) tool.
- iv. **Reducing runoff and soil erosion** through retaining cover, controlled traffic and improved irrigation management for pesticides with greater soil sorption (Davis et al. 2024).

In the assessment of cost-effectiveness of pesticide management in agricultural industries, the 2022 SCS identified that economic returns remain variable. However, for sugarcane, progressing from traditional to industry standard herbicide management is generally profitable across sugarcane districts (Davis et al. 2024).

The outcomes of the review of the management practice framework in each region are presented in Appendix 8: Table 30. The practices include a more holistic package of risk management actions (drawing on the actions above), and specific actions identified within regions such as the use of banded residual herbicides, dual herbicide sprayers and optimised pesticide selection and application.

Case study: Project Bluewater 2

The Project Bluewater 2 initiatives in the Mackay Whitsunday and Burdekin regions (Dowie 2024; Sluggett 2024) exemplify successful implementation of risk reduction management actions. Particularly important was the incorporation of extension, engagement and agronomic advice that supported the uptake of the actions, as well as the collaborative nature of the project. These projects engaged growers managing over 46,000 hectares across the two regions and achieved a total pesticide risk reduction of more than 6.4 million risk units in Mackay Whitsunday and 1.6 million risk units in the Burdekin.

Key elements of these successful projects included:

- Direct grower engagement and one-on-one on-farm extension
- Technical skill development and training delivered by recognised experts
- Tailored advice and agronomic assistance to support practice change
- Spraying equipment upgrades with shared-cost incentives
- Identification and solutions for issues like point-source pollution from mixing sites
- Development and refinement of decision support tools
- On-farm demonstrations of water quality, product selection and management
- Improved knowledge of water quality and pesticide behaviour through knowledge sharing from water quality scientists and access to water quality data
- Regular communications through multiple channels

The importance of disseminating the right advice, and tailoring information to the values of the growers, was highlighted. A major challenge was local pesticide resellers providing advice to growers that conflicted with the pesticide management plans developed by the project team, which led to increased pesticide risks. The need for stronger strategies to influence reseller practices was highlighted; while targeted workshops to engage and educate resellers were held, discrepancies between reseller claims and actual pesticide sales still remained. Critically, the project team also observed growing scepticism toward Reef science and “reef fatigue” within the sugar industry over the project period, which required an adjustment to the messaging strategy being used to overcome the resistance. The most effective approach involved reframing pesticide management around local stewardship rather than Reef impacts—bringing consequences “closer to home” by highlighting pesticides in household groundwater, engaging farm women through dedicated chemical safety and water quality workshops, and emphasising personal health benefits alongside environmental outcomes. This localised, safety-oriented messaging resonated more strongly with many in industry and provides a valuable template for future engagement, though substantial opportunities remain to expand adoption across the broader grower community.

6.1 Urban and other non-agricultural management practices

While urban areas only occupy around 0.8% of the GBR catchment area they can contribute disproportionately high levels of pollutants to the GBR per unit area. Urban areas generate approximately 4.2% of the overall DIN loads and 1.4% of the fine sediment loads highlighting that further management of urban and non-agricultural land uses could contribute to improving GBR water quality outcomes. In addition to DIN and fine sediment, other pollutants including those described in Section 4.2.4 are also associated with urban areas.

The current Reef 2050 WQIP land use management target relevant to urban is: *The management of urban, industrial and public land uses for water quality shows an improving trend*. Also relevant to all land and catchment management targets is the human dimensions target of: *Active engagement of communities and land managers in programs to improve water quality outcomes is increased*. Options for an urban, land use management target are currently being investigated as part of the review of the Reef 2050 WQIP (DETSI 2025).

6.1.1 Current management frameworks

The Urban Water Stewardship Framework (UWSF) (part of the Queensland Reef Water Quality Program) provides the most complete guidance and performance assessment of non-agricultural (currently specifically urban) initiatives for water quality outcomes in the GBR. The results of such initiatives are reflected in the Regional Report Cards in the Wet Tropics, Dry Tropics (covering Townsville), Mackay Whitsunday and Gladstone regions. The latest reporting period (2022–23) showed that while point source management (management of sewage treatment plants (STPs)) generally operates at current best practice, diffuse source pollution management from developing and established urban areas was below best practice standards and could be the focus of targeted improvement strategies.

Additional support mechanisms include the Reef Guardian Councils Program and the GBR Erosion and Sediment Control and Urban Stormwater Capacity Building Project, which deliver training, education, and foster communities of practice among urban water management professionals.

6.1.2 Management options

The 2022 SCS reviewed the effectiveness of pollutant reduction interventions in non-agricultural areas (Thorburn et al. 2024). It highlighted that effective urban water quality management requires a combination of structural and non-structural approaches tailored to the region's specific challenges. Non-structural approaches to manage urban nutrient and sediment contributions include policy reforms, urban planning regulations and compliance, extension and education programs, and appear to be most effective when applied as part of an integrated approach (Waterhouse et al. 2024b). Structural measures can involve engineered solutions such as STPs and stormwater treatment trains designed to intercept and treat stormwater before it reaches waterways, as well as simpler approaches such as maintaining riparian zone vegetation to filter stormwater runoff (Thorburn et al. 2024; Waterhouse et al. 2024b). It was concluded that the use of planning and regulatory approaches continues to support the application of suitable nutrient management actions (both structural and non-structural) and are most effective when considered in conjunction with specific treatment controls. In general, combining treatments into treatment trains is more effective than single treatments (Bartley and Murray 2024). The selection of the most appropriate management options would be driven by a range of factors including social values and economic drivers, as is the case for agricultural land uses described above.

6.1.2.1 Nutrients and sediments

Sewage Treatment Plants

Improvements in technologies for wastewater management show that systems such as membrane filtration and chemical addition are likely to perform well in terms of reducing DIN loads (Thorburn et al. 2024). Further, recycling and reuse of wastewater shows considerable potential, though there are issues with the management of nutrients where that reuse water is applied (particular in areas of shallow groundwater aquifers, such as those present in the Burdekin Irrigation Area and the nearby delta).

STPs in Queensland are designed for a specific lifespan and volumetric capacity in terms of the number of equivalent persons' waste they can treat effectively. The systems are licensed with load-limits defined in environmental authorities under the *Environmental Protection Act 1994*. While those STPs that are within their design life and capacity are unlikely to require an upgrade between now and 2030 (DETSI 2025), there may be some systems that are reaching load limits. In the GBR catchment area, most STPs were under 85% of the design capacity reached as of 2019 (DETSI 2025), with the following exceptions: Atherton, Mossman, Mirani, Millbank and Bundaberg North (Ramsay et al. 2020). Treatment upgrades may be required in some systems to address load limits.

Operational improvements to STPs include enhanced management practices, staff training, and regular maintenance at existing facilities. STP upgrades incorporating advanced technologies such as membrane filtration, biological nutrient removal, and chemical treatments can significantly reduce DIN loads. These options are most appropriate where STPs contribute substantially to urban DIN loads (e.g. Ross and Barron basins) or are approaching capacity limits. However, technology upgrades come at a substantial cost and

may have diminishing returns at advanced treatment levels. Further, the larger STPs in the Barron, Ross and Plane Creek basins are already advanced treatment systems and there are significant limits on the amount of further nutrient reduction that can be expected to be achieved through technology or operational upgrades (DETSI 2025). DETSI (2025) examines the available options and should be consulted for further information.

Wastewater recycling and reuse could reduce the volume of treated effluent discharged to waterways (Thornburn et al. 2024). This approach could suit regions with agricultural or industrial demand for water. Effectiveness depends on local demand for recycled water, available land for application, and the economic viability of distribution infrastructure (Ramsay et al. 2024). Treated wastewater reuse is also assessed in DETSI (2025) and is highlighted as a potential opportunity for several STPs in the Barron basin (Atherton, Kuranda, Tinaroo) and Ross basin (Mount St John and Cleveland).

Offset schemes can address residual DIN loads, particularly for new facilities under “no net decline” regulations. These are most appropriate where direct treatment is cost-prohibitive, though implementation remains challenging due to limited established offset types in Queensland (DETSI 2025).

Stormwater Management

Non-structural measures for stormwater management include strategic land use planning, vegetation retention/buffering, and constructed wetlands. Opportunities to reduce sediment and nutrient loads in new urban areas are based on erosion and sediment control on construction and infrastructure maintenance sites, and stormwater runoff from new developments. The aspect less discussed is the maintenance and enhancement of natural assets that mitigate the impacts of stormwater runoff. While natural assets such as riparian vegetation and natural wetlands can mitigate stormwater runoff through removing or trapping some of the nutrients and sediment in stormwater runoff before they enter local waterways and slowing the flow of stormwater runoff in waterways, these systems are often highly modified in developed areas. There is limited evidence of the effectiveness of these management options in the GBR. For sediments, gross pollutant traps and sediment basins can support pollutant reduction, preventing large debris and sediments from entering aquatic ecosystems (Thorburn et al. 2024). Biofilters have shown considerable potential for use in tropical climates, though leaching of nutrients from the media needs to be managed, and the choice of plant species is an important consideration. The systems appear to improve in performance for denitrification over time suggesting that nutrient removal may improve with system age rather than decline (Thorburn et al. 2024).

Wetland systems in non-agricultural areas are largely constructed vegetated systems with engineered inflow and outflow controls, usually incorporating pre-treatment such as sediment basins, and extensive areas of emergent and floating macrophytes in vegetation zones. Constructed wetlands can effectively remove sediments and nutrients (Thorburn et al. 2024; Waltham et al. 2024). Although they require substantial space, they can provide additional ecosystem services and community benefits, which could make them suitable for new developments or areas with available public land.

One of the most efficient and economic strategies to control soil erosion on roadsides is revegetation (Bartley and Murray 2024). Vegetated swales are linear drainage structures that may contain grass or emergent macrophytes that interact with stormwater flows to promote sedimentation and infiltration. Swales are most effective as part of broader treatment trains along roadways and drainage routes where linear treatment systems are appropriate.

Options identified by DETSI (2025) for existing or ‘mature’ urban areas include retrofitting stormwater treatment systems, investment in innovation and catchment restoration, however, all of these options can be costly and require dedicated investment.

6.1.2.2 Pesticides

The 2022 SCS reviewed the effectiveness of management options for reducing pesticide loss in urban areas (Davis et al. 2024). Pesticides in urban areas originate from multiple sources including residential lawn and garden care, commercial landscaping, pest control for buildings and infrastructure, and municipal weed management in parks and along roadways. These compounds can reach waterways through both point

sources (wastewater treatment plant discharges) and diffuse sources (stormwater runoff from lawns, gardens, and hardscapes). While agricultural pesticide use typically dominates loading to the GBR, urban contributions can be locally significant, particularly in intensively developed coastal catchments (Davis et al. 2024).

Effective management of urban pesticides involves both non-structural and structural approaches. Non-structural measures include regulatory controls restricting use of problematic compounds, which have demonstrated effectiveness in reducing organochlorine pesticide concentrations in waterways like the Brisbane River. Education programs targeting homeowners and pest control operators can reduce overapplication and improve application timing, while local government procurement policies can decrease pesticide use on public lands. These regulatory and behavioural interventions provide cost-effective first barriers to pesticide contamination (Davis et al. 2024).

Structural approaches provide additional treatment of pesticides that enter urban water systems. Advanced wastewater treatment technologies have proven effective, with membrane bioreactors, ozonation, and UV treatment achieving >90% removal of many pesticides. For stormwater, biofilters with appropriate media and constructed wetlands can remove pesticides through sorption, photodegradation, and microbial breakdown, though performance depends on retention time and system design. Alternative application methods like stem implantation of pesticide-containing capsules for weed control show promise by minimising environmental exposure compared to conventional spraying. While monitoring data on treatment effectiveness in the GBR context remains limited, integrating regulatory controls with strategic structural interventions offers the most comprehensive approach to reducing urban pesticide inputs (Davis et al. 2024).

The non-agricultural land use priorities relating to urban sediment, nutrients and pesticides that are relevant to the water quality management response assessment are documented in DETSI (2025) and include:

- STP upgrades and greater reuse.
- Onsite sewage system management for nutrients in rural residential and peri-urban areas.
- Urban Sensitive Stormwater Design and integrated water cycle planning for fine sediment and nutrient reductions and stormwater treatment retrofitting.
- Erosion and sediment controls.
- Treatment systems including constructed wetlands, biofilters and vegetated channels for nutrient reductions.
- Focus on low toxicity pesticides used by local government (e.g. weed spraying or insecticides), and pest controllers (insecticides, fungicides, herbicides) noting that it is anticipated that pesticide contributions from non-agricultural activities are likely to be low and mostly related to herbicides.

6.1.3 Urban priorities

The urban catchment management prioritisation conducted by DETSI (2025) used a range of datasets related to urban areas, urban DIN and fine sediment contributions, and predicted population growth to identify particular basins within the broader GBR catchment that warrant priority investment in improving urban land use management:

- Mossman
- Barron
- Mulgrave-Russell
- Ross
- O'Connell
- Pioneer
- Plane
- Burnett
- Mary

These results are reflected in the water quality management response assessment presented in Section 7.2.

6.2 Engineered solutions

The P2R review of management practices did not focus on active large-scale engineered solutions (sometimes referred to as ‘landscape remediation’ options). However, all regions identified these management practices as being central to managing gully or streambank erosion such as the management of linear features, stabilisation of frontage areas and management/rehabilitation of heavily degraded areas.

6.2.1 Gully remediation

Gully remediation treatments can include major earth works and reshaping, soil treatment, installation of rock chute structures, earth bunds and water points, fencing and revegetation. A combination of these treatments can achieve over 90% fine sediment reduction within one to two years. In contrast, direct hillslope gully treatments appear less effective in reducing fine sediment exports (7 to 17% effectiveness). Destocking catchments may reduce hillslope gully sediment yields by up to 60% after ~25 years, however there is limited information on the practicality and costs of this approach (Brooks et al. 2024).

Alluvial gully treatments typically have shorter response times in terms of fine sediment reductions and can be treated at larger scales and in fewer locations, resulting in additional logistical efficiencies. However, ongoing maintenance (including livestock exclusion) of the remediation sites is essential to retain these benefits (Brooks et al. 2024).

Of relevance to management prioritisation, the available studies indicate that a small number of gullies (~2% of the total number) contribute a substantial proportion of the sediment yield (30%), highlighting the need to target the high yielding gullies as a means of efficiently reducing fine sediment exports to the GBR (Brooks et al. 2024).

The management actions identified in available studies focused on diverting runoff, gully head rock chutes, and reshaping and vegetation along with rock capping as noted in the Gully and Streambank Toolbox (Wilkinson et al. 2022). These actions can vary significantly based on the site-specific actions required, and the quantity of products such as rocks that are required to be brought in from other locations. The technical design costs can vary significantly based on the complexity of where the gully sits in the landscape, along with the proximity and delivery of sediment to the end of the catchment. The location itself can impact the costs depending on transportation needs and access to earthmoving machinery. For sites in closer proximity to the end-of-catchment (and therefore with high delivery ratios), recorded costs ranged from \$718 to \$5,517 per tonne delivered to the end-of-catchment. For the sites above dams or with a small delivery ratio, costs ranged from \$8,708 to \$9,820 per tonne delivered to the end-of-catchment (as described in Section 6.1). Some sites have required additional maintenance costs, and these have not been incorporated into these ranges, nor have the complementary extension and trust-building actions. Therefore, these costs are likely to understate the overall cost of gully remediation.

6.2.2 Streambank rehabilitation

Streambank rehabilitation treatments include interventions to increase riparian vegetation, either directly through planting, or indirectly through the removal of disturbance pressures such as grazing to encourage natural colonisation, and in some cases bank reprofiling and stabilisation, which enables subsequent revegetation via planting and/or natural colonisation (Wilkinson et al. 2022; Brooks et al. 2024).

Rehabilitation works cannot currently be evaluated due to limited measurement of treatment effectiveness, but studies have shown that bank erosion generally occurs at lower rates on vegetated streambanks than non-vegetated streambanks. There is a need to refocus efforts from site-scale management to catchment-wide approaches that seek to maximise recovery of riparian vegetation at the river reach to network scale, rather than focus on individual erosion sites (Brooks et al. 2024). While streambank rehabilitation will assist in reducing sediment export in the GBR catchment area, estimates of return on investment are poorly understood.

The cost of streambank activities is similarly varied, based on site specific attributes with the stream-order, soil type and proximity to materials all influencing the activity and subsequent costs. In the review of past

projects (as described in Section 6.1), the costs of engineered solutions for streambanks ranged between \$597 and \$3,129 delivered to the end of the catchment. Some sites have required ongoing maintenance, and these costs have not been incorporated into these ranges, nor has the complementary extension and trust-building actions with landholders. Therefore, these costs are likely to understate the overall cost of streambank rehabilitation.

6.2.3 Treatment systems

Treatment (or constructed) wetlands, and related vegetated treatment systems for improving water quality, are largely engineered systems that are designed to intercept, slow down, and remove sediments, nutrients, and other pollutants (e.g. pesticides) from water. DESI (2022) defines treatment or constructed wetlands as: *“...engineered systems that replicate and enhance the physical, biological, and chemical treatment processes occurring in natural wetlands. They differ from restored or natural wetlands in that they are designed and managed primarily to improve water quality”*. Other names for treatment wetlands are constructed wetlands, surface flow wetlands, and free-water wetlands. Treatment systems include floating wetlands, vegetated drains, recycle pits, swales and buffer strips and bioreactors.

The 2022 SCS reviewed the role of wetlands in water quality improvement in the GBR (Star et al. 2024; Waltham et al. 2024), and this was further expanded in Waterhouse et al. (2024c). These reports built on the extensive information available on *WetlandInfo*. Generally, constructed/treatment wetlands are effective in nitrogen removal if appropriately designed and built, with effectiveness increasing over time if the system is properly maintained. Constructed wetlands in the GBR catchment area have demonstrated nitrogen removal rates ranging from -5% to 90%, depending on design, vegetation, and inflow concentrations. Studies have demonstrated that constructed wetlands with higher vegetation cover (which promotes denitrification) and optimised hydrology perform better. There is more confidence in the evidence about the effectiveness of treatment wetlands than other wetland systems due to the higher number of studies (including in the GBR) and the fact that measuring removal efficiencies in constructed systems is more straightforward than in natural wetlands.

Bioreactors, which use organic materials like woodchips to enhance microbial nitrogen removal, have demonstrated significant potential in agricultural settings when effectively designed and strategically placed. For instance, studies in the GBR have shown that bioreactors can remove up to 80% of nitrogen, with performance largely dependent on nitrate concentration, subsurface flow pathways and water flow rates. However, challenges related to design (including placement in the landscape and adequate input concentrations) and maintenance can impact their overall effectiveness which may limit their application in the GBR catchment area. There were limited studies that reported removal efficiencies for total phosphorus, sediments, and pesticides.

Although less studied in the GBR, stormwater wetland systems in urban areas have shown global success in treating runoff when properly designed and maintained. These systems are particularly effective in removing coarse sediments and nutrients from urban stormwater and can include biofilters. Biofilters are in effect, vertical wetlands with a vegetated zone on the surface, but allowing water to pass through soil filter media before treated water is collected in underflow drains. Biofilters have shown considerable effectiveness for stormwater management across Australia and are already in extensive use in new urban areas in the GBR (Thorburn et al. 2024).

To maximise the benefits of treatment systems, it is essential to invest in long-term monitoring, research, and adaptive management strategies such as the Whole-of-System, Values-Based Framework that account for the diverse services that wetlands provide and the challenges they face in a changing environment.

6.3 Systems repair

Systems repair is defined in the Whole-of-System Values-Based Framework as *“improving processes or components of an ecosystem to a desired state that will deliver agreed ecosystem services and values,*

*primarily through natural means*²⁰. Systems repair management options are relatively low risk compared to engineered solutions but must consider connections to other systems and processes. They might be adopted in instances where the ecosystem may be able to repair itself or do so with minimal engineering. In many cases systems repair requires reinstating or improving vegetation cover (e.g. through natural regeneration or active revegetation), removing some of the pressures on the system or changing minor hydrological flows (e.g. barrier removal).

The focus of this section is systems repair in freshwater wetlands, in the context of the role of wetlands in water quality improvement. System repair activities such as riparian revegetation and small-scale gully management are already incorporated into the P2R Water Quality Risk Frameworks and identified above.

As noted above, the 2022 SCS reviewed the role of natural/near-natural wetlands and constructed / treatment wetlands in water quality improvement in the GBR (Star et al. 2024; Waltham et al. 2024). The review was further expanded in Waterhouse et al. (2024c). These reports built on the extensive information available on *WetlandInfo*. The evidence shows that natural/near-natural and constructed/treatment wetlands can be effective in water quality improvement in certain conditions, however, it is crucial to equally prioritise wetland health, intrinsic values and the ecosystem services that natural/near-natural wetlands provide. The report evaluated the ability of several wetland and treatment systems to reduce pollutants and the key findings are extracted below.

Natural and Near-Natural Wetlands

- Global evidence shows that natural and near-natural wetlands, which include lacustrine, palustrine, and riverine wetlands, are typically more effective at nutrient and pesticide removal than constructed or restored wetlands, and that sediment is often retained in wetlands but can be remobilised in large flow events.
- Their performance depends heavily on hydrological factors including residence time and flow, vegetation cover, pollutant concentrations and loading rates which influence rates of denitrification. High denitrification rates can lead to high removal of nitrogen, particularly in first flush events. Only a few studies in the GBR have measured denitrification rates in palustrine and lacustrine wetlands.
- The review of global studies suggest that natural wetlands can remove nitrogen at efficiencies of 63% and phosphorus at efficiencies of 75%, and near-natural wetlands at efficiencies of 34% for nitrogen and 54% for phosphorus, although this varies across different wetland systems and environmental conditions. These rates refine the findings of the 2017 SCS and are now supported by a much larger evidence base.
- There is limited evidence about the effectiveness of sediment processing in natural and near-natural wetlands, with some trapping occurring, although sedimentation can cause shallowing and infilling of natural wetlands compromising wetland values. There are very few studies for pesticides globally and there are no studies that measure pesticide/herbicide removal in GBR wetlands, only studies that measure *in situ* concentrations. However, the potential negative impacts of pesticides on wetland ecosystems are an important consideration.

Constructed/Treatment Wetlands

- Generally, constructed/treatment wetlands are effective in nitrogen removal if appropriately designed and built, with effectiveness increasing over time if the system is properly maintained.
- Constructed wetlands in the GBR catchment area have demonstrated nitrogen removal rates ranging from -5% to 90%, depending on design, vegetation, and inflow concentrations. Studies have demonstrated that constructed wetlands with higher vegetation cover (which promotes denitrification) and optimised hydrology perform better.
- There is more confidence in the evidence about the effectiveness of treatment wetlands than other wetland systems due to the higher number of studies (including in the GBR) and the fact that measuring removal efficiencies in constructed systems is more straightforward than in natural wetlands.

²⁰ <https://wetlandinfo.des.qld.gov.au/wetlands/management/rehabilitation/rehab-process/step-4/systems-repair.html>

- Bioreactors, which use organic materials like woodchips to enhance microbial nitrogen removal, have demonstrated significant potential in agricultural settings when effectively designed and strategically placed. For instance, studies in the GBR have shown that bioreactors can remove up to 80% of nitrogen, with performance largely dependent on nitrate concentration, subsurface flow pathways and water flow rates. However, challenges related to design (including placement in the landscape) and maintenance can impact their overall effectiveness. There were limited studies that reported removal efficiencies for total phosphorus, sediments, and pesticides.
- Although less studied in the GBR, stormwater wetland systems in urban areas have shown global success in treating runoff when properly designed and maintained. These systems are particularly effective in removing coarse sediments and nutrients from urban stormwater.

There are several important considerations for maximising pollutant removal efficiency and determining future protection and management opportunities for GBR wetlands. These include the hydrological characteristics (water flow and residence time), presence of vegetation, type and density, pollutant concentrations and loads, wetland configuration, climate and seasonal variability, biogeochemical processes, and the need for ongoing and long-term management of natural wetlands and maintenance of treatment systems. While the importance of these factors varies between different wetland and treatment systems, hydrology and vegetation are key drivers to pollutant processing in most systems. The performance of treatment systems in water quality improvement depends on careful design, ongoing maintenance, and integration within the broader landscape and management of natural wetlands and their surrounds. Other pollutants, such as pesticides and sediment can be reduced within wetland systems, but can cause negative effects such as vegetation loss, siltation and impacts on biological communities.

Wetland rehabilitation projects can come with significant costs, influenced by factors such as hydrology, location, and design requirements (Star et al. 2024). International studies highlight key cost drivers for wetland construction and rehabilitation, including design, construction, and ongoing maintenance. Understanding these cost drivers is crucial to designing effective and sustainable wetland projects, particularly with regard to incentivising landholder participation and ensuring long-term sustainability. Key considerations for assessing cost-effectiveness of projects and programs include initial construction and design, maintenance and monitoring, and economic and environmental co-benefits.

To maximise the benefits of wetland and treatment systems, it is essential to invest in long-term monitoring, research, and adaptive management strategies such as the Whole-of-System, Values-Based Framework that account for the diverse services that wetlands provide and the challenges they face in a changing environment.

6.3.1 *Specific actions linked to wetland condition*

Management actions for wetlands have been identified for this assessment to help to focus management options within management units. Suggested foci of management options for wetlands/aggregations within management units include:

Safeguarding or re-establishing native vegetation: Protect existing native vegetation and /or re-establish vegetation, including grasslands, woody grasslands, and other woody vegetation, both within wetlands and their buffer zones. This also involves maintaining the structure and composition of the remnant regional ecosystems and preventing the introduction, establishment, or spread of exotic vegetation, re-establishing connectivity from wetlands extending to the broader landscape and avoiding vegetation clearing in and near wetlands.

Maintaining or reinstating hydrological integrity: Preserve or reinstate the natural flow of floodplains, the hydrological connectivity of wetlands, and their natural water regimes. This includes minimising or reducing water abstraction for human or animal use and preventing further hydrological modifications such as bunding, excavation, drainage, and irrigation activities. Additionally, impacts from existing hydrological modifications should be mitigated, and the development of linear infrastructure of wetlands avoided or mitigated where it can impact a wetland.

Preventing, controlling and reducing spread of exotic and invasive species: Protect wetlands and their buffer zones from the introduction, establishment, and spread of plant and animal pest species, as well as exotic plants.

Minimising and controlling pollution: Safeguard against anthropogenic sedimentation, pesticide inflows, and excessive nutrient inflows. Prevent the introduction of stormwater and other point source inflows into natural wetlands, regularly maintaining existing septic systems and new septic installations should avoid proximity to wetlands.

Minimising and/or reducing soil disturbance: Minimise, control and reduce ungulate access and human activities that disturb and expose the soil surface in wetlands and their buffer areas. Ensure that groundcover is maintained to protect the soil.

Based on these foci, more specific management actions aligned with the condition indicators used in the wetland assessment are detailed in Appendix 8.

Many of the actions are recommended for application in the monitored wetland aggregations specifically. The P2R Wetland Condition Monitoring Program captures around 65% of freshwater floodplain wetlands based on version 3 of the wetland mapping, which was current when the program was established. Although the methods used at the time may have missed areas where there are few, but larger wetlands, or those with a more linear distributions (mostly inland), it did capture most aggregations, important wetland areas and a significant portion of freshwater floodplain wetlands. While the area / number of monitored wetlands is small, the program was designed to be spatially balanced and representative of wetlands within the combined suite of aggregations. The reasons for targeting the suggested management focus on the monitored aggregations are:

- The aggregations capture a significant number / area of freshwater floodplain wetlands within management units, including those in lower floodplain nearer to the coast.
- Targeting the monitored aggregations allows for a coordinated approach to addressing landscape scale as well as wetland specific management responses.
- Focusing management action on the monitored aggregations allows for concerted and targeted efforts, that can be more cost effective and likely result in a greater water quality, landscape and ecosystem benefits than a more scattered approach.
- The actions listed in Appendix 8 are aligned with the indicators used to assess condition within the monitored aggregations and thus determining wetland condition. Although it is possible that wetlands outside of the sample areas (aggregations) would result in the same condition outcomes this is not certain, so recommendations to apply the same actions may not be appropriate since those wetlands are not part of the representative sample.
- A focus on the monitored aggregations does not discount the values of wetlands outside of these areas and some communities may choose to include a wider scope of wetlands.
- Greater focus on the aggregations would support observation of the implications of such management actions on the wetlands values through capturing and quantifying the outcomes through the monitoring efforts.

The application of these management options in the context of the water quality management response assessment is explored further in Section 7.2.

6.4 Monitoring, evaluation and applied research

Effective monitoring is essential for assessing the success of management changes aimed at improving water quality in the GBR. Monitoring programs provide critical data to assess and track trends in water quality and ecosystem condition, evaluate the effectiveness of management responses, and ensure management

objectives are being met. The Queensland Wetlands Program Whole-of-System, Values-Based Framework recognises that monitoring may be undertaken for different purposes²¹, including:

- **Status:** Assessing the condition of water quality and ecosystem health over time.
- **Trend:** Detecting changes in key water quality indicators, such as sediment and nutrient loads and pesticide risk, and ecosystem condition to determine whether conditions are improving or deteriorating.
- **Implementation:** Evaluating how well a management intervention (e.g. riparian revegetation) has been put into practice.
- **Effectiveness:** Measuring whether the intervention has achieved its intended water quality improvements.
- **Validation:** Comparing real-world outcomes against conceptual or empirical models to confirm the effectiveness of management actions.
- **Surveillance:** Ensuring that a site maintains its water quality condition and that no new pressures emerge.
- **Investigative:** Understanding the key processes affecting water quality and the interactions between land use and aquatic ecosystems.

It is out of the scope of this assessment to consider this wide variety of monitoring purposes and to define the detailed monitoring, evaluation and applied research needs for all basins and management units in the GBR. However, a number of principles have been incorporated to the Water Quality Management Response Decision Support Framework described in Section 7. While many of these aspects are incorporated to varying degrees within the P2R program, the current spatial or temporal extent may include limitations that need to be addressed.

In essence, as pollutant exposure levels increase across basins and/or management units, monitoring, evaluation, and applied research activities should correspondingly expand in scope, intensity, and integration. In areas with minimal pollutant exposure, ongoing routine monitoring of key indicators of pollutant exposure and ecosystem condition establishes essential baseline data and enables early detection of emerging issues or changes. Surveillance of water quality drivers such as groundcover extent, woody vegetation extent, floodplain wetland extent, is required to identify likely causes of any changes. Monitoring programs should expand to incorporate new developments and potential sources, complemented by targeted investigations into specific areas of concern or knowledge gaps. Existing monitoring efforts may need to be expanded to incorporate condition monitoring for areas that are not currently assessed. Reactive monitoring of large-scale disturbance events (e.g. large episodic rainfall and discharge events, cyclone, or bleaching events) will be necessary to inform management responses for recovery and repair, as well as understanding increased scales of pollutant exposure and impacts on ecosystems.

As pollutant exposure increases, additional and comprehensive Monitoring, Evaluation, Reporting, and Improvement (MERI) frameworks become essential, providing structured approaches for adaptive management and systematic learning. These frameworks need to evaluate both the implementation of actions and their effectiveness in improving water quality outcomes. At this level of response, integrated monitoring systems that track multiple parameters across various spatial and temporal scales are necessary, alongside sophisticated modelling to understand complex pollutant dynamics, trends, and system responses. While the P2R program provides a comprehensive framework for this level of assessment, the need for applied research will be ongoing as new practices or combinations of practices and approaches are implemented, or conditions change. Throughout this progression, a focus on both process indicators (measuring implementation) and outcome indicators (measuring actual water quality and ecosystem improvements) would ensure that management interventions remain effective and responsive to changing conditions. Outcome indicators require long-term monitoring sites underpinned by skilled capacity and resources to analyse and interpret trends across a range of indicators, processes and system components.

²¹ <https://wetlandinfo.des.qld.gov.au/wetlands/management/rehabilitation/rehab-process/step-4/applied-research.html#citation-reference-1>

Maintenance efforts, and the implementation of monitoring metrics to evaluate maintenance outcomes on a regular basis, are required. Monitoring efforts in the GBR benefit from partnerships among government agencies, universities, industry, NRM bodies, and community groups. Citizen science initiatives also contribute valuable data, increasing public engagement in GBR protection efforts.

An important consideration in whole-of-system approaches is the incorporation of social indicators to evaluate the ‘how’ of program delivery. For example, monitoring and evaluation metrics often fail to measure the impacts of collaborative processes. While this is not within the scope of this assessment, it is identified as an important element in any supporting monitoring and evaluation program.

Finally, assessing the cost-effectiveness of actions, projects and programs in a consistent way continues to be a challenge for GBR water quality initiatives. Quantification of the cost-effectiveness of management solutions across projects, programs and instruments using consistent and comparable approaches was identified as a priority knowledge gap in the 2022 SCS (Waterhouse et al. 2024a). Consistent and agreed metrics should be incorporated to management programs as a high priority to support future decision making and investment programs.

6.5 Planning, extension, trust-building and collaboration

6.5.1 Planning and institutional arrangements

Planning and institutional arrangements encompass the policies, systems, processes, and structures that organisations use to plan, manage, and coordinate their activities, ensuring efficient and effective implementation of their mandates. The planning and institutional arrangements for the GBR are extensive, involving multiple levels of government, Traditional Owners, industry, and community stakeholders. These frameworks aim to ensure coordinated policy development, implementation, and monitoring efforts to protect the GBR’s ecological, social, economic and cultural values.

It is outside the scope of this report to undertake a comprehensive review of the relevant planning and institutional arrangements for managing water quality in the GBR. However, it is recognised as an important factor in the water quality management response assessment. The key governance and institutional frameworks of relevance to GBR water quality management include:

- The Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan) which is the overarching strategy for protecting the GBR. It is co-developed by the Australian and Queensland Governments with input from scientists, Traditional Owners, and stakeholders. It is underpinned by Australian Government-funded Reef Trust and climate adaptation and resilience programs, and the Queensland Government Reef Water Quality Program.
- The Reef 2050 WQIP which specifically aims to improve water quality in the GBR.
- Regional plans for water quality improvement, for example, the Reef Regional Water Quality Strategies currently in development and earlier Regional Water Quality Improvement Plans (which had direct links to water policy and legislation including the *Environmental Protection (Water) Policy 2009* under the *Environment Protection Act 1994* and links to the National Water Management Strategy).
- Local Government Planning Schemes and relevant legislation.
- Indigenous Australians, particularly Traditional Owner groups, have a crucial role in managing Land and Sea Country. Institutional arrangements include: Traditional Use of Marine Resources Agreements (TUMRAs), co-management agreements recognising Indigenous rights to marine resources, Indigenous Land and Sea Ranger Programs, and supporting Indigenous rangers in monitoring and conservation activities.

- There are several key policies and plans that guide decision making and implementation for water quality outcomes such as the Reef 2050 Wetlands Strategy²² and the Reef 2050 Traditional Owner Implementation Plan²³.
- There are a number of legislative requirements to consider in water quality management such as the *Great Barrier Reef Marine Park Act 1975*, *Environmental Protection Act 1994*, Environmental Protection (Water and Wetland Biodiversity) Policy 2019, Reef Protection Regulations, [*Chemical Usage \(Agricultural and Veterinary\) Control Act 1988*](#), native vegetation management (Vegetation Management Act 1999, in conjunction with the Planning Act 2016), protected flora (Nature Conservation Act 1992) and cultural heritage (Aboriginal Cultural Heritage Act 2003).

Institutional and governance arrangements including intergovernmental coordination, the adoption of collaborative approaches and key aspects such as the lack of long-term funding are critical factors that influence the delivery and implementation of water quality programs in the GBR. The approach to on-ground investment should consider the potential constraints and impacts on trust-building and collaboration. Short-term projects, short-term contracts for extension staff, and other priorities (e.g. scientific publications and impact metrics) have been observed to constrain collaborative approaches and the critical relationship building required to establish trust (Coggan et al. 2021; Murray-Prior et al. 2024).

6.5.2 Effective Traditional Owner engagement

The Reef 2050 Traditional Owner Implementation Plan outlines actions to achieve Traditional Owners' aspirations for the GBR as part of the Reef 2050 Plan. It brings Traditional Owner actions together from across the Reef 2050 Plan into a cohesive framework for implementation. The Plan identifies six Work Areas including one related to Land and Coast. The Plan states: *"This part of the Plan is about reducing impacts to the GBR from the land by improving the health of our waterways and coastal ecosystems. It is about freshwater. How it flows through Country and connects us all - from the top of the range, across land to the sea. And how we need to work together to design more holistic programs that tackle the things that have made our freshwater sick and how to make our Country healthy again. There are a lot of big programs aimed at improving the health or 'quality' of water in the catchment. But until recently there has been little recognition of our connections to Country, our traditional knowledge and practices, or the value our culture places on water and our coastal ecosystems. What it means to us and how we care for Country. This is slowly changing but more needs to be done."* Through this Plan, Traditional Owners hope to build capacity and create opportunities for Traditional Owners to lead and work with partners to co-design more holistic place-based programs which bring actions around water, wetlands, and shorelines together to help get Country and People healthy again. The Plan identifies eight actions to support Traditional Owner-led and co-designed programs, projects and initiatives including approaches to increase the level of Traditional Owner participation in the governance, design and delivery of major GBR water quality programs, provide leadership opportunities and increase Traditional Owner connections with Country through cultural heritage mapping, planning and improved protection of sensitive sites.

The 2022 SCS provides an additional resource for decision makers seeking evidence of the critical success factors for greater Indigenous involvement in water quality decision making and management for the GBR (Espinoza et al. 2024). While Indigenous knowledge and input would be required to fully address this question, the 2022 SCS process identified several factors and learnings from national and international peer reviewed studies which align with the actions identified in the Plan above. Improved understanding and collaboration across all sectors of natural resource management to recognise Indigenous connections to Country, the need for improved engagement frameworks specifically recognising social and cultural factors, and the socio-ecological benefits of Indigenous involvement in management and decision-making were identified as common needs for environmental programs globally. Critical factors and key learnings from national and international studies included increased understanding and knowledge of Indigenous culture

²² <https://wetlandinfo.des.qld.gov.au/resources/static/pdf/management/policy/reef-2050-wetlands-strategy-report.pdf>

²³ https://reefto.au/wp-content/uploads/2023/09/DES_GBR_TO-Report_WEB.pdf

and connection to Country, helping to establish trust and respect between all partners through relationship building, support for increased capacity to engage and become involved in programs, support for improved capability to collaborate and deliver across all aspects of planning and delivery, and adoption of an adaptive management approach to program delivery.

It is outside the scope of this report to go into the detail of the delivery and implementation of actions to support and improve Traditional Owner engagement in GBR water quality plans, programs and initiatives. However, Traditional Owner engagement is recognised as a critical component of management responses for water quality improvement in the GBR and is incorporated into the water quality management response assessment in Section 7.

6.5.3 Extension, education, capability and capacity building

The rate and scale of adopting land management practices to improve water quality needs to increase as pollutant exposure increases (particularly if good water quality is required for ecosystem resilience and recovery from climate change impacts), requiring investment in activities and processes that will encourage more intensive and larger-scale adoption rates. The 2022 SCS included a review of factors affecting the adoption of management practices in the GBR. It focused on system level factors rather than individual factors. Murray-Prior et al. (2024) concluded that *“While real and perceived economic factors are important to landholder decision making, even profitable practices can take time to be adopted because of the interactions within and between economic factors and landholders, research, extension, industry and community attitudes and systems. Less profitable practices are likely to take even longer and will require further development of approaches, supporting policies and instruments. Additionally, for all land uses, demonstrating links between practice change and improved water quality outcomes is an important factor that could enable and hinder practice adoption”*. Other factors for major land uses that are critical for the design of extension and education programs were also identified, including:

- For sugarcane: Social norms, costs of adoption, compatibility with farming systems, economies of size effects, and the interaction of technology characteristics and context.
- For grazing: The interaction of weather and climate with property and decision-maker context, financial and other support over time, transaction costs and skills required.
- For urban: Social resilience, and innovative and adaptive capacity may be important.

The ADOPT process was able to identify practices to target to improve water quality. Selecting a behaviour (a practice) is the first step in designing a behaviour change strategy. There are additional steps that need to be taken to identify and ground truth the current state of the influences on adoption. The next step is to identify the current state of the influences on adoption through the triangulation of varying data sources (such as through observation, focus groups, surveys, etc.) (McKenzie-Mohr 2008). Data from landholders on their perceptions of management practice changes collected by the Behavioural Insights team in OGBRWH as part of the P2R Human Dimension program (Kanakakis et al. 2024), and additional data sources providing broader insights into factors which influence adoption, need to be considered. As identified through the ADOPT process, these influences will vary depending on the practice itself, the industry, and the region. The influences on adoption can be categorised as:

- **Capability:** Psychological (e.g. awareness, knowledge) and physical (e.g. skills)
- **Opportunity:** Physical (e.g. environmental context, resources, costs) and social (e.g. norms)
- **Motivation:** Reflective (e.g. beliefs, intentions) and automatic (e.g. emotions, habits) (Michie et al. 2011).

Trust can influence each of the above categories (e.g. trust in the information source, trust within a group). Evidence consistently shows that landholder distrust of government, scientists, and program delivery organisations hinders the adoption of recommended management practices that could improve GBR water quality outcomes (Murray-Prior et al. 2024). This mistrust creates a barrier that even well-designed technical solutions and financial incentives struggle to overcome. Identifying trusted stakeholders and information sources, as well as building trust in management institutions and the scientific evidence that underpins

decision-making and solutions, is foundational for adoption of conservation-related behaviours and changes in land management practices (Curnock et al. 2024; Murray-Prior et al. 2024).

Once the practice has been selected, and the influences identified, a strategy can then be developed that increases the benefits and decreases the barriers to practices that can minimise impact on water quality and decreases the benefits and increases the barriers to practices that can decrease water quality. There are a range of behaviour change strategies that can be used to achieve this and that can be used in unison to achieve accelerated adoption. Some examples of behaviour change strategies include gaining commitment, prompts, increasing convenience, norms and social diffusion, services (e.g. one-on-one extension) and products (e.g. equipment, decision tools), communication, and incentives/disincentives (including nonmonetary) (McKenzie-Mohr 2008).

With respect to determining appropriate delivery models and engagement approaches, an overarching conclusion of the 2022 SCS states that *“Greater focus on locally effective management solutions can encourage faster adoption, especially when designed and delivered using collaborative approaches involving landholders, Indigenous communities, the broader community, policy makers and scientists”* (Waterhouse et al. 2024a). Collaborative approaches that actively involve key groups throughout the entire process—from problem identification to solution development, testing, and scaling—are critical to overcome barriers of mistrust (Murray-Prior et al. 2024). Evidence indicates that collaborative principles in planning and implementation not only build essential trust but also improve the effectiveness of management practices (James 2021). While these approaches require greater initial investment than traditional top-down delivery, they ultimately reduce implementation costs by increasing voluntary adoption and reducing compliance needs (James 2021).

Developing appropriate and scaled engagement models, interventions and behaviour change strategies will require a robust scientific approach, utilising the available data and developing a deep understanding of target audiences through direct engagement and shared experiences. Collectively, these can help overcome resistance to recommended water quality management practices and facilitate more effective collaboration between scientists, policymakers, and stakeholders (Coggan et al. 2022).

The water quality management response assessment in Section 7 recognises that engagement, extension and education play a critical role in the design, delivery and implementation of management options. As described in Section 6.1.1.3, there are many factors that influence landholder and stakeholder engagement in delivering management options that improve GBR water quality.

Extension in this context implies professional capacity building through skills and education which employs the range of extension models (Figure 55), depending on the situation and need. These extension models have varying requirements for resourcing as well as large variations in their effectiveness, particularly for complex issues. Raising awareness through the provision of information is appropriate for easily implemented and adopted issues, however, issues with a track record of low adoption will generally require emphasis on one-on-one extension.

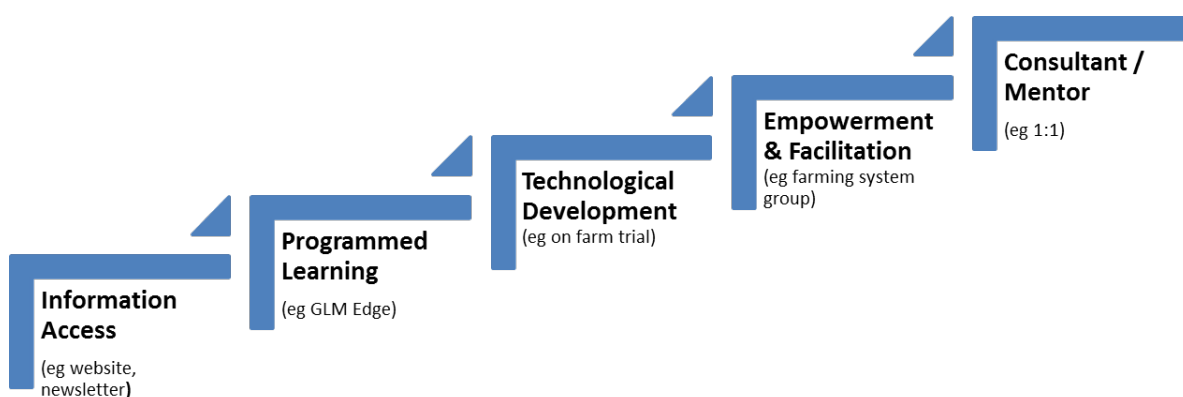


Figure 55. Extension models employed in capacity building extension. Source: Coutts and Roberts (2003).

Extension programs in the GBR for water quality outcomes have shown promise, with one-on-one extension more effective than group-based activities in promoting practice changes (Wegscheidl et al. 2015; Rolfe et al. 2020). Technology and co-designed monitoring-extension platforms can help overcome stakeholder scepticism, acknowledging that water quality risks vary across different ecosystems and seasons (e.g. Davis et al. 2017; Waterhouse et al. 2017a).

Extension models can be grouped together into similar types such as empowerment and facilitation, and consulting/mentoring such as the formation of a network of participatory action learning teams. In the latter, teams are built around existing socio-geographic networks and within local areas and are typically a partnership between producers and the project staff where there is a high degree of commitment, trust and participation. The approach supports a producer-driven process supported by a multi-disciplinary skilled project team. Learning and capacity building is enabled through identifying areas for improvement, and the knowledge, skills, and actions necessary to make those improvements. The initial focus within each team is identifying management improvements leading to production and/or profit enhancement in the context of managing a business that is viable in the long-term, including consideration of the natural resource base. For this model, one-on-one relationships are often formed to support the landholder to continue with their long-term management changes (Williams et al. 2021).

Review of past Australian and Queensland Government investments to understand the cost implications of programs (Coggan et al. 2024) indicates that with a focus on information access, programmed learning, and technological development, large numbers of landholders are engaged but smaller reductions in loads are achieved over a larger area. These types of programs do not require the same level of staff capacity as the approaches that focus on empowerment and the consult/mentor level of extension. It is also necessary to consider the spatial and capacity elements of extension effort in terms of time and ability to meet landholders on a one-on-one basis, and the need to have the skilled workforce to deliver this level of extension.

As described in Section 6.1.1.3, the cost of past projects has been reviewed as part of this assessment. Past extension projects in grazing have been assessed in the P2R frameworks as the reduction of hillslope sediment load, regardless of the connectivity to other landscape remediation activities. For grazing these costs have ranged from \$73 to \$6,038 per tonne of fine sediment delivered to the end-of-catchment. For sugarcane there has been a range of \$202 to \$572 per tonne of DIN delivered to the end of the catchment (noting that sugarcane areas are typically on the coast and near the end-of-catchment, so have high delivery ratios). The cost of pesticide load reduction through sugarcane extension has also been assessed.

Economic factors play an important role in landholder decision making, however, even profitable practices can take time to be adopted and less profitable practices even longer (Murray-Prior et al. 2024). In recognition that practice adoption takes time, extension programs should maintain consistent presence and build relationships that support ongoing change. There is a strategic opportunity to implement proactive management responses in catchments with low or minimal pollutant exposure, establishing the programs and relationships early on before water quality becomes a bigger issue.

6.5.4 Science communications

Effective science communication serves as a critical bridge between evidence and action in water quality management, transforming complex scientific understandings into accessible knowledge that can drive meaningful change across the GBR catchment area. Science communication is a critical aspect of education, engagement and capacity building and can be considered across five key dimensions:

1. **Awareness and understanding:** Foundational activities that create broad recognition of the projects, the outputs of the projects, the key scientific understandings and its potential outcomes for different stakeholder groups.
2. **Knowledge translation:** Converting complex scientific findings into accessible, relevant information for different audiences. This helps to bridge the gap between scientific understanding and its practical application.

3. **Engagement:** Activities that facilitate meaningful engagement/dialogue with stakeholders and Traditional Owners to help them meet their knowledge requirements, access scientific information, connect the science with local contexts and values, and build confidence in the ability to make informed choices in relation to management changes through education.
4. **Long-term trust building:** Activities that help build long-term public trust in the scientific information, build credibility with stakeholders and Traditional Owners, and help counter distrust and misinformation.
5. **Evaluation and feedback:** Activities to measure the effectiveness of the communication activities and strategy overall and adapting approaches based on responses. This ensures continuous improvement and responsiveness.

The need for the implementation of activities within these dimensions would depend on the situation, and program objectives. The potential implications of the different approaches would need to be considered. For example, some studies in the GBR have investigated the impact of communication strategies on scaling and adoption of management practices. Hay et al. (2019) found that message complexity, message tone, and the relationship between verbal and visual imagery can influence its perception and have positive, negative or unintended consequences. Framing of messages was found to have an effect, with positive framing of a diversity of farmers' stories being a factor that promotes change (Kealley and Quirk 2016; Hay et al. 2019; Pickering et al. 2019; Moore et al. 2021; Herd et al. 2022). For example, a key element of the Cane Changer project was to destigmatise change by 'setting the record straight' (Pickering et al. 2019; Moore et al. 2021). As a result of their deliberate strategy to promote positive stories across the industry, participants felt more positively recognised by the community and accepted a greater personal responsibility for water quality (Pickering et al. 2019).

In addition to the challenges of translating and communicating scientific knowledge for developing policies, designing fit-for-purpose management strategies, supporting behaviour change and ensuring the evidence is accessible for non-technical audiences and end-users, uptake and trust of evidence is also challenged by mistrust in science and research institutions, particularly global trends in climate change denialism, anti-science sentiment, and misinformation (Curnock et al. 2024). Lack of trust in scientific information can arise for several reasons: the need for translation by intermediaries creates opportunities for misinterpretation; media fragmentation limits the reach of science-based content; and broader societal polarisation. These factors, combined with deliberate misinformation, can undermine public support for evidence-based water quality policies and practices (Curnock et al. 2024). Effective science communication strategies can help build trust by using relatable messengers, demonstrating shared values and a common vision, using clear framing of issues and solutions, showcasing scientific consensus while being honest about uncertainties, maintaining scientific integrity in policy contributions, and committing to long-term participatory engagement. Developing these approaches requires deep understanding of target audiences. As demonstrated in the Project Bluewater 2 case study (Section 6.1.5), direct engagement and shared experiences can help overcome resistance to recommended water quality management practices and facilitate more effective collaboration between scientists, policymakers, and stakeholders.

Consistent messaging from trusted sources and integrating these with social media strategies have been suggested as likely to improve uptake (Wegscheidl et al. 2015; Hay et al. 2019). This messaging should not be confined to farmers, but should also include industry advisors, industry advocates and regional partners (Wegscheidl et al. 2015; Herd et al. 2022). Messaging needs to be flexible and tailored for context so that it meets the needs of farmers with different motivations and goals (Greiner et al. 2009; Pickering et al. 2017; Hay et al. 2019; Cleary et al. 2022). Where possible messaging should focus on the triple bottom line for landholders (Lockie et al. 2002; Wegscheidl et al. 2015; Kealley & Quirk 2016). This is discussed further below.

7. Water quality management response assessment

7.1 Overview of the Water Quality Management Response Decision Support Framework

The Framework guides management responses based on two factors: pollutant exposure (or hazard) to ecosystems and current ecosystem condition (Figure 56). These factors combine to determine the appropriate management response level and suggested scales of intervention for each basin and/or management unit. There are four key management response levels determined by pollutant exposure that include and build on from the Foundational management response. The **Foundational** management response should be applied across all GBR catchments as a minimum response.

1. The **Foundational management response** includes all the core components of management to set the foundation of water quality management in all areas to maintain good water quality and prevent future issues. This includes those areas that have Minimal water quality exposure and ecosystems in Good condition. The response should build on the strengths of what is already established and available: e.g. skills, expertise, and innovations, and the networks, relationships and trust with stakeholders, Traditional Owners and communities. The scale of effort is broadscale and could be viewed as a minimum level of water quality management across the GBR catchment area. This response focuses on maintaining regulated minimum practice standards, regulatory compliance, actively maintaining ecosystem values and services, fostering Traditional Owner involvement, identifying established strengths for program delivery, design and development of fit-for-purpose engagement models for supporting adoption of sustainable land management practices with water quality benefits, strategic communications, building relationships and preparing for future developments.
2. The **Proactive management response** builds on the *Foundational* management response with localised actions where pollutant exposure is Low but may be increasing. Adopting a proactive approach will ensure that emerging issues are addressed and good water quality is maintained in these areas into the future. Small-scale localised interventions could include actions in specific land uses, active uptake of practices with water quality benefits, small scale system repair and landscape restoration actions and presence of industry stewardship programs.
3. The **Accelerated management response** builds on the previous management responses, with more targeted and coordinated approaches where pollutant exposure is Moderate and action to reduce pollutants needs to be stepped up. The focus shifts from 'preventing' to 'reducing' pollutant exposure and impact, and the need to manage pollutant exposure to support ecosystem recovery potential, and reducing or managing disturbances (where possible) at the local or regional scale. This requires targeted and tailored management options, most likely across multiple land uses with a diversity of management options in strategically defined and targeted sub-catchment areas within the basin or management unit. Greater levels of collaboration more intensive coordination and planning, strategic design, program development and delivery are critical to support accelerated change.
4. The **Intensive management response** requires comprehensive, urgent action across multiple land uses where exposure is High and ecosystems may be under significant stress. It builds on previous management responses with increasing intensity to deliver large-scale land management, targeting all dominant pollutant sources, multiple land uses (with intensity depending on contributions) and water quality drivers. Involves integrated whole-of-system strategic design, planning and delivery of programs with implementation of a comprehensive suite of options for sustainable land management including management practices with water quality and co-benefits, engineered solutions and systems repair. Recognition of co-benefits is important to facilitate additional resourcing for areas requiring intensive management.

The current ecosystem condition also influences management actions in the framework. Within each management response level, there are additional actions that are triggered according to the ecosystem condition. These actions vary depending on the level of exposure:

- **Good condition** ecosystems: Require routine and ongoing monitoring of ecosystem condition and water quality drivers, with reactive monitoring of large-scale disturbance events. Under Moderate and High exposure, additional responses are required for **increased vigilance** of changes in ecosystem condition to ensure condition does not decline.
- **Moderate condition** ecosystems: Under Minimal or Low pollutant exposure an **investigation** would be triggered to determine the other pressures driving the poor condition (assuming it is not related to nutrient, sediment or pesticide impacts) and to inform relevant managers of the need to act. Under Moderate or High pollutant exposure, a Moderate condition ecosystem would trigger **further assessment** to understand additional pressures on the ecosystem, to identify trends in ecosystem condition and to understand the role of pollutant impacts on the ecosystem's state to avoid further declines. **Tailored communications** on these ecosystems, drivers and pressure under threat should be developed and disseminated.
- **Poor condition** ecosystems: Under Minimal or Low pollutant exposure an **immediate investigation** would be triggered to determine the drivers of the condition and inform relevant managers of the need to act. Under Moderate or High pollutant exposure, a Poor condition ecosystem would trigger an **evaluation** of the ecosystem's ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Depending on the outcome of the evaluation, other intervention options may need to be considered. **Tailored communications** on these ecosystems under threat should be developed and disseminated.

		Pollutant Exposure			
		Minimal	Low	Moderate	High
Ecosystem Condition	Poor	Foundational response + Investigate	Proactive response + Investigate	Accelerated response + evaluate	Intensive response + evaluate
	Moderate	Foundational response + Investigate	Proactive response + Investigate	Accelerated response + further assessment	Intensive response + further assessment
	Good	Foundational response	Proactive response	Accelerated response + increased vigilance	Intensive response + increased vigilance
		Trust development, prepare for future developments	Small-scale intervention	Targeted intervention	Comprehensive intervention
Management approach					

Figure 56. Water Quality Management Response Decision Support Framework.

Table 24 describes the components of each of the Management Responses in terms of ecosystem condition, pollutant exposure, management focus, key characteristics of the management response, monitoring, evaluation and investigation needs, and potential program elements and delivery and activities that need to be considered as part of detailed program design to support water quality outcomes. These components align with the management options described in Section 6.

Table 24. Management Response Decision Support Framework.

FOUNDATIONAL RESPONSE (Minimal pollutant exposure) <i>Management aim: Good water quality is maintained to ensure that ecosystems remain protected from impacts of poor water quality into the future.</i>				
Management scale and Principles				
Elements of the management response	Potential mechanisms and activities for delivery of the management response <i>(All ecosystem condition levels)</i>	Additional activities by Ecosystem Condition <i>(Freshwater floodplain wetlands and Marine ecosystems)</i>		
		<i>Good</i>	<i>Moderate</i>	<i>Poor</i>
Sustainable land management options, interventions and strategies	• Maintain regulated minimum practice standards across all land uses. • Maintain and foster practices that go beyond the minimum standards. • Continue compliance of other regulatory requirements (e.g. vegetation clearing). • Maintain ecosystem values and services through best practice management, including reducing drivers of poor water quality and actively managing wetlands in monitored wetland aggregations (<i>depending on the condition – see Appendix 8 Tables 45 & 46</i>). • Foster Traditional Owner involvement in decision-making, program design and delivery, as per the actions to achieve Traditional Owner aspirations for the GBR outlined in the Reef 2050 Traditional Owner Implementation Plan. • Identify the established strengths of the area in program delivery, e.g. existing skills, capacity, capability, networks, past successes, and new opportunities. • Design and develop fit-for-purpose engagement models for supporting adoption of sustainable land management practices with water quality benefits, which may include: – Extension and education programs on minimum standards for land use and best practices for maintaining ecosystem values and services. – Positive recognition of existing practices with water quality benefits. – Capability and capacity building. – Community-based social marketing to foster community ownership, awareness and pride about state of natural systems and recognition of managers doing a good job. – Proactive trust development and regular engagement with new and established relationships, networks and key groups. • Deliver strategically designed and scaled communications for the area including promotion of good stewardship. • Embed key strategic governance and institutional planning frameworks and oversight to support water quality improvement including planning and protection mechanisms for key sensitive ecosystems that may be at risk from new developments or land use changes.		Tailored communications on ecosystems under threat	Tailored communications on ecosystems under threat
Monitoring, Evaluation and Investigation	• Ecosystem condition monitoring where there are current limitations to temporal or spatial coverage. • Routine/ ongoing monitoring of key water quality, catchment condition, behavioural insights and management indicators with expansion to incorporate the influence of new developments as required. • Reactive monitoring of large-scale disturbance events. • Integrated analysis, modelling, evaluation and reporting across indicators (including trend analysis). • Compliance monitoring of regulated activities. • Including Traditional Owner knowledge and the monitoring of values through practices that uphold cultural integrity and safeguard knowledge and information. • Broadly accessible information and results from local monitoring activities.		Investigate drivers of ecosystem condition & inform relevant managers of need to act	Immediate investigation of drivers of ecosystem condition & inform relevant managers of need to act

PROACTIVE RESPONSE (Low pollutant exposure) <i>Management aim: Ensure that emerging pollutant hazard / exposure issues are addressed, and good water quality is maintained into the future.</i>				
Management scale and principles - Implement Foundational management response - Small-scale, localised areas and programs for actions in specific land uses within the Basin or Management Unit				
Elements of the management response	Potential mechanisms and activities for delivery of the management response (All ecosystem condition levels)	Additional activities by Ecosystem Condition (Freshwater floodplain wetlands and Marine ecosystems)		
		Good	Moderate	Poor
Sustainable land management options, interventions and strategies	Implement the <i>Sustainable land management practices, interventions and strategies</i> of: Foundational Management Response level In addition to: - Identify where and how land management practice change can support water quality improvement. - Identify local and/or landscape water quality drivers of pollutant exposure in freshwater floodplain wetlands. - Assist uptake of land management practices with water quality benefits. - Implement small scale system repair and landscape restoration actions. - Design and develop fit-for-purpose engagement models, interventions and behaviour change strategies for supporting adoption of land management with water quality benefits, which may include: - Proactive planning and strategy development for delivery of programs in targeted areas. - Extension and education programs on practices and initiatives with water quality benefits. - Engagement of specialised capability and capacity for targeted areas. - Coordinated and collaborative processes in targeted areas. - Community-based social marketing (as per Foundational) with specific reference to local issues. - Presence of industry stewardship programs as point of engagement.		Tailored communications on ecosystems under threat	Tailored communications on ecosystems under threat
Monitoring, Evaluation and Investigation	Implement <i>Monitoring, evaluation & investigation</i> activities of: Foundational Management Response level In addition to: - Actively implement MERI (Monitoring, evaluation, reporting, improvement) for adaptive management. - Local water quality and condition monitoring designed to provide evidence of success of small-scale interventions. - Periodic evaluation of program effectiveness to inform future investments.		Investigate drivers of ecosystem condition & inform relevant managers of need to act	Immediate investigation of drivers of ecosystem condition & inform relevant managers of need to act

ACCELERATED RESPONSE (Moderate pollutant exposure) <i>Management aim: Accelerate efforts to reduce pollutant hazard / exposure, protect ecosystems and support recovery from escalating climate impacts.</i>				
Management scale and principles: - Implement Foundational and Proactive Management responses - Small- to medium-scale, tailored interventions in strategic and targeted sub-catchment areas across multiple land uses within the Basin or Management Unit				
Elements of the management response	Potential mechanisms and activities for delivery of the management response (All ecosystem condition levels)	Additional activities by Ecosystem Condition (Freshwater floodplain wetlands and Marine ecosystems)		
		Good	Moderate	Poor
Sustainable land management options, interventions and strategies	Implement the <i>Sustainable land management practices, interventions and strategies</i> of: Foundational Management Response level Proactive Management Response level In addition to: - Additional resourcing and coordination for planning, strategic design, program development and delivery to support accelerated change. - Identify critical success factors for accelerating adoption of practices and behaviour change (with water quality benefits) and assist with accelerated uptake of those practices. - Implement sub-catchment scale system repair and landscape restoration actions. - Coordinated and where necessary, specialist extension programs focused on targeted areas, communities and stakeholders. - Development of capability and capacity including institutional capacity for coordinated management and delivery. - Compliance agency presence with overt focus on education and awareness of duty of care. - Community-based social marketing (as per Foundational) also promotes positive norms around changing practices, social recognition and rewards for engaged managers.		Further assessment of ecosystem condition to understand additional pressures on the ecosystem, increase confidence in the condition status (in terms of trends) and/or the role of pollutant impacts. Tailored communications on ecosystems under threat	Evaluation of the ecosystem's ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment). Tailored communications on ecosystems under threat
Monitoring, Evaluation and Investigation	Implement <i>Monitoring, evaluation & investigation</i> activities of: Foundational Management Response level Proactive Management Response level In addition to: - Investigate ecosystem condition where confidence in condition is low (e.g. wetlands not previously monitored with moderate exposure level). - Local water quality monitoring with direct specialist technical support for land managers. Monitoring aims to clarify responsibility and promote ownership. Managers can engage individually or preferably in facilitated action-learning groups.	Increased vigilance of changes in ecosystem condition for areas of 'Good' condition	Increased monitoring of ecosystem condition	Increased monitoring of ecosystem condition

INTENSIVE RESPONSE (High pollutant exposure) <i>Management aim: Maximise efforts to address high pollutant hazard/ exposure to reduce widespread water quality impacts within critical timeframes, enabling ecosystem recovery in response to escalating climate impacts.</i>				
Management scale and principles - Implement Foundational, Proactive and Accelerated management responses - Comprehensive and large-scale land management, targeting all dominant pollutant sources, multiple land uses and water quality drivers				
Elements of the management response	Potential mechanisms and activities for delivery of the management response (All ecosystem condition levels)	Additional activities by Ecosystem Condition (Freshwater floodplain wetlands and Marine ecosystems)		
		Good	Moderate	Poor
Management scale	Large-scale land management, targeting all dominant pollutant sources, multiple land uses and water quality drivers + Foundational, Proactive and Accelerated management responses.			
Sustainable land management options, interventions and strategies	Implement the <i>Sustainable land management practices, interventions and strategies</i> of: Foundational Management Response level Proactive Management Response level Accelerated Management Response level In addition to: - Integrated, whole-of-system strategic design, planning and delivery of programs. - Identify and deliver a comprehensive suite of interventions for sustainable land management, including land management practices, landscape-scale system repair, and landscape restoration actions with water quality benefits. - Facilitate urgent uptake of identified practices and interventions. - Identify the current state of influences on scaled adoption and behaviour change and incorporate into program design. - Identify scaling bottlenecks and build capacity for scaling to support the successful expansion and adoption of interventions (e.g. skills and capacity, adoption levels, resources). - Foster institutional leadership and policy change to support scaling of interventions.		Further assessment of ecosystem condition to understand additional pressures on the ecosystem, increase confidence in the condition status (in terms of trends) and the role of pollutant impacts. Tailored communications on ecosystems under threat	Evaluation of the ecosystem's ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem restoration/recovery may need to be considered (based on values assessment). Tailored communications on ecosystems under threat
Monitoring, Evaluation and Investigation	Implement <i>Monitoring, evaluation & investigation</i> activities of: Foundational Management Response level Proactive Management Response level Accelerated Management Response level In addition to: - Real time monitoring and reporting to support adaptive learning and scaling of sustainable land management. - On-farm trials of alternative practices to address water quality issues.	Increased vigilance of changes in ecosystem condition for areas of 'Good' condition	Increased monitoring of ecosystem condition	Increased monitoring of ecosystem condition and values

7.2 Results of the water quality management response assessment

The results of the water quality management response assessment are presented in Table 25. Management response outcomes for freshwater floodplain wetlands were based on exposure at the management unit scale (Exposure-MU), rather than exposure at the GBR catchment scale (Exposure-GBRCA), along with wetland condition assessment results where available. As such, outcomes of the Management Response Decision Support Framework for the 21 management units with no wetland condition data available are based on Exposure (MU) results only. Outcomes for the remaining 27 management units are based on Exposure (MU) and condition assessment results. Those 27 management units contain at least one monitored wetland aggregation, with each having a minimum of one wetland monitored at least once to date, as part of the GBR Wetland Condition Monitoring Program (see Section 5.2).

The marine-driven management response was based on the exposure assessment for DIN and sediment (Section 4.2), and the end-of-catchment pesticide risk assessment where available. The marine ecosystem condition in Section 5.3 provides the basis for the condition assessment, noting that there are some limitations to the spatial coverage of ecosystem monitoring in some regions. As these assessments were undertaken at a basin scale, the marine results have not been directly applied to the management units within the Burdekin, Fitzroy or Herbert basins.

The results in Table 25 are used to define an overall management focus for each basin and/or management unit, presented in Table 26. The following decision rules were applied in the assessment:

- Marine-driven response dominates the initial assessment, i.e. basin scale end-of-catchment, then specifically within wetlands within that basin.
- Overall response is ordered with marine first—most intensive to least intensive, then wetlands. Other columns are in consistent order of nutrients, sediment, pesticides (where possible).
- Proactive response—localised action, e.g. localised sediment management.
- Accelerated response—targeted action, e.g. Targeted management for wetlands in hazard exposed areas.
- For wetlands, if validation is required: 'Validate wetland sediment hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas'.
- Where a basin has at least 1 Intensive and 1 Accelerated response: 'Multi-pollutant, strategic management required across multiple land uses...' (provided there are multiple dominant land uses to target).
- Where ecosystem condition is Moderate and exposure is Minimal or Low: 'Investigate drivers of [ecosystem] condition, or if ecosystem condition is Poor: 'Immediate investigation of drivers of [ecosystem] condition'.
- Where ecosystem condition is Moderate and exposure is Moderate (for wetlands) or High: 'Further assessment of [ecosystem] condition to understand additional pressures on the ecosystem, increase confidence in the condition status (in terms of trends) and the role of pollutant impacts.'
- Where ecosystem condition is Poor and exposure is Moderate or High: 'Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem restoration/recovery may need to be considered (based on values assessment).'
- Where ecosystem has not been monitored or low confidence: 'Investigate [ecosystem condition]'

Table 25. Water quality management response assessment for each basin, and where available management unit (MU), in the GBR including ecosystem condition, exposure/hazard assessment and management response. For each basin or management unit, the first row contains the ecosystem condition and hazard/exposure assessment, and the second row contains the associated management response based on the Management Response Decision Support Framework. DIN = Dissolved inorganic nitrogen. For Hazard/Exposure – Min = Minimal, Mod = Moderate. For Ecosystem Condition: Mod = Moderate. For Management Responses: F = Foundational, P = Proactive, A = Accelerated and I = Intensive. + Depending on the ecosystem condition, the management response includes recommendations for additional activities that should be undertaken e.g. increasing vigilance or investigating other drivers of ecosystem condition (refer to Table 24 for more detail). For wetlands, also refer to Table 11 for GBR catchment-wide hazard prioritisation of management units (i.e. Exposure (GBRCA) results). * MUs with spatial under-representation of nutrient hazard due to smaller areas of high hazard being offset by larger areas of low hazard within ACA mapping units; # MUs with large areas exposed to nutrient hazard but with only a small area of wetlands.

NRM Region	Basin	Management Unit	Floodplain wetlands				Marine				
			Condition	Hazard			Condition		Exposure		
			Wetlands	Nutrients	Sediment	Pesticides	Seagrass meadows	Coral reefs	DIN	Fine sediments	Pesticides
Cape York	Jacky Jacky	No data	Min	Low	Min		Good	Good	Min	Min	Min
			F	P	F				F	F	F
	Olive-Pascoe	No data	Min	Min	Min		Good	Good	Min	Min	Min
			F	F	F				F	F	F
	Lockhart	No data	Min	Min	Min		Good	Good	Min	Min	Min
			F	F	F				F	F	F
	Stewart	No data	Min	Min	Min		Mod	Good	Min	Min	Min
			F	F	F				F	F+	F+
	Normanby	Good	Low	Mod	Min		Mod	Good	Min	High	Min
			P	A+	F				F	I+	F+
	Jeannie	No data	Min	Min	Min		Mod	Good	Min	Min	Min
			F	F	F				F	F+	F+
	Endeavour	No data	Mod	Mod	Min		Mod	Good	Min	Low	Min
			A+	A+	F				F	P+	F+
Wet Tropics	Daintree*	No data	Min	Min	Min		Mod	Mod	Mod	Min	Min
			F	F	F				A+	F+	F+
	Mossman	No data	Min	Min	High		Good	Mod	Mod	Min	Low
			F	F	I+				A+	F+	P+
	Barron	No data	High	High	High		Good	Mod	Mod	Mod	Min
			I+	I+	I+				A+	A+	F+

NRM Region	Basin	Management Unit	Floodplain wetlands				Marine				
			Condition Wetlands	Nutrients	Hazard Sediment	Pesticides	Condition Seagrass meadows	Coral reefs	DIN	Exposure Fine sediments	Pesticides
	Mulgrave-Russell*		Mod	Low	Low	High	Mod	Mod	Mod	Low	Mod
				P+	P+	I+			A+	P+	A+
	Johnstone		Poor	High	High	High	Mod	Mod	Mod	Mod	Mod
				I+	I+	I+			A+	A+	A+
	Tully		Mod	High	High	High	Poor	Mod	High	Mod	Mod
				I+	I+	I+			I+	A+	A+
	Murray		Poor	High	High	High	Poor	Mod	Mod	Min	High
				I+	I+	I+			A+	F+	I+
	Herbert	Upper Herbert	Mod	High	High	Mod					
				I+	I+	A+					
		Lower Herbert	Poor	High	High	High					
				I+	I+	I+					
	Herbert basin total					A+ (U) I+ (L)	Poor	Mod	High I+	High I+	Mod A+
Burdekin	Black#		Poor	High	High	Mod	Poor	Mod	Min	Min	Min
				I+	I+	A+			F+	F+	F+
	Ross		Mod	Mod	High	Low	Mod	Mod	Mod	Min	Min
				A+	I+	P++			A+	F+	F+
	Haughton		Poor	High	High	High	Poor	Mod	High	Mod	High
				I+	I+	I+			I+	A+	I+
	Burdekin	East Burdekin#	Good	High	High	High					
				I+	I+	I+					
		Burdekin Delta	Poor	High	High	High					
				I+	I+	I+					
Belyando	No data	Mod	High	Min							
		A+	I+	F							

NRM Region	Basin	Management Unit	Floodplain wetlands				Marine				
			Condition Wetlands	Nutrients	Hazard Sediment	Pesticides	Condition Seagrass meadows	Coral reefs	DIN	Exposure Fine sediments	Pesticides
		Suttor	No data	Mod	High	Low					
				A+	I+	P					
		Upper Burdekin	Mod	Mod	High	Min					
				A+	I+	F+					
		Bowen Bogie#	No data	High	High	Min					
				I+	I+	F					
		Cape Campaspe	Good	High	High	Min					
				I+	I+	F					
		Burdekin basin total					Mod	Mod	High	High	Low
				I+ for EB, BD, BB, CC; A+ for B, S, UP	I+	I+ for EB, BD; P for S; F for B, BB, CC; F+ for UB			I+	I+	P+
Mackay Whitsunday	Don River		Mod	High	High	Mod	Mod	Mod	Min	Mod	Low
				I+	I+	A+			F+	A+	P+
	Proserpine		Poor	High	High	High	Mod	Poor	Mod	Min	High
				I+	I+	I+			A+	F+	I+
	O'Connell		No data	High	High	High	Mod	Poor	Mod	Mod	High
				I+	I+	I+			A+	A+	I+
	Pioneer		No data	High	High	High	Mod	Poor	Mod	Mod	High
				I+	I+	I+			A+	A+	I+
	Plane Creek		Poor	High	Mod	High	Mod	Poor	Mod	Low	High
				I+	A+	I+			A+	P+	I+

NRM Region	Basin	Management Unit	Condition Wetlands	Floodplain wetlands			Condition		Marine			
				Nutrients	Hazard Sediment	Pesticides	Seagrass meadows	Coral reefs	DIN	Exposure Fine sediments	Pesticides	
Fitzroy	Styx		No data	Min	Mod	Min	Poor	Poor	Min	Min	Min	
				F	A+	F			F+	F+	F+	
	Shoalwater		No data	Min	Mod	Min	Poor	Poor	Min	Min	No data	
				F	A+	F			F+	F+	F+	
	Waterpark Creek		Mod	Min	Min	Min	Poor	Poor	Min	Min	Min	
				F+	F+	F+			F+	F+	F+	
	Fitzroy	Lower Fitzroy	Poor	High	High	Min						
				I+	I+	F+						
		Dawson	Mod	High	High	Mod						
				I+	I+	A+						
		Isaac	Mod	High	High	Mod						
				I+	I+	A+						
		Mackenzie	Mod	High	High	Mod						
				I+	I+	A+						
		Comet	No data	High	High	Low						
				I+	I+	P						
		Nogoa	Poor	High	High	Mod						
				I+	I+	A+						
		Theresa Creek	No data	High	High	High						
				I+	I+	I+						
		Fitzroy basin total						Poor	Poor	Min	High	Low
					I+	I+	I+ for TC; A+ for D, I, M, N; P for C			F+	I+	P+
		Calliope#			No data	Mod	High	Min	Poor	Poor	Min	Min

NRM Region	Basin	Management Unit	Floodplain wetlands				Condition		Marine		
			Condition Wetlands	Nutrients	Hazard Sediment	Pesticides	Seagrass meadows	Coral reefs	DIN	Exposure Fine sediments	Pesticides
				A+	I+	F			F+	F+	F+
	Boyne#	No data	High	High	Min	Poor	Poor	Min	Min	Min	
			I+	I+	F			F+	F+	F+	
Burnett Mary	Baffle	Mod	High	High	Mod	Poor	Mod	Min	Min	Min	
			I+	I+	A+			F+	F+	F+	
	Kolan	No data	High	High	High	Poor	Mod	Low	Min	Low	
			I+	I+	I+			P+	F+	P+	
	Burnett	Poor	High	High	High	Poor	Mod	High	Mod	Low	
			I+	I+	I+			I+	A+	P+	
	Burrum	Good	High	High	Mod	Poor	Mod	Min	Min	Mod	
			I+	I+	A+			F+	F+	A+	
	Mary	Mod	High	High	High	Poor	Mod	Mod	High	Low	
			I+	I+	I+			A+	I+	P+	

Table 26. Results of the water quality management response assessment for freshwater floodplain wetlands and marine ecosystems, based on the Management Response Decision Support Framework and the results of the ecosystem exposure and condition assessments. Management responses for freshwater floodplain wetlands are more targeted to areas within the basin that present a hazard to the wetlands, whereas the management responses for marine exposed areas are at the basin level, noting that management responses at the Management Unit (MU) level are only presented for freshwater floodplain wetlands. The dominant pollutant sources and pathways are sourced from Appendix 3 and Appendix 4. For pesticides, the mix of land use with higher pesticide risk at basin scale is shown. Conservation sources have been excluded from the assessment to target management of anthropogenic sources and grazing was excluded for DIN. The default management response for all areas is 'Foundational', additional levels of response are featured where required for specific pollutants. The overall management and focus areas for the basin defaults to the Basin-level (marine-driven) management response. The 2017 remaining natural unmodified freshwater floodplain wetland extent and proportion remaining since pre-development conditions are sourced from Appendix 2. In the overall management response, particulate nutrients are grouped with DIN or sediments where the dominant sources are consistent.

Notes: ¹ The freshwater floodplain wetland nutrient hazard exposure does not distinguish particulate and dissolved nutrient forms. In these basins, the dominant nutrient influence is likely to be particulate nutrients (informed by loads by land use data), however, validation is required to distinguish dissolved and particulate sources.

* Low confidence due to insufficient data or observations (requires validation or investigation).

Basin	Combined management response for the basin or management unit (MU) Basin-level - targeting marine pollutant exposure. Wetlands - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and pathways (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Jacky Jacky	Basin-level Foundational response for DIN, sediment and pesticides Wetlands: Foundational response for nutrients and pesticides Proactive response for sediment*	Sediment & particulate nutrients: Minimal anthropogenic sources <i>Hillslope</i> Pesticides: No high-risk land uses	Marine: Coral – Good* Seagrass – Good Wetland: <i>no monitored wetland aggregations*</i>	1,354 ha (100%)	• Broadscale foundational management across the basin for all pollutants. • Validate wetland sediment hazard assessment and where required, implement appropriate management for wetlands in sediment hazard exposed areas. • Investigate wetland and coral condition.
Olive-Pascoe	Basin-level Foundational response for nutrients, sediment and pesticides Wetlands: Foundational response	Sediment & particulate nutrients: Minimal anthropogenic sources <i>Hillslope</i> Pesticides: No high-risk land uses	Marine: Coral – Good* Seagrass – Good Wetland: <i>no monitored wetland aggregations*</i>	2,558 ha (100%)	• Broadscale foundational management across the basin for all pollutants. • Investigate wetland and coral condition.
Lockhart	Basin-level Foundational response for DIN, sediment and pesticides Wetlands: Foundational response for nutrients, sediment and pesticides	Sediment & particulate nutrients: Minimal anthropogenic sources <i>Hillslope</i> Pesticides: No high-risk land uses	Marine: Coral – Good* Seagrass – Good Wetland: <i>no monitored wetland aggregations*</i>	N/A	• Broadscale foundational management across the basin for all pollutants. • Investigate wetland and coral condition.

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Stewart	Basin-level Foundational response for DIN, sediment and pesticides Wetlands: Foundational response for nutrients, sediment and pesticides	Sediment & particulate nutrients: Minimal anthropogenic sources <i>Hillslope</i> Pesticides: No high-risk land uses	Marine: Coral – Good* Seagrass – Moderate* Wetland: <i>no monitored wetland aggregations*</i>	857 ha (100%)	• Broadscale foundational management across the basin for all pollutants. • Investigate wetland and coral condition. • Further assessment of seagrass condition to understand additional pressures, increase confidence in status (including trends) and qualify the role of pollutant impacts.
Normanby	Basin-level Foundational response for DIN and pesticides Intensive response for sediment Wetlands: Proactive response for nutrients Accelerated response for sediment Foundational response for pesticides	Sediment & particulate nutrients: Grazing <i>Gully & Hillslope</i> Pesticides: Dryland Cropping, Bananas & Irrigated Cropping	Marine: Coral – Good* Seagrass – Moderate Wetland: Good	14,253 ha (100%)	• Large-scale intensive management of sediment at the basin level. Broadscale foundational management in all other areas across the basin. • Accelerated management of sediments for wetlands in hazard exposed areas. • Validate wetland nutrient¹ hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. • Investigate coral condition.
Jeannie	Basin-level Foundational response for DIN, sediment and pesticides. Wetlands: Foundational response for DIN, sediment and pesticides.	Sediment & particulate nutrients: Minimal anthropogenic sources <i>Hillslope</i> Pesticides: Dryland Cropping & Horticulture	Marine: Coral – Good* Seagrass – Moderate Wetland: <i>no monitored wetland aggregations*</i>	N/A	• Broadscale foundational management across the basin for all pollutants. • Investigate wetland and coral condition. • Further assessment of seagrass condition to understand additional pressures, increase confidence in status (including trends) and qualify the role of pollutant impacts.
Endeavour	Basin-level Foundational response for DIN and pesticides. Proactive response for sediment. Wetlands: Accelerated response for nutrients ^{1*} and sediment. Foundational response for pesticides.	Sediment & particulate nutrients: Grazing <i>Hillslope</i> Pesticides: Dryland Cropping, Horticulture & Bananas	Marine: Coral – Good* Seagrass – Moderate Wetland: <i>no monitored wetland aggregations*</i>	277 ha (80%)	• Broadscale foundational management across the basin for all pollutants, with localised proactive management of sediment at the basin level. Accelerated management of sediments for wetlands in hazard exposed areas. • Validate wetland nutrient¹ hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. • Investigate wetland condition and coral condition. • Further assessment of seagrass condition to understand additional pressures, increase confidence in status (including trends) and qualify the role of pollutant impacts.

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Daintree	Basin-level Accelerated response for DIN. Foundational response for sediment and pesticide. Wetlands: Foundational response for DIN, sediment and pesticides*.	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Streambank in various land uses & Grazing <i>Hillslope & Streambank</i> Pesticides: Sugarcane	Marine: Coral – Moderate Seagrass – Moderate Wetland: <i>no monitored wetland aggregations*</i>	1,353 ha (76%)	• Broadscale foundational management across the basin for all pollutants, with accelerated management of nutrients in targeted sub-catchment areas. • Validate wetland pesticide hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. • Investigate wetland condition.
Mossman	Basin-level Accelerated response for DIN Foundational response for sediment Proactive response for pesticides Wetlands: Foundational response for nutrients and sediment. Intensive response for pesticides*.	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Minimal anthropogenic sources (some Sugarcane & Urban) <i>Hillslope</i> Pesticides: Sugarcane	Marine: Coral – Moderate Seagrass – Good Wetland: <i>no monitored wetland aggregations*</i>	4 ha (3%)	• Accelerated management of nutrients in targeted sub-catchment areas, and localised proactive management of pesticides. Broadscale foundational management in all other areas across the basin. • Validate wetland pesticide hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. • Investigate wetland condition.
Barron	Basin-level Accelerated response for DIN and sediment Foundational response for pesticides Wetlands: Intensive response for nutrients*, sediment* and pesticides*	Nutrients (DIN): Urban, Sewage Treatment Plants, Sugarcane & Bananas Sediment & particulate nutrients: Streambank in various land uses & Grazing <i>Streambank & Hillslope</i> Pesticides: Sugarcane, Irrigated Cropping, Horticulture & Bananas	Marine: Coral – Moderate Seagrass – Good Wetland: <i>no monitored wetland aggregations*</i>	97 ha (13%)	• Accelerated management of nutrients and sediment in targeted sub-catchment areas. Intensive management of all pollutants for wetlands in hazard exposed areas following validation. Broadscale foundational management in all other areas across the basin. • Validate wetland hazard assessment for nutrients, sediments and pesticides. • Investigate wetland condition.
Mulgrave-Russell	Basin-level Accelerated response for DIN and pesticides Proactive response for sediment Wetlands: Proactive response for nutrients* and sediments Intensive response for pesticides	Nutrients (DIN): Sugarcane, Bananas, Urban & Sewage Treatment Plants Sediment & particulate nutrients: Streambank in various land uses, Sugarcane & Grazing <i>Hillslope & Streambank</i> Pesticides: Sugarcane, bananas	Marine: Coral – Moderate Seagrass – Moderate Wetland: Moderate	4,612 ha (44%)	• Accelerated management of nutrients and pesticides across multiple land uses in targeted sub-catchment areas, and localised proactive management of sediment. Broadscale foundational management in all other areas across the basin. • Validate wetland nutrient hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. Intensive management of pesticides and localised management of sediment for wetlands in hazard exposed areas. • Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition.

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Johnstone	Basin-level Accelerated response for DIN, sediment and pesticides Wetlands: Intensive response for nutrients, sediment and pesticides	Nutrients (DIN): Sugarcane, Bananas & Urban Sediment & particulate nutrients: Streambank in various land uses & Grazing <i>Hillslope & Streambank</i> Pesticides: Sugarcane, Bananas & Urban	Marine: Coral – Moderate Seagrass – Moderate Wetland: Poor	1,494 ha (22%)	- Accelerated management of nutrients, sediment and pesticides across multiple land uses in targeted sub-catchment areas. Intensive management of all pollutants for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Evaluate wetland ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem rehabilitation /recovery may need to be considered (based on values assessment).
Tully	Basin-level Intensive response for DIN Accelerated response for sediment and pesticides Wetlands: Intensive response for nutrients, sediment and pesticides	Nutrients (DIN): Sugarcane & Bananas Sediment & particulate nutrients: Streambank in various land uses & Sugarcane <i>Hillslope & Streambank</i> Pesticides: Sugarcane & Bananas	Marine: Coral – Moderate Seagrass – Poor Wetland: Moderate	3,665 ha (35%)	- Multi-pollutant, strategic management required across multiple land uses, with intensive large-scale management of nutrients and accelerated management of sediment and pesticides in targeted sub-catchment areas. Intensive management of all pollutants for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition. - Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).
Murray	Basin-level Accelerated response for DIN Foundational response for sediment Intensive response for pesticides Wetlands: Intensive response for nutrients, sediment* and pesticides	Nutrients (DIN): Sugarcane & Bananas Sediment & particulate nutrients: Streambank in various land uses & Sugarcane <i>Hillslope & Streambank</i> Pesticides: Sugarcane & Bananas	Marine: Coral – Moderate Seagrass – Poor* Wetland: Poor	3,280 ha (38%)	- Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of pesticides and accelerated management of nutrients in targeted areas. Intensive management of nutrients and pesticides for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Validate wetland sediment hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Evaluate wetland and seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem rehabilitation/recovery may need to be considered (based on values assessment).

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Herbert	Basin-level Intensive response for DIN and sediment Accelerated response for pesticides Wetlands: Upper Herbert MU - Intensive response for nutrients* and sediments, accelerated response for pesticides*. Lower Herbert MU - Intensive management of nutrients, sediment and pesticides	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Grazing, Streambank in various land uses & Sugarcane <i>Hillslope & Streambank</i> Pesticides: Sugarcane & Irrigated Cropping	Marine: Coral – Moderate Seagrass – Poor Wetland: Upper Herbert – Moderate Lower Herbert – Poor	<i>Basin total: 6,644 ha (39%)</i> <i>Upper Herbert MU – 1,553 ha (75%)</i> <i>Lower Herbert MU – 5,091 ha (27%)</i>	- Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of nutrients and sediment and accelerated management of pesticides in targeted sub-catchment areas. Intensive management of all pollutants for wetlands in hazard exposed areas in the Lower Herbert MU and for sediments in the Upper Herbert MU. - Validate wetland nutrient and pesticide hazard assessment in the Upper Herbert MU and where required, implement appropriate management for wetlands in hazard exposed areas. - Evaluate wetland ecological, social and cultural values in the Lower Herbert, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem rehabilitation/recovery may need to be considered (based on values assessment). - Further assessment of wetland condition in the Upper Herbert MU to understand the role of pollutant impacts and actively manage other drivers of wetland. - Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).
Black	Basin-level Foundational response for DIN, sediment and pesticides Wetlands: Intensive response for nutrients¹ and sediment* Accelerated response for pesticides	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Grazing <i>Hillslope</i> Pesticides: Sugarcane, Horticulture & Urban	Marine: Coral – Moderate Seagrass – Poor Wetland: Poor	<i>44 ha (79%)</i>	- Broadscale foundational management across the basin for all pollutants - Validate wetland nutrient¹ and sediment* hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Evaluate wetland ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem rehabilitation /recovery may need to be considered (based on values assessment).

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Ross	Basin-level Accelerated response for DIN Foundational response for sediment and pesticides Wetlands: Accelerated response for nutrients Intensive response for sediment* Proactive response for pesticides*	Nutrients (DIN): Sewage Treatment Plants Sediment & particulate nutrients: Grazing <i>Hillslope</i> Pesticides: Horticulture, Irrigated Cropping & Urban	Marine: Coral – Moderate Seagrass – Moderate Wetland: Moderate	335 ha (33%)	- Broadscale foundational management across the basin for all pollutants, with accelerated management of nutrients in targeted sub-catchment areas including for wetlands in hazard exposed areas. - Validate wetland sediment and pesticide hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition.
Haughton	Basin-level Intensive response for DIN and pesticides Accelerated response for sediment Wetlands: Intensive response for nutrients, sediment and pesticides	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Grazing & Sugarcane <i>Gully & Hillslope</i> Pesticides: Sugarcane	Marine: Coral – Moderate Seagrass – Poor Wetland: Poor	4,102 ha (54%)	- Multi-pollutant, strategic management required across multiple land uses, with intensive large-scale management of nutrients and pesticides and accelerated management of sediment in targeted sub-catchment areas. Intensive management of all pollutants for wetlands in hazard exposed areas. Broadscale foundational management in all other areas across the basin. - Evaluate wetland and seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Burdekin	Basin-level Intensive response for DIN and sediment Proactive response for pesticides Wetlands: East Burdekin - Intensive response for nutrients, sediments and pesticides*. Burdekin Delta – Intensive response for nutrients, sediments and pesticides. Belyando - Accelerated response for nutrients^{1*}, intensive response for sediment, foundational response for pesticides. Suttor - Accelerated response for nutrients^{1*}, intensive response for sediment*, proactive response for pesticides*. Upper Burdekin - Accelerated response for nutrients^{1*}, intensive response for sediment, foundational response for pesticides. Bowen Bogie and Cape Campaspe - Intensive response for nutrients^{1*} and sediment, foundational response for pesticides.	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Grazing Gully Burdekin Delta - Streambank in various land uses <i>Streambank</i> Pesticides: Dryland Cropping, Irrigated Cropping & Sugarcane	Marine: Coral – Moderate Seagrass – Moderate Wetland: East Burdekin – Good Burdekin Delta – Poor Upper Burdekin – Moderate Cape Campaspe – Good Belyando, Suttor, Bowen Bogie – <i>no monitored wetland aggregations*</i>	Basin total: <i>15,319 ha (82%)</i> East Burdekin MU – <i>27 ha (100%)</i> Burdekin Delta MU – <i>779 ha (26%)</i> Belyando MU – <i>3,928 ha (95%)</i> Suttor MU – <i>628 ha (76%)</i> Upper Burdekin MU – <i>5,036 ha (96%)</i> Bowen Bogie MU – <i>26 ha (99%)</i> Cape Campaspe MU – <i>4,895 ha (89%)</i>	- Multi-pollutant, strategic management required across multiple land uses at the basin level, with intensive large-scale management of nutrients and sediment (including for wetlands in hazard exposed areas). Localised, proactive management of pesticides except for wetlands in hazard exposed areas where pesticide management increases to intensive in the Burdekin Delta. Broad-scale foundational management in all other areas across the basin. - Validate wetland nutrient¹ hazard assessment for Belyando, Suttor, Upper Burdekin, Bowen Bogie and Cape Campaspe, and where required, implement appropriate management for wetlands in nutrient hazard exposed areas. - Validate wetland pesticide hazard assessment for East Burdekin MU, and pesticide and sediment hazard for Suttor MU. Where required, implement appropriate management for wetlands in hazard exposed areas. - Investigate wetland condition in the Belyando, Suttor and Bowen Bogie MU. - Evaluate wetland ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery in the Burdekin Delta. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment). - Further assessment of wetland condition in the Upper Burdekin MU to understand the role of pollutant impacts and actively manage other drivers of wetland condition.
Don River	Basin-level Foundational response for DIN Accelerated response for sediment Proactive response for pesticides Wetlands: Intensive response for nutrients and sediments Accelerated response for pesticides*	Nutrients (DIN): Horticulture Sediment & particulate nutrients: Grazing Gully Pesticides: Horticulture & Irrigated Cropping	Marine: Coral – Moderate Seagrass – Moderate Wetland: Moderate	<i>267 ha (15%)</i>	- Accelerated management of sediment in targeted sub-catchment areas and localised proactive management of pesticides. Intensive management of nutrients and sediment for wetlands in hazard exposed areas. - Validate wetland pesticide hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition.

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Proserpine	Basin-level Accelerated response for DIN Foundational response for sediment Intensive response for pesticides Wetlands: Intensive response for nutrients, sediment and pesticides	Nutrients (DIN): Sugarcane & Urban Sediment & particulate nutrients: Grazing & Streambank in various land uses <i>Hillslope & Streambank</i> Pesticides: Sugarcane	Marine: Coral – Poor Seagrass – Moderate Wetland: Poor	4,089 ha (65%)	- Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of pesticides and accelerated management of nutrients in targeted sub-catchment areas. Intensive management of all pollutants in wetland hazard exposed areas. Broad-scale foundational management in all other areas across the basin. - Evaluate wetland and coral ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).
O'Connell	Basin-level Accelerated response for DIN and sediment Intensive response for pesticides Wetlands: Intensive response for nutrients*, sediment* and pesticides*	Nutrients (DIN): Sugarcane & Urban Sediment & particulate nutrients: Streambank in various land uses & Grazing <i>Streambank & Hillslope</i> Pesticides: Sugarcane	Marine: Coral – Poor Seagrass – Moderate Wetland: <i>no monitored wetland aggregations*</i>	132 ha (18%)	- Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of pesticides and accelerated management of nutrients and sediment in targeted sub-catchment areas. Broad-scale foundational management in all other areas across the basin. - Validate wetland nutrient, sediment and pesticide hazard assessment, and where required, implement appropriate management for wetlands in hazard exposed areas. - Investigate wetland condition. - Evaluate coral ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).
Pioneer	Basin-level Accelerated response for DIN and sediment Intensive response for pesticides Wetlands: Intensive response for nutrients*, sediments* and pesticides*	Nutrients (DIN): Sugarcane & Urban Sediment & particulate nutrients: Streambank various land uses <i>Streambank & Hillslope</i> Pesticides: Sugarcane & Urban	Marine: Coral – Poor Seagrass – Moderate Wetland: <i>no monitored wetland aggregations*</i>	227 ha (8%)	- Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of pesticides and accelerated management of nutrients and sediment in targeted sub-catchment areas. Broad-scale foundational management in all other areas across the basin. - Validate wetland nutrient, sediment and pesticide hazard assessment and where required, implement appropriate management for wetlands in nutrient hazard exposed areas. - Investigate wetland condition. - Evaluate coral ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Plane	Basin-level Accelerated response for DIN Proactive response for sediments Intensive response for pesticides Wetlands: Intensive response for nutrients and pesticides Accelerated response for sediments	Nutrients (DIN): Sugarcane & Urban Sediment & particulate nutrients: Grazing, Streambank in various land uses & Sugarcane <i>Hillslope & Streambank</i> Pesticides: Sugarcane	Marine: Coral – Poor Seagrass – Moderate Wetland: Poor	975 ha (22%)	- Multi-pollutant, strategic management required across multiple land uses, with large-scale intensive management of pesticides, accelerated management of nutrients in targeted sub-catchment areas, and localised proactive management of sediment. Intensive management of pesticides and nutrients, and accelerated management of sediment in wetland hazard exposed areas. Broad-scale foundational management in all other areas across the basin. - Evaluate wetland and coral ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).
Styx	Basin-level Foundational response for DIN, sediment and pesticides Wetlands: Foundational response for nutrients and pesticides Accelerated response for sediment*	Sediment & particulate nutrients: Grazing <i>Gully & Hillslope</i> Pesticides: Sugarcane	Marine: Coral – Poor* Seagrass – Poor* Wetland: <i>no monitored wetland aggregations*</i>	494 ha (100%)	- Broad-scale foundational management across the basin for all pollutants. - Validate wetland sediment hazard assessment and where required, implement appropriate management for wetlands in hazard exposed areas. - Investigate wetland condition., and immediate investigation of drivers of coral and seagrass condition.
Shoalwater	Basin-level Foundational response for DIN, sediment and pesticides Wetlands: Foundational response for nutrients and pesticides Accelerated response for sediment*	Sediment & particulate nutrients: Grazing <i>Hillslope & Gully</i> Pesticides: No high-risk land uses	Marine: Coral – Poor* Seagrass – Poor* Wetland: <i>no monitored wetland aggregations*</i>	186 ha (38%)	- Broad-scale foundational management across the basin for all pollutants. - Validate wetland sediment hazard assessment and where required, implement appropriate management for wetlands in sediment hazard exposed areas. - Investigate wetland condition, and immediate investigation of drivers of coral and seagrass condition.
Waterpark Creek	Basin-level Foundational response for DIN, sediment and pesticides Wetlands: Foundational response for pesticides, nutrients and sediment	Sediment & particulate nutrients: Grazing <i>Hillslope</i> Pesticides: Horticulture & Dryland Cropping	Marine: Coral – Poor* Seagrass – Poor* Wetland: Moderate	3,042 ha (91%)	- Broad-scale foundational management across the basin for all pollutants., Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition. - Immediate investigation of drivers of coral and seagrass condition.

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Fitzroy	Basin-level Intensive response for sediment Proactive response for pesticides Foundational response for nutrients Wetlands: Lower Fitzroy MU- Intensive response for nutrients^{1*} and sediments, foundational response for pesticides Dawson, Isaac, and Mackenzie MUs - Intensive response for nutrients^{1*} and sediments, accelerated response for pesticides* Comet MU - Intensive response for nutrients^{1*} and sediments*, proactive response for pesticides* Nogoa MU - Intensive response for nutrients^{1*} and sediments*, accelerated response for pesticides* Theresa Ck MU - Intensive response for nutrients^{1*}, sediments* and pesticides*	Sediment & particulate nutrients: Grazing, Streambank in various land uses & Dryland Cropping (Dawson, Comet, Theresa Creek) <i>Gully & Streambank</i> Pesticides: Dryland Cropping, Irrigated Cropping & Urban	Marine: Coral – Poor Seagrass – Poor Wetland: Lower Fitzroy – Poor Dawson – Moderate Isaac – Moderate Mackenzie – Moderate Nogoa – Poor Comet and Theresa Creek – <i>no monitored wetland aggregations*</i>	Basin total: 25,883 ha (72%) Lower Fitzroy MU - 7,800 ha (49%) Dawson MU - 7,939 ha (91%) Isaac MU - 1,400 ha (85%) Mackenzie MU - 1,375 ha (79%) Comet MU - 5,888 ha (91%) Nogoa MU - 1,294 ha (82%) Theresa Ck MU - 187 ha (82%)	- Multi-pollutant, strategic management across multiple land uses at the basin level, with intensive large-scale management of sediment (including for wetlands in hazard exposed areas), and localised proactive management of pesticides. Broadscale foundational management in all other areas across the basin. - Investigate sources of DIN marine exposure. - Validate wetland nutrient¹ and pesticide hazard assessment, and where required, implement appropriate management response. Validate wetland sediment hazard assessment in the Comet, Nogoa and Theresa Ck MUs and where required, implement appropriate management response. - Investigate wetland condition in the Comet and Theresa Creek MU. - Evaluate wetland (in Lower Fitzroy and Nogoa MU), coral and seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment). - Further assessment of wetland condition in Dawson, Isaac and Mackenzie MU to understand the role of pollutant impacts and actively manage other drivers of wetland condition.
Calliope	Basin-level Foundational response of DIN, sediment and pesticides Wetlands: Accelerated response for nutrients^{1*} Intensive response for sediment* Foundational response for pesticides	Sediment & particulate nutrients: Grazing <i>Hillslope & Gully</i> Pesticides: Horticulture, Dryland Cropping & Irrigated Cropping	Marine: Coral – Poor Seagrass – Poor Wetland: <i>no monitored wetland aggregations*</i>	40 ha (100%)	- Broadscale foundational management across the basin for all pollutants. - Validate wetland nutrient¹ and sediment hazard assessment and implement appropriate management response where required. - Investigate wetland condition, and immediate investigation of drivers of coral and seagrass condition.

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Boyne	Basin-level Foundational response for DIN, sediment and pesticides Wetlands: Intensive response for nutrients ^{1*} and sediments* Foundational response for pesticides	Sediment & particulate nutrients: Grazing <i>Hillslope & Gully</i> Pesticides: Dryland Cropping & Irrigated Cropping	Marine: Coral - Poor Seagrass - Poor Wetland: <i>no monitored wetland aggregations*</i>	4 ha (3%)	• Broadscale foundational management across the basin for all pollutants. • Validate wetland nutrient¹ and sediment hazard assessment and implement appropriate management response where required. • Investigate wetland condition. • Evaluate coral ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).
Baffle	Basin-level Foundational response for DIN, sediment and pesticides Wetlands: Intensive response for nutrients ^{1*} and sediments* Accelerated response for pesticides	Sediment & particulate nutrients: Grazing & Urban <i>Hillslope & Gully</i> Pesticides: Horticulture, Sugarcane & Irrigated Cropping	Marine: Coral – Moderate* Seagrass – Poor* Wetland: Moderate	6,541 ha (77%)	• Broadscale foundational management across the basin for all pollutants, with management increasing accelerated for pesticides, in wetland hazard exposed areas. • Validate wetland nutrient¹ and sediment hazard assessment and implement appropriate management response where required. • Investigate coral and seagrass condition. • Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition.
Kolan	Basin-level Proactive response for DIN, sediment and pesticides Wetlands: Intensive response for nutrients ^{1*} , sediment* and pesticides*	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Streambank in various land uses & Grazing <i>Hillslope & Streambank</i> Pesticides: Sugarcane, Horticulture & Urban	Marine: Coral – Moderate* Seagrass – Poor Wetland: <i>no monitored wetland aggregations*</i>	178 ha (53%)	• Localised, proactive management for nutrients, sediment and pesticides at the basin level. • Validate wetland nutrient¹, sediment and pesticide hazard assessment and where required, implement appropriate management response. • Investigate wetland and coral condition. • Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Burnett	Basin-level Intensive response for DIN Accelerated response for sediment Proactive response for pesticides Wetlands: Intensive response for nutrients, sediments and pesticides	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Streambank in various land uses & Grazing <i>Streambank</i> Pesticides: Dryland Cropping, Irrigated Cropping, Sugarcane, Horticulture & Urban	Marine: Coral – Moderate* Seagrass – Poor Wetland: Poor	840 ha (61%)	- Multi-pollutant, strategic management required across multiple land uses at the basin level, with intensive large-scale management of nutrients, accelerated management of sediment in targeted sub-catchment areas, and localised proactive management of pesticides at the basin level. Intensive management of all pollutants for wetlands in hazard exposed areas. Broad-scale foundational management in all other areas across the basin. - Investigate coral condition. - Evaluate wetland and seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).
Burrum	Basin-level Foundational response for nutrients and sediments Accelerated response for pesticides Wetlands: Intensive response for nutrients and sediments Accelerated response for pesticides	Nutrients (DIN): Sugarcane Sediment & particulate nutrients: Urban & Horticulture <i>Hillslope</i> Pesticides: Sugarcane, Horticulture & Urban	Marine: Coral – Moderate* Seagrass – Poor Wetland: Good	5,935 ha (75%)	- Broad-scale foundational management across the basin for all pollutants, with accelerated management of pesticides in targeted sub-catchment areas including for wetlands in hazard exposed areas. Intensive management of nutrients and sediment for wetlands in hazard exposed areas. - Investigate coral condition. - Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).

Basin	Combined management response for the basin or management unit (MU) <i>Basin-level</i> - targeting marine pollutant exposure. <i>Wetlands</i> - hazard exposed areas within the basin.	Dominant pollutant sources for targeting management (ranked) and <i>pathways</i> (ranked)	Ecosystem condition	Area of remaining natural unmodified floodplain wetland extent in 2017 (% remaining)	Overall management and focus areas
Mary	Basin-level Accelerated response for DIN Intensive response for sediments Proactive response for pesticides Wetlands: Intensive response for nutrients, sediments and pesticides	Nutrients (DIN): Sugarcane & Urban Sediment & particulate nutrients: Streambank in various land uses, Grazing & Urban <i>Streambank & Hillslope</i> Pesticides: Sugarcane, Horticulture, Irrigated Cropping & Urban	Marine: Coral – Moderate Seagrass – Poor Wetland: Moderate	4,612 ha (44%)	- Multi-pollutant, strategic management required across multiple land uses at the basin level, with intensive large-scale management of sediment, accelerated management of nutrients in targeted sub-catchment areas, and localised proactive management of pesticides. Intensive management of all pollutants for wetlands in hazard exposed areas. Broad-scale foundational management in all other areas across the basin. - Further assessment of wetland condition to understand the role of pollutant impacts and actively manage other drivers of wetland condition. - Evaluate seagrass ecological, social and cultural values, other potential drivers of the poor condition and the ecosystem's potential for recovery. Other intervention options for ecosystem repair/recovery may need to be considered (based on values assessment).

It is recognised that the suggested management responses are relatively high level, and specifically for wetlands, once the appropriate management response has been determined for the wetland aggregation(s) within each management unit, several factors should be considered to help guide the response for specific wetlands. There are no additional factors specified for the marine-driven response.

First, the wetland condition assessment is based on mean indicator scores of wetlands surveyed by the GBR Wetland Condition Monitoring Program, noting that variation around the mean scores tended to be higher when based on fewer wetlands (Appendix 5: Wetland condition). Therefore, the number of wetlands from which the aggregation's overall condition was determined should be considered when prioritising management actions. For example, the condition assessment for wetland aggregation(s) in the Black, Plane Creek, Nogoia and Burnett management units was based on data from one wetland only (Appendix 5: Table 20). In addition, the percentage (by number and area) of wetlands in the aggregation(s) within a management unit that are monitored, should be considered. For instance, if indicator data from only one wetland were available for analysis, and less than 1% (by number and by area) of wetlands in the management unit's aggregation(s) are monitored, then more information may be required for decision making purposes. Percentages were calculated using spatial data as outlined in Section 4.1 (except for the East Burdekin management unit for which calculations could not be performed) and indicated that all management units besides Baffle, Plane Creek and Proserpine had greater than approximately 1% of wetland area in aggregation(s) monitored as part of the GBR Wetland Condition Monitoring Program (Table 27).

Second, the percentage of wetland area within a management unit that is of High and/or Very High Conservation Value (HVHCV) (Department of Environment, Science, Tourism and Innovation 2024a) should be considered where data are available. For example, if < 10% is HVHCV then this can be taken into consideration when prioritising the management action to be implemented in the management unit's wetlands and aggregations. To this end, percentages were calculated using data from Aquatic Conservation Assessment (ACA) mapping (DETSI 2024b), which identifies conservation values relating to the ecological or conservation significance of aquatic ecosystems within a catchment. These values help prioritise protection or rehabilitation efforts and can include factors such as biodiversity richness, habitat quality, and connectivity. Calculations for the percentage of wetland areas classified as HVHCV could only be performed for the Wide Bay Burnett catchment. All four management units in the area where data for HVHCV percentage calculations were available (Baffle, Burnett, Burrum and Mary) had more than 10% of wetlands that are of High and/or Very High Conservation Value (Table 27). For other catchments, the wetland area and HVHCV data do not share the same source data version, so are not directly comparable so for the purposes of this report % HVHCV areas were unable to be calculated.

Third, and as described in Section 6.4.1, the mean scores of individual indicators for the wetland aggregation(s) within each management unit can be used to help focus the management response, depending on the mean scores. Suggested foci of management responses for aggregations within management units that have condition indicators with mean scores < 2.5 (i.e. better condition) or ≥ 3.5 (worse condition), as per Appendix 5: Wetland condition, are listed in Appendix 8: Tables 45 and 46.

Finally, the management response outcome for wetlands and aggregation(s) within a management unit with respect to one pollutant should be considered alongside the outcomes with respect to the two remaining pollutants. For example, if the response outcome for wetlands within a management unit's aggregations was different for nutrients and sediments, then a mix of management actions targeting the different and/or compatible response priorities for nutrients vs sediments is likely required.

Table 27. Influencing factors on the proposed management response for wetlands and wetland aggregations within management units monitored by the GBR Wetland Condition Monitoring Program.

NRM Region	Management Unit	No. of wetlands where condition was determined	% of wetland area in aggregation(s) that is monitored	% of wetlands in aggregation(s) that are monitored	% of wetland area High and/or Very High Conservation Value - Aqua BAMM based assessments
Cape York	Normanby	35	3	3	Data unavailable (incompatible)#
Wet Tropics	Mulgrave-Russell	3	21	2	Data unavailable (incompatible)#
	Johnstone	2	5	1	Data unavailable (incompatible)#
	Tully	12	14	4	Data unavailable (incompatible)#
	Murray	12	6	5	Data unavailable (incompatible)#
	Upper Herbert	5	5	4	Data unavailable (incompatible)#
	Lower Herbert	12	10	3	Data unavailable (incompatible)#
Burdekin	Black	1	14	8	Data unavailable (incompatible)#
	Ross	3	28	3	Data unavailable (incompatible)#
	Haughton	16	2	2	Data unavailable (incompatible)#
	East Burdekin	1	No data	No data	Data unavailable (incompatible)#
	Burdekin Delta	6	9	2	Data unavailable (incompatible)#
	Upper Burdekin	3	3	6	Data unavailable (incompatible)#
	Cape Campaspe	5	2	3	Data unavailable (incompatible)#
	Don River	3	4	8	Data unavailable (incompatible)#
Mackay Whitsunday	Proserpine	3	1	2	Data unavailable (incompatible)#
	Plane Creek	1	1	1	Data unavailable (incompatible)#
Fitzroy	Waterpark Creek	3	3	6	Data unavailable (incompatible)#
	Lower Fitzroy	17	13	4	Data unavailable (incompatible)#
	Dawson	22	5	4	Data unavailable (incompatible)#
	Isaac	10	19	10	Data unavailable (incompatible)#
	Mackenzie	4	2	4	Data unavailable (incompatible)#
	Nogoa	1	3	4	Data unavailable (incompatible)#

NRM Region	Management Unit	No. of wetlands where condition was determined	% of wetland area in aggregation(s) that is monitored	% of wetlands in aggregation(s) that are monitored	% of wetland area High and/or Very High Conservation Value - Aqua BMM based assessments
Burnett Mary	Baffle	9	1	2	75
	Burnett	1	2	2	21
	Burrum	18	33	7	76
	Mary	9	2	2	88

Footnote # Data for wetland area and HVHCV are based on different source data versions and cannot be directly compared.

7.3 Key findings

The application of the Management Response Decision Support Framework across the GBR catchment area has identified distinct patterns in management needs based on pollutant exposure and ecosystem condition. The assessment identified that 24 basins require **Intensive** management responses for at least one pollutant type: 13 individual basins for the marine-driven management response (5 for nutrients, 5 for sediments, 6 for pesticides) and 24 individual basins for the freshwater wetland management response (20 for nutrients, 21 for sediments, 17 for pesticides). Thirteen basins were assessed as requiring **Intensive** management responses across all pollutants for the freshwater wetland management response, but none for the marine-driven management response. However, several had a combination of at least two pollutants requiring a combination of **Intensive** and **Accelerated** management response. Examples of these basins in the marine-driven assessment include the Tully, Haughton and Pioneer. This pattern was also evident in the freshwater wetland-driven assessment, for example, in the Herbert, Don River and Plane Creek basins. Conversely, several basins consistently required **Foundational** or **Proactive** management responses for the marine-driven and freshwater wetland-driven assessments, identifying areas where current water quality conditions are relatively good but require ongoing maintenance and proactive intervention to ensure future protection. These include most basins in the Cape York region but with the notable exception of the Normanby which requires **Intensive** management of sediment.

Regional patterns in Management Response levels

Clear geographical patterns emerge from the assessment results. The Wet Tropics, Burdekin and Mackay Whitsunday regions consistently require more intensive management responses across multiple pollutants, which is coupled with moderate to poor condition of freshwater wetlands, seagrass and coral ecosystems in these regions.

The Cape York region generally requires less intensive management responses and has generally good ecosystem condition (where data is available) with the exception of some seagrass habitats in the southern basins, highlighting the need for ongoing maintenance and proactive management to prevent increases in pollutant exposure and protection of these ecosystems.

The Fitzroy and Burnett Mary regions show a mixed pattern, with intensive management needed for sediment and nutrients across most management units, particularly for freshwater wetlands, but varying levels of response required for pesticides. Both regions generally show moderate to poor ecosystem condition.

The assessment results highlight the critical importance of cross-boundary management approaches, as adjacent basins often share similar management needs, particularly for sediment management in larger basin areas like the Burdekin and Fitzroy.

Pollutant-specific management needs

The management response assessment reveals distinct patterns in pollutant-specific management needs:

- **Nutrients:** The most comprehensive nutrient management responses are concentrated in agricultural areas, particularly in the Wet Tropics, Burdekin and Mackay Whitsunday regions.

Intensive dissolved inorganic nitrogen (DIN) management associated with the marine-driven assessment (DIN exposure to coral reefs) is required in the Tully, Herbert (Lower), Haughton, Burdekin (in the Delta) and Burnett basins. However, there is lower confidence in the results for the Burnett basin due to limitations with the DIN loads used in the marine exposure assessment and data availability for a single wetland aggregation. All other basins in the Wet Tropics, the Ross basin in the Burdekin region, the basins in the Mackay Whitsunday region and the Mary basin in the Burnett Mary region are assessed as needing **Accelerated** nutrient management response for the marine-driven assessment. A **Proactive** management response was identified for the Kolan basin, and **Foundational** management response for the Black and Burrum basins. Most basins in the Cape York region, and management units in the upper Fitzroy region were consistently identified as requiring **Foundational** nutrient management response for wetland and marine ecosystems. For **wetlands** the **Intensive** management response for nutrients was identified in most management units except for basins in the Cape York region and others mentioned below. **Accelerated** nutrient management is identified for the Endeavour, Ross, Belyando, Suttor, Upper Burdekin and Calliope basins and management units. **Proactive** nutrient management is identified for the Normanby and Mulgrave-Russell. Basins in the Cape York region (except the Normanby and Endeavour) plus the Styx, Shoalwater and Waterpark Creek basins in the upper Fitzroy regions were identified in the **Foundational** management response for wetlands.

- **Sediments:** For sediment management, an **Intensive** management response is needed in most basins except those in Cape York for wetland ecosystems, and in the Normanby, Herbert, Burdekin, Fitzroy and Mary basins for marine (coral reef and seagrass) ecosystems, where extensive grazing lands contribute significantly to sediment loads. The **Accelerated** management response is identified for the Barron, Johnstone, Tully, Haughton, Don, O’Connell, Pioneer and Burnett basins from the marine-driven assessment. **Proactive** management responses associated with the marine-driven assessment were identified as being needed for the Endeavour, Mulgrave-Russell, and Plane Creek basins. For **wetland ecosystems**, 34 management units were identified as requiring **Intensive** sediment management to address exposure hazards. However, in many instances, further validation of the sediment hazard assessment is recommended, especially where there is no monitoring of wetland aggregations in the management unit. The Normanby, Endeavour, Plane Creek, Styx and Shoalwater basins were identified as needing an **Accelerated** management response. The Jacky Jacky and Mulgrave-Russell basins were identified as needing a **Proactive** management response. There are fewer basins that were consistently identified as requiring the **Foundational** sediment management response for both marine and wetland ecosystems, but these included the basins with limited catchment development including the Olive-Pascoe, Lockhart, Stewart and Jeannie in the Cape York region, the Daintree and Mossman in the Wet Tropics region and Waterpark Creek in the Fitzroy region.
- **Pesticides:** Based on the pesticide risk assessment for marine ecosystems, **Intensive** pesticide management responses are primarily required in the Mackay Whitsunday basins—Proserpine, O’Connell, Pioneer and Plane Creek—as well as the Murray in the Wet Tropics and Haughton in the Burdekin region. **Accelerated** responses are primarily required in the Wet Tropics region—Mulgrave-Russell, Johnstone, Tully and Herbert basins—as well as the Burrum basin in Burnett Mary. **Proactive** management responses are required in the Mossman, Burdekin, Don, Fitzroy, Kolan, Burnett and Mary basins. In the **wetland assessment**, 18 management units were identified as requiring an **Intensive** management response for pesticides. An **Accelerated** management response is needed for the Upper Herbert, Black, Don River, Dawon, Isaac, Mackenzie, Nogoa, Baffle and Burrum management units, and a **Proactive** management response is needed in the Ross and Suttor basins in the Burdekin region and Comet in the Fitzroy. The basins in the Cape York region, the Daintree in the Wet Tropics, and some management units and basins in the Fitzroy region were identified as requiring a **Foundational** pesticide management response for both marine and wetland ecosystems. A **Foundational** response was also identified for wetland ecosystems in some management units in the Burdekin basin (Belyando, Upper Burdekin, Bowen Bogie, Cape Campapsee).

Relationship between ecosystem condition and Management Response

The Management Response Decision Support Framework's integration of ecosystem condition with pollutant exposure provides important context for management priorities. For marine ecosystems, coral and seagrass condition varies across the GBR, with the condition of many areas declining in recent years due to multiple pressures including water quality, climate change, and other disturbances.

For wetland ecosystems, of the 27 management units that were assessed, the assessment revealed that:

- Four of the management units have monitored wetland aggregations that remain in good condition, requiring protection-focused management to maintain their values.
- Twelve of the management units have monitored wetland aggregations in moderate condition, requiring closer monitoring and targeted interventions.
- Eleven of the management units have monitored wetland aggregations in poor condition, requiring immediate investigation of drivers and tailored interventions.

The assessment highlights that management responses need to be tailored not only to pollutant levels but also to ecosystem condition. For example, in areas like the Mulgrave-Russell basin where some wetlands remain in moderate condition despite significant development, management approaches need to address both protection and restoration priorities.

The assessment highlights important information about remaining floodplain wetland extent, which ranges from as little as 3% remaining in highly developed basins like the Mossman and Boyne (noting though that these basins had relatively small areas of wetlands, less than 150 ha, to start with), to nearly 100% remaining in less developed Cape York basins. This information is crucial for contextualising the urgency and scale of wetland management responses.

Implementation considerations

The management response assessment provides guidance on the relative level of effort required for effective intervention in each management unit. Areas requiring **Intensive** management responses will generally need greater resources, more comprehensive stakeholder engagement, and more extensive collaborative governance approaches.

The results indicate that extension, trust-building, and collaboration requirements increase significantly with higher management response levels. For areas requiring **Intensive** intervention, strategic multi-stakeholder engagement with management response co-development processes and large-scale collaborative programs will be essential.

The assessment highlights the importance of monitoring, evaluation, and investigation, particularly for areas where ecosystem condition is poor or where confidence in current condition assessments is low. This underscores the need for ongoing investment in both management actions and the knowledge base supporting adaptive management.

7.4 Identifying management actions for each basin or management unit

As described in Section 6.6, the mix of management actions in a basin or management unit will be driven by area-specific characteristics including the factors affecting adoption, a range of social factors and current actions and funding opportunities. It is outside the scope of this assessment to recommend specific management actions for each basin or management unit. However, as a means to demonstrate the application of the Management Response results to inform management prioritisation at a regional scale, a worked example of a 'Catchment Profile' for the Tully basin is presented below²⁴. The example shows the results for each of the major components of the assessment and provides an example of how this information could be presented to improve accessibility of this assessment to a wider audience.

²⁴ Note that the Catchment Profiles incorporate the updated pollutant load information from Catchment model V3.0 (last supplied March 2026).

Wet Tropics Region

Tully catchment

SUMMARY



For more information, access the full report here

The Tully catchment is located in the southern section of the Wet Tropics region and covers 1,668 km². The catchment has an average rainfall of 2,763 mm and a long-term median river discharge of 3,393 giganlitres per year. While the majority of the Tully catchment is in conservation areas (73%), the lowland floodplains of the Tully have intensive agricultural use, principally sugarcane (12%), grazing (6.8%) and bananas (2.4%).

Landscape disturbance factors that could influence water quality in the Tully primarily stem from historical native vegetation clearing, with 77% of floodplain vegetation and 48% of freshwater floodplain wetland riparian vegetation cleared by 2018. In the Tully, 65% of the estimated historical freshwater floodplain wetland extent had been lost and/or modified, with 3,665 hectares of natural unmodified wetlands remaining in 2017.

The Tully catchment is the fourth largest exporter of dissolved inorganic nitrogen (DIN) to the Great Barrier Reef (GBR) and has a modelled total annual average DIN load of 731 tonnes. It is estimated that 65% of the DIN load is from anthropogenic rather than natural sources. The primary contributing land uses are sugarcane (35%) and bananas (32%). The modelled total annual average fine sediment load is 105 kilotonnes, with 49% estimated to come from anthropogenic sources. Pesticide risk ranges from Low to Moderate depending on the sampling year (2015 to 2023). Diuron and imidacloprid are the biggest contributors of the risk.

Freshwater floodplain wetlands are in Moderate condition and face pressures including pest species, sediment inputs, vegetation clearing, loss of regional ecosystems, drainage modifications, and reduced landscape connectivity. The wetland scores for exposure to nutrient, sediment and pesticide hazards were all assessed as High.

In the marine environment, coral reefs adjacent to the Tully catchment are in Moderate condition and seagrass meadows are in Poor condition (2022–23). The marine DIN exposure score is High, ranking second among all GBR catchments reflecting the significant anthropogenic DIN load, high frequency of river discharge and relatively large area of coral reefs in the highest exposure categories. Sediment exposure is Moderate, ranking fifth among all GBR catchments. Pesticide exposure is Moderate.

Overall management and focus areas

Multi-pollutant, strategic management required across multiple land uses with large-scale, **intensive management of nutrients** and **accelerated management of sediment and pesticides** in targeted sub-catchment areas. **Intensive management of all pollutants for wetlands** in hazard exposed areas. Broad-scale foundational management in all remaining areas across the catchment.

Refer to the Management Assessment page for more information.

RECOMMENDED MANAGEMENT RESPONSES FOR THE TULLY

	Nutrients (W) / Dissolved inorganic nitrogen (M)	Fine sediments & particulate nutrients	Pesticides
Freshwater Flood- plain Wetlands (W)	Intensive+	Intensive+	Intensive+
Marine (M)	Intensive+	Accelerated+	Accelerated+

ASSESSMENT FRAMEWORK

Management responses were determined based on an assessment of ecosystem condition and likely exposure to each pollutant.

		Pollutant exposure			
		Minimal	Low	Moderate	High
Ecosystem condition	Poor	Foundational response + investigate	Proactive response + investigate	Accelerated response + evaluate	Intensive response + evaluate
	Moderate	Foundational response + investigate	Proactive response + investigate	Accelerated response + further assessment	Intensive response + further assessment
	Good	Foundational response	Proactive response	Accelerated response + increased vigilance	Intensive response + increased vigilance
		Trust development, prepare for the future	Small-scale intervention	Targeted intervention	Comprehensive intervention
		Management options			

Tully



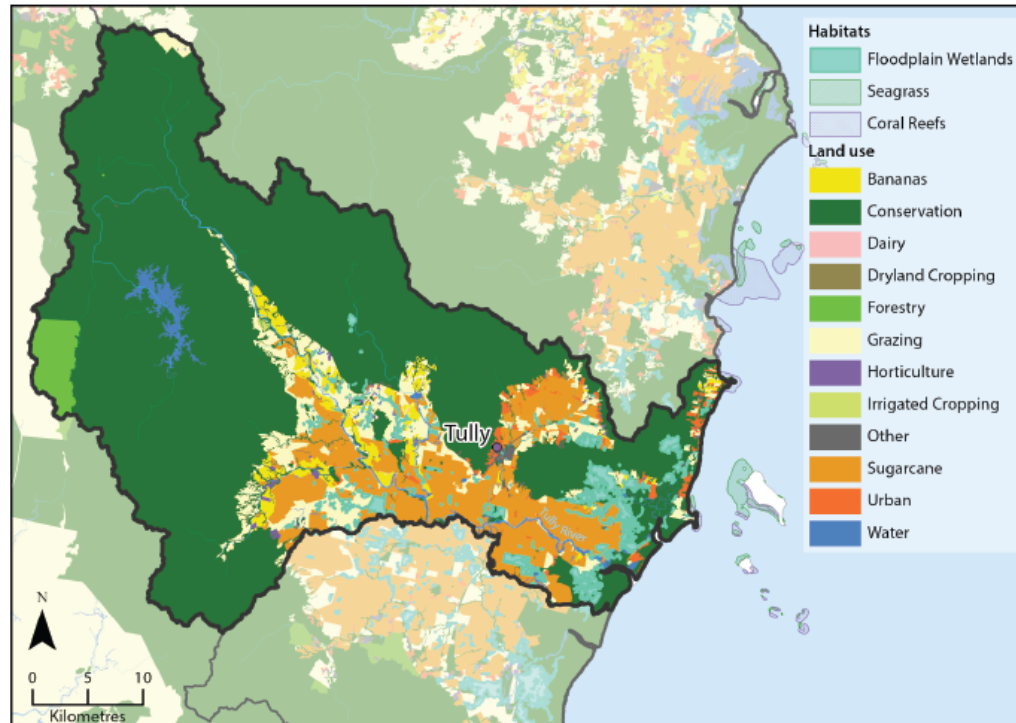
Climate

Rainfall averages 2,763 mm per year. Although rainfall totals are typically concentrated in the summer months (December to April), the catchment receives regular rainfall throughout the year. [1]



River discharge

The long-term median discharge from the Tully is around 3,393 gigalitres per year. [2]



LAND

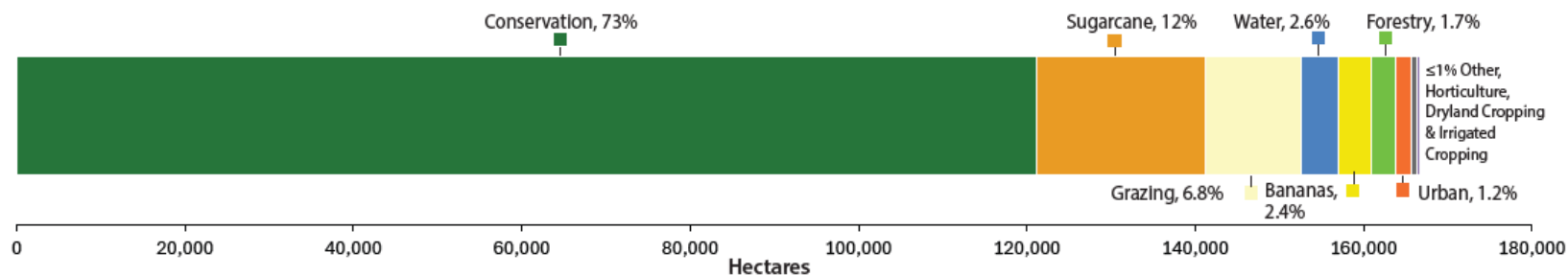
The Tully catchment is located in the southern section of the Wet Tropics region and covers 1,668 km². The majority of the catchment is drained by the Tully River, with the remaining area captured by the Hull River and several smaller coastal creeks. The upper reaches of the Tully River are fed by streams from rainforests of the Wet Tropics World Heritage Area. The Koombooloomba Dam is also located in the upper catchment area. The lowland floodplains of the Tully catchment have intensive agricultural land use, principally of sugarcane (12%), grazing (6.8%) and banana (2.4%) crops. The main urban area is the township of Tully at the foot of the mountain range, and there are several smaller coastal localities, including Hull Heads, Tully Heads and Mission Beach. [3]

WETLANDS AND NEARSHORE MARINE ECOSYSTEMS

The Tully catchment contains 9,669 hectares of wetlands including 1,635 hectares of riverine, 4,442 hectares of palustrine wetlands (freshwater vegetated swamps), 27 hectares of lacustrine wetlands (lakes), and 1,946 hectares of estuarine or intertidal wetlands (saltmarsh, salt flats and mangroves). Artificial or highly modified wetland areas covered 1,617 hectares in 2021 [4]. In the marine environment, there are seagrass meadows and coral reefs in close proximity of the coastline.

For the rest of this catchment profile, the focus is on freshwater floodplain wetlands (lakes and swamps).

CATCHMENT PROFILE



Tully

An orange icon against a driver denotes the catchment is in the **top ten** of the 35 GBR catchments for that driver.

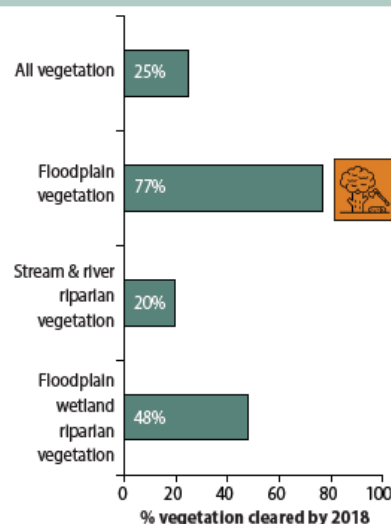
Landscape drivers of water quality

Landscape disturbance factors that could influence water quality in the Tully primarily stem from historical native vegetation clearing, with 77% of floodplain vegetation and 48% of freshwater floodplain wetland riparian vegetation cleared by 2018. Between 2019 and 2022, 70 hectares of woody vegetation was cleared. In addition, 65% of the estimated historical freshwater floodplain wetland extent has been lost and/or modified, with 3,665 hectares of natural unmodified wetlands remaining in 2017. Long-term mean late dry season groundcover (1987 to 2022) is 82% and the gully network is small (31 km).

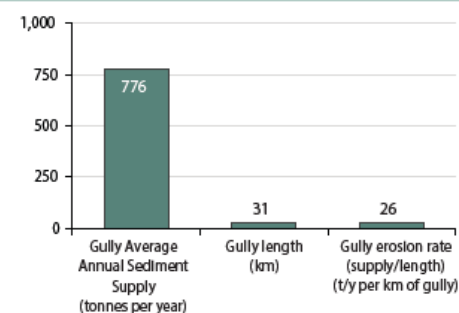
HISTORICAL AND RECENT NATIVE VEGETATION CLEARING

Vegetation clearing is one of the most significant drivers affecting land-based runoff to the GBR's waterways and is measured over time using satellite imagery. Historical and ongoing clearing of native vegetation has substantially modified catchment hydrology, resulting in increased runoff and reducing the landscape's natural capacity to trap and filter pollutants. Riparian areas adjacent to rivers, streams, or wetlands act as a buffer between the land and aquatic environment and play a crucial role in stabilising banks, filtering pollutants, and providing habitat for wildlife.

The highest rates of historical native vegetation clearing in the Tully are associated with floodplains (77% of native vegetation cleared by 2018), and freshwater floodplain wetland riparian areas (48% cleared) [5]. Between 2019 and 2022, 0.1% of the 2019 woody vegetation extent was cleared (70 hectares), including 0.2% of the 2019 woody vegetation extent on floodplains (31 hectares), and 0.1% of the 2019 woody vegetation extent in freshwater floodplain wetland riparian areas (11 hectares) [6].



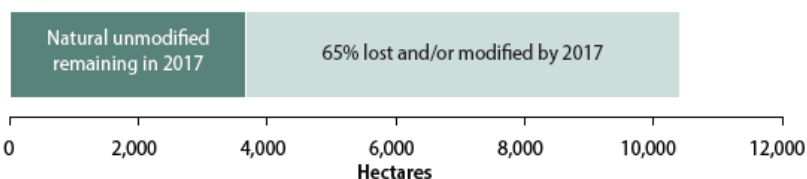
GULLIES



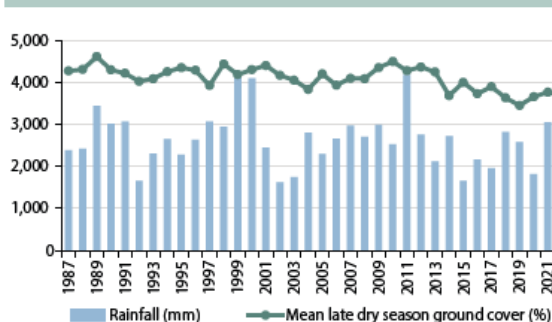
Gullies can efficiently deliver sediments and particulate nutrients directly to stream networks. Left untreated, gullies can contribute substantially to water quality degradation, particularly sediment export. The Average Annual Sediment Supply (AASS) represents total eroded soil mass (both fine and coarse sediment). While fine sediment export is a particular concern for GBR ecosystems, total sediment supply can be important for catchment ecosystem health, including freshwater floodplain wetlands. Gully length provides an indication of gully presence in each catchment. Recent mapping indicates low gully presence and low erosion rates in the Tully catchment [7].

FRESHWATER FLOODPLAIN WETLANDS

Floodplain wetlands act as natural filters in the landscape, trapping sediments, nutrients and pesticides before they reach waterways. Since European settlement, many wetlands have been lost or modified for agriculture and urban development. These changes mean fewer natural systems are available to process pollutants, which can contribute to poorer water quality. In the Tully catchment, 65% of the estimated historical freshwater floodplain wetland extent had been lost and/or modified by 2017. Of the original 10,411 hectares of freshwater floodplain wetlands, only 3,665 hectares of natural unmodified wetlands remained in 2017 [4].



GROUNDCOVER



Groundcover is critical for protecting GBR water quality as it shields soil from erosion. Maintaining at least 70–75% coverage significantly reduces sediment runoff. When groundcover drops below 30–50%, erosion increases dramatically. Between 1987 and 2022, the long-term mean late dry season groundcover in the Tully was 82% [8].

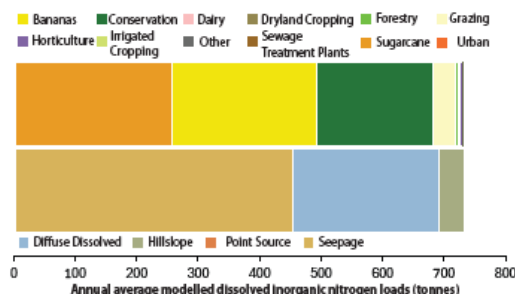
CATCHMENT PROFILE

Tully

DISSOLVED INORGANIC NITROGEN

DIN

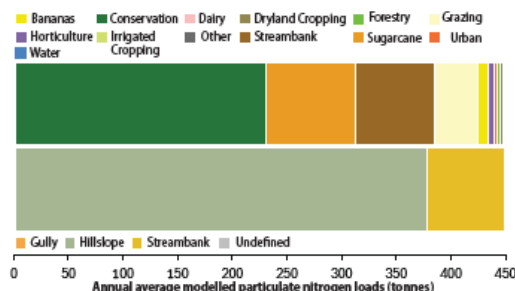
The modelled annual average DIN load from the Tully is 731 tonnes. It is the fourth largest exporter of DIN to the GBR, contributing 7.9% of the total load. It is estimated that 65% is from anthropogenic rather than natural sources. The primary contributing land uses are sugarcane (35%) and bananas (32%). The main loss pathway is seepage (62%), followed by diffuse dissolved (33%) [9].



PARTICULATE NITROGEN

PN

The modelled annual average particulate nitrogen load is 449 tonnes. Conservation (51%), sugarcane (18%), streambank (16%) and grazing (8.9%) areas are the primary sources. Hillslope erosion is the dominant transport pathway (84%) [9].

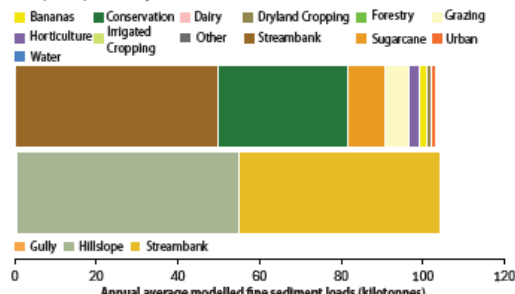


An orange icon indicates that the catchment is one of the **top five** exporters for that pollutant across the 35 GBR catchments.

FINE SEDIMENTS



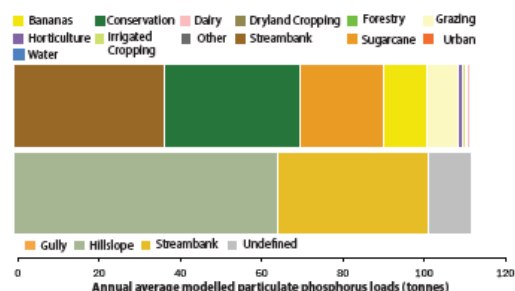
The modelled annual average fine sediment load is 105 kilotonnes. It is estimated that 49% is from anthropogenic rather than natural sources. Streambank areas contribute around 50% of the fine sediment load, followed by conservation areas (32%) and sugarcane (9.0%). Hillslope erosion (52%) and streambank erosion (48%) are the dominant transport pathways [9].



PARTICULATE PHOSPHORUS

PP

The modelled annual average particulate phosphorus load is 113 tonnes. Streambank (33%) and conservation (30%) areas are the primary sources, followed by sugarcane (18%) and bananas (9.4%). Hillslope erosion is the dominant transport pathway (58%), followed by streambank erosion (33%) [9].

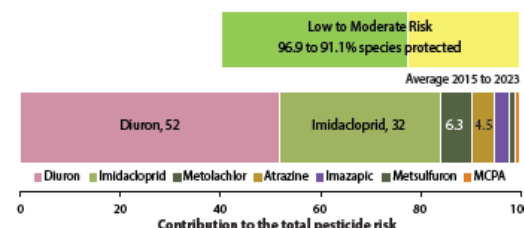


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PESTICIDES



The wet season daily average pesticide risk (Pesticide Risk Metric) at the Tully end-of-catchment monitoring site ranged from Low to Moderate (96.9 to 91.1% species protected) between 2015 and 2023. Diuron and imidacloprid were the biggest contributors of this risk (~84% combined contribution), followed by metolachlor, atrazine and imazapic. The largest land use areas in the Tully catchment with a higher potential for pesticide runoff are sugarcane, bananas and horticulture [10].



Dominant pollutant source and pathway for targeting management (ranked)

DIN

Sugarcane and Bananas



Streambank in various land uses and Sugarcane
Hillslope and streambank erosion



Sugarcane and Bananas

Dominant pesticides

Diuron and Imidacloprid

POLLUTANT LOADS AND SOURCES

Tully



Ecosystem condition: Not assessed Good Moderate Poor

ECOSYSTEM CONDITION



This assessment evaluated wetland environmental values and pressures using data from the GBR Wetland Condition Monitoring Program which assesses condition based on a suite of biotic (including habitat and connectivity), physical (including hydrological) and land use hazard indicators [13]. A composite index was calculated from the indicators to classify condition as Good, Moderate or Poor [14].

There were 3,729 hectares of natural and slightly modified freshwater floodplain wetlands included in the hazard assessment for the Tully. Freshwater floodplain wetlands in the Tully (n = 12 wetlands assessed) were assessed as being in overall Moderate condition. Wetlands face several pressures in this catchment including issues associated with pest plant and/or animal species, sediment supply (modelled), native vegetation clearing, loss of wetland regional ecosystems, drainage modifications and artificial structures altering natural surface flows, and landscape vegetation connectivity.

Key Findings

Freshwater floodplain wetlands (n = 12 assessed) are in Moderate condition and face pressures including pest species, sediment inputs, vegetation clearing, loss of regional ecosystems, drainage modifications, and reduced landscape connectivity. Of the 3,729 hectares of freshwater floodplain wetlands included in the hazard assessment, 51% are exposed to High or Very High nutrient hazard, 52% are exposed to High or Very High sediment hazard, and 88% are exposed to Moderate, High, or Very High pesticide hazard, all representing High exposure.

WETLAND EXPOSURE TO POLLUTANT HAZARD

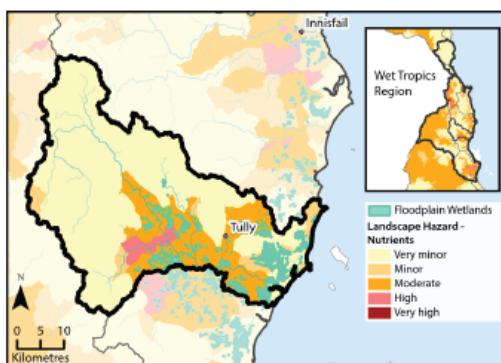
Exposure of freshwater floodplain wetlands to pollutant hazards was assessed by categorising and weighting land use data to identify areas with High or Very High hazard levels for nutrients and sediments, and also Moderate hazard levels for pesticides and these maps are shown below for each pollutant. For each catchment or management unit, the final exposure score was calculated as the percentage of the natural and slightly modified freshwater floodplain wetland area, as of 2019, that fell within these identified hazard zones [14].

Exposure score: Minimal Low Moderate High

Nutrients



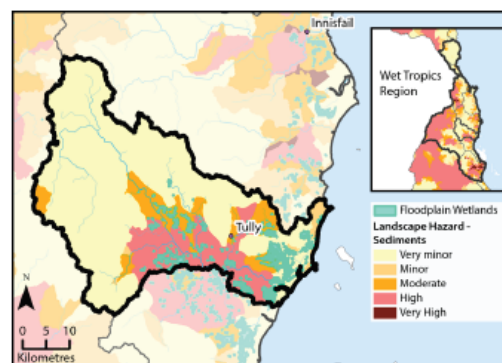
Approximately 1,901 hectares (51%) of freshwater floodplain wetlands in the Tully are exposed to High or Very High nutrient hazard, representing a High exposure score within the catchment.



Sediments



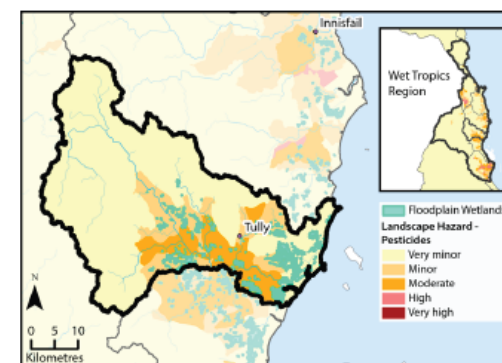
Approximately 1,953 hectares (52%) of freshwater floodplain wetlands in the Tully are exposed to High or Very High sediment hazard, representing a High exposure score within the catchment.



Pesticides



Approximately 3,290 hectares (88%) of freshwater floodplain wetlands in the Tully are exposed to Moderate, High, or Very High pesticide hazard, representing a High exposure score within the catchment.



FRESHWATER FLOODPLAIN WETLANDS

Tully

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Ecosystem condition: Not assessed Good Moderate Poor
Exposure score: Minimal Low Moderate High

ECOSYSTEM CONDITION

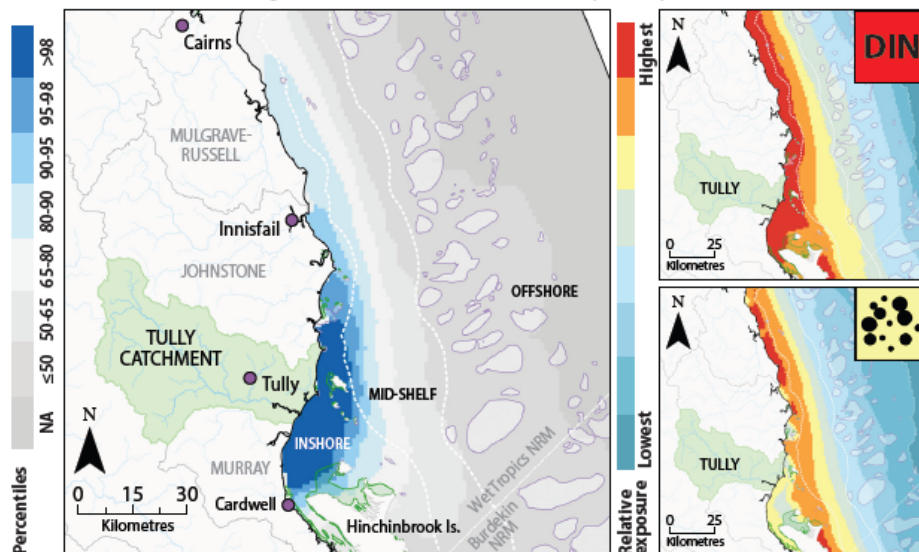
Marine ecosystem condition was assessed using the GBR Marine Monitoring Program's indices for coral reefs and seagrass for 2022–23. The Coral Index integrates measures of coral cover, juvenile abundance, macroalgae cover, coral cover change, and community composition [14]. The Seagrass Index combines abundance and resilience indicators [15]. These indices classify ecosystem condition as Good, Moderate, or Poor.

In 2022–23, coral reefs adjacent to the Tully catchment were in Moderate condition and seagrass meadows were in Poor condition.

SEDIMENT & NUTRIENT EXPOSURE

Marine exposure to DIN and fine sediments (2011–2022) was assessed using eReefs modelled river footprints, overlaid with spatial layers of anthropogenic pollutant exposure (current vs. pre-development). Relative Exposure was classified from highest to lowest and weighted by the river footprints, which represent the frequency of river influence. These weighted layers were categorised from Very High to Very Low and combined with ecosystem distribution to calculate exposure scores. The graph highlights areas in the Very High to Moderate Low categories which are most ecologically relevant. Catchments with low anthropogenic loads (DIN < 50 t/year or TSS < 50 kt/year) were assigned a Minimal exposure score [14].

The modelled river footprint in the Tully catchment can extend up to 16,466 km², with 1,928 km² regularly influenced by river discharge (shown in blue shading below). There are 3,579 hectares of coral reefs and 9,698 hectares of seagrass meadows in this area of more frequent exposure.



Key Findings

Coral reefs adjacent to the Tully catchment are in Moderate condition and seagrass meadows are in Poor condition. DIN exposure is High, ranking second among all GBR catchments reflecting the significant anthropogenic DIN load, high frequency of river discharge and relatively large area of coral reefs in the highest exposure categories. Sediment exposure is Moderate, ranking fifth among all GBR catchments. Pesticide exposure is Moderate.

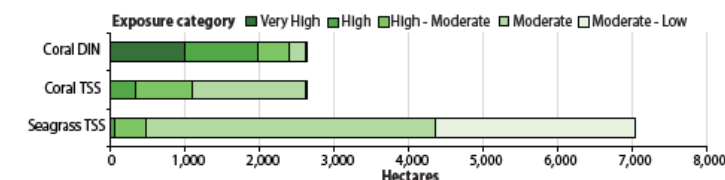
PESTICIDE EXPOSURE

Three complementary lines of evidence were used to assess marine pesticide exposure: end-of-catchment monitoring data (Pesticide Risk Metric) providing comprehensive temporal coverage for up to 22 pesticides; a whole-of-catchment risk baseline using land use patterns to fill spatial monitoring gaps in the catchment; and a diuron marine modelling case study illustrating pesticide marine dispersal and potentially affected marine ecosystems [10, 11, 12].

The Tully has a Moderate pesticide exposure score. The pesticide monitoring data and the whole-of-catchment pesticide risk baseline indicated a Moderate Risk of pesticides. The diuron marine modelling also indicated no potential marine hotspots, with further assessment required.

Dissolved inorganic nitrogen (DIN)

The Tully has a High DIN marine exposure score, ranking second among all GBR catchments, and highest in the Wet Tropics region. This reflects the significant anthropogenic DIN load, high frequency of river discharge and relatively large area of coral reefs in the river footprint. There are 1,977 hectares of coral reefs in the highest (Very High to High) exposure categories.



Fine sediments (TSS)

The Tully has a Moderate marine fine sediment exposure score, ranking fifth among all GBR catchments, and second highest in the Wet Tropics region. This reflects the high frequency of river discharge and relatively large area of coral reef and seagrass ecosystems in the river footprint. There are 341 hectares of coral reef and 66 hectares of seagrass in the highest (Very High to High) exposure categories, with much larger areas in the Moderate and Moderate-High exposure categories.

Overall management and focus areas

Multi-pollutant, strategic management required across multiple land uses with large-scale, **intensive management of nutrients** and **accelerated management of sediment and pesticides** in targeted sub-catchment areas. **Intensive management of all pollutants for wetlands** in hazard exposed areas. Broadscale foundational management in all remaining areas across the catchment. *Further assess wetlands in Moderate condition to understand pollutant influences and actively manage other drivers of condition to avoid further decline. As seagrass is in Poor condition, evaluate drivers of condition, and the need and potential for intervention options to assist ecosystem recovery / rehabilitation.*

ECOSYSTEM CONDITION x HAZARD/EXPOSURE

The management response level is determined by ecosystem condition and pollutant hazard / exposure.

Ecosystem condition: ■ Not assessed ■ Good ■ Moderate ■ Poor
Hazard / Exposure score: ■ Minimal ■ Low ■ Moderate ■ High

	Ecosystem condition	Hazard / Exposure
Freshwater floodplain wetlands (W)		  
Marine ecosystems (M)	 	  



RECOMMENDED MANAGEMENT RESPONSES

Within the management response levels, specific actions are included depending whether ecosystems are in Good, Moderate, or Poor condition with different emphasis on protection versus recovery and rehabilitation.

Nutrients (W) / Dissolved inorganic nitrogen (M)	Fine sediments & particulate nutrients	Pesticides
Intensive+	Intensive+	Intensive+
Intensive+	Accelerated+	Accelerated+

FOUNDATIONAL

Management aim: Good water quality is maintained to ensure that ecosystems remain protected from impacts of poor water quality into the future.

- Broadscale, widespread application of actions across all land uses within the catchment.
- Apply 'Whole-of-System, values-based' management principles.

PROACTIVE

Management aim: Ensure that emerging pollutant hazard / exposure issues are addressed, and good water quality is maintained into the future.

- Implement Foundational management response.
- Small-scale, localised areas and programs for actions in specific land uses within the catchment.

ACCELERATED

Management aim: Accelerate efforts to reduce pollutant hazard / exposure, protect ecosystems and support recovery from escalating climate impacts.

- Implement Foundational and Proactive management responses.
- Small to medium scale, tailored interventions in strategic and targeted sub-catchment areas across multiple land uses.

INTENSIVE

Management aim: Maximise efforts to address high pollutant hazard / exposure levels to reduce widespread water quality impacts within critical timeframes, enabling ecosystem recovery in response to escalating climate impacts.

- Implement Foundational, Proactive and Accelerated management responses.
- Comprehensive and large-scale land management, targeting all dominant pollutant sources, multiple land uses and water quality drivers.

Sources of information

Full report

Waterhouse J, Star M, Molinari B, Sambrook K, VanderGragt M, Leigh C, Sutcliffe T, Smith R, Choukroun S, Tracey D, Lewis S (2025) Decision support framework for management options to maintain and improve water quality in the Great Barrier Reef catchment area. Analysis of key spatial factors impacting water quality and the condition of wetlands, corals and seagrass in the Great Barrier Reef. Commonwealth of Australia and Queensland Government | [Link](#)

A summary of the 'Decision support framework for management options to maintain and improve water quality in the Great Barrier Reef catchment area' is contained in the Methods Summary | [Link](#)

Data sources

- [1] **Climate and rainfall:** Australian & Queensland Government 2019, Reefplan Catchment Profiles 2019 | [Link](#)
- [2] **Long-term median basin discharge (1990–91 to 2019–20).** Moran D, Waterhouse J, Petus C, Howley C, Lewis S, Gruber R, James C, Logan M, Bove U, Brady B, Choukroun S, Connellan K, Davidson J, Mellors J, O'Callaghan M, O'Dea C, Shellberg J, Dick E, Polglase L, Tracey D, Molinari B, Zagorski I (2025) Great Barrier Reef Marine Monitoring Program Inshore Water Quality Monitoring: Annual Report 2023–24. Great Barrier Reef Marine Park Authority, Townsville. 322 pp. | [Link](#)
- [3] **Land use data (2021):** Department of the Environment, Tourism, Science and Innovation (DETSI). Queensland Land Use Mapping Program (QLUMP). Queensland Government | [Link](#)
- [4] **Wetland extent (2019) and historical wetland loss (up to 2017):** Department of the Environment, Tourism, Science and Innovation (DETSI), WetlandInfo Wetlands mapping Version 6.0 | [Link](#)
- [5] **Historical vegetation clearing (up to 2018):** Neldner VJ, Wilson BA, Dillewaard HA, Ryan TS, Butler DW, McDonald WJF, Richter D, Addicott EP, Appelman CN (2023) Methodology for survey and mapping of regional ecosystems and vegetation communities in Queensland. Version 7.0. Updated December (2023) Queensland Herbarium, Department of the Environment, Science and Innovation, Brisbane, Queensland. | [Link](#)
- [6] **Recent vegetation clearing (2019 to 2022):** Department of the Environment, Tourism, Science and Innovation (2024) Statewide Landcover and Trees Study (SLATS) - Methodology Overview v1.2. Queensland Government | [Link](#)
- [7] **Gullies (1970 to 2023):** Department of the Environment, Tourism, Science and Innovation (unpublished). Long-term Total Gully Average Annual Sediment Supply (1970 to 2023), gully length and gully erosion rate (supply/length). Paddock to Reef program Catchment Model inputs, version supplied April 2025.
- [8] **Groundcover (1987 to 2022):** Reef Water Quality Report Card 2021 and 2022, State of Queensland, Brisbane | [Link](#)
- [9] **Sediment and nutrient loads, sources and pathways:** Department of the Environment, Tourism, Science and Innovation (DETSI) (2026) Modelled estimates of dissolved inorganic nitrogen, fine sediment and particulate nutrients delivered from the Great Barrier Reef catchments. Reef Report Card 2023/24 baseline loads. Version supplied March 2026. Note: *This is an updated version of the pollutant load information presented in the full report (Waterhouse et al. 2025).*
- [10] **End-of-catchment pesticide monitoring:** Water Quality & Investigations (2024b) Tahbil - Water Quality Data Portal. [website]. Queensland Government, Brisbane. | [Link](#)
- [11] **Whole-of-catchment pesticide risk baseline:** Warne M St J, Neelamraju C, Strauss J, Smith RA, Turner RDR, Mann RM (2020) Development of a method for estimating the toxicity of pesticide mixtures and a Pesticide Risk Baseline for the Reef 2050 Water Quality Improvement Plan. Brisbane: Department of the Environment and Science, Queensland Government.
- [12] **Diuron marine modelling case study:** eReefs model re-run based on the approach presented in Skerratt J, Baird ME, Mongin M, Ellis R, Smith RA, Shaw M, Steven ADL (2023) Dispersal of the pesticide diuron in the Great Barrier Reef. Science of the Total Environment, 879, 163. | [Link](#)
- [13] **Freshwater floodplain wetlands condition (2017 to 2024):** Most recent survey data (as at June 2024), derived from Wetland Condition Science Team (2024) Wetland Condition Monitoring Program for the Great Barrier Reef Catchment Area. Queensland Government Department of the Environment, Tourism, Science and Innovation, Brisbane, Queensland. | [Link](#)
- [14] **Wetlands hazard assessment, River footprints (2011 to 2022), Marine Exposure and Condition:** Waterhouse J, Star M, Molinari B, Sambrook K, VanderGragt M, Leigh C, Sutcliffe T, Smith R, Choukroun S, Tracey D, Lewis S (2025) Decision support framework for management options to maintain and improve water quality in the Great Barrier Reef catchment area. Analysis of key spatial factors impacting water quality and the condition of wetlands, corals and seagrass in the Great Barrier Reef. Commonwealth of Australia and Queensland Government. | [Link](#)
- [15] **Seagrass condition (2022–23):** McKenzie LJ, Collier CJ, Langlois LA, Brien H, Yoshida RL (2024) Marine Monitoring Program: Annual Report for Inshore Seagrass Monitoring 2022–23. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville. 178 pp. | [Link](#)

Additional resources

- ▶ 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition | [Link](#)
- ▶ Reef 2050 Catchment Water Quality Strategy | [Link](#)
- ▶ Great Barrier Reef Outlook Report 2024 | [Link](#)
- ▶ Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef program) | [Link](#)
- ▶ Great Barrier Reef Marine Monitoring Program | [Link](#)
- ▶ WetlandInfo | [Link](#)

REFERENCES



8. Comparison to previous results, limitations of the assessment and future knowledge needs

8.1 Comparison to previous assessments

It is not straightforward to compare this assessment to the results of the 2017 water quality management prioritisation (Waterhouse et al. 2017b) as the approach is significantly different, shifting from a simple prioritisation of the basins posing the highest relative risk to GBR ecosystems, to include recognition of the value of ecosystems in good condition and where there is low pollutant exposure. However, it is recognised that a comparison of the results is relevant to decision makers and is briefly covered here. At the highest level, the basins identified in the **Intensive** management response typically align with the basins that were identified as High priority in the 2017 assessment, but the current assessment is much more nuanced. As a result, some additional basins of relevance are highlighted such as the Normanby for sediment, the Burdekin (Delta) and Burnett for nutrients and the Murray, Proserpine and O'Connell for pesticides. Several basins that were previously identified as Very High or High priority are now identified in the lower management response categories including the Mulgrave-Russell, Johnstone, Plane and Mary for nutrients and the Burnett for sediments.

The 2017 SCS presented an assessment of the likelihood of exposure and potential risks from land-based pollutants to GBR coastal (floodplain wetlands and floodplains) and marine (coral reefs and seagrass meadows) ecosystems. The assessment included all 35 basins that discharge into the GBR. Coastal aquatic ecosystems were included for the first time, specifically, floodplain wetlands (i.e. vegetated swamps and lakes) and floodplains. A comparison of those basins identified as highest management priority based on marine exposure, and the **Intensive** management responses in the current assessment is shown in Table 28, highlighting the differences in the assessment when individual river footprints, longer-term datasets and ecosystem condition are taken into account. A comparison of those management units identified as highest management priority based on the wetlands assessment is shown in Table 29. There is a high degree of consistency between the 2017 and current assessment, with the identification of several additional areas.

*Table 28. Comparison between the highest priority (Very High and High) basins for each pollutant in the 2017 management prioritisation, and the basins identified for Intensive marine-driven management response in this assessment. *The basins highlighted in bold are common between the assessments.*

Pollutant	2017 assessment* (Very High and High priority)	Current assessment (Intensive management response, marine driven)
Nutrients	Mulgrave-Russell, Johnstone, Tully, Herbert, Haughton , Plane, Mary	Tully, Herbert (Lower), Haughton , Burdekin (Delta), Burnett
Sediments	Herbert, Burdekin, Fitzroy , Burnett, Mary	Normanby, Herbert (Upper) , Burdekin, Fitzroy, Mary
Pesticides	Haughton, Pioneer, Plane	Murray, Haughton , Proserpine, O'Connell, Pioneer, Plane

Table 29. Comparison between the highest likelihood of exposure management units for each pollutant in the 2017 management prioritisation for floodplain wetlands, and the management units identified for Intensive wetlands-driven management response in this assessment. *The management units highlighted in bold are common between the assessments.

Pollutant	2017 assessment* (High likelihood of exposure to pollutant hazard)	Current assessment (<i>Intensive</i> management response, wetlands driven)
Nutrients	Barron, Johnstone, Tully, Murray, Lower Herbert, Haughton, East Burdekin, Burdekin Delta, Proserpine, O'Connell, Pioneer, Theresa Creek, Kolan, Burnett and Mary	Barron, Johnstone, Tully, Murray, Upper Herbert, Lower Herbert, Black, Haughton, East Burdekin, Burdekin Delta, Bowen Bogie, Cape Campaspe, Don, Proserpine, O'Connell, Pioneer, Plane Creek, Lower Fitzroy, Dawson, Isaac, Mackenzie, Comet, Nogoa, Theresa Creek, Boyne, Baffle, Kolan, Burnett, Burrum and Mary
Sediments	Barron, Johnstone, Tully, Murray, Lower Herbert, Haughton, East Burdekin, Burdekin Delta, Proserpine, O'Connell, Pioneer, Theresa Creek Kolan, Burnett and Mary	Barron, Johnstone, Tully, Murray, Upper Herbert, Lower Herbert, Black, Ross, Haughton, East Burdekin, Burdekin Delta, Belyando, Suttor, Upper Burdekin, Bowen Bogie, Cape Campaspe, Don, Proserpine, O'Connell, Pioneer, Lower Fitzroy, Dawson, Isaac, Mackenzie, Comet, Nogoa, Theresa Creek, Calliope, Boyne, Baffle, Kolan, Burnett, Burrum and Mary
Pesticides	Barron, Johnstone, Tully, Murray, Lower Herbert, Haughton, East Burdekin, Burdekin Delta, Proserpine, O'Connell, Pioneer, Theresa Creek Kolan, Burnett and Mary	Mossman, Barron, Mulgrave-Russell, Johnstone, Tully, Murray, Lower Herbert, Haughton, East Burdekin, Burdekin Delta, Proserpine, O'Connell, Pioneer, Plane, Theresa Creek, Kolan, Burnett and Mary

In the 2017 assessment, the Cape York basins were identified as priority for protection / maintaining current water quality given their relatively low risk contributions and relatively good condition of the adjacent marine ecosystems. However, this was not the focus of the management response in the investment period that followed.

8.2 Improvements to the assessment

Within the current assessment there have been significant improvements to the datasets, and in some cases the methods, used when compared to those used in the 2017 assessment, including some that were previously highlighted as limitations. These improvements influence the results, leading to differences in the outcomes for some locations. Improvements to the datasets include:

- Recognition of the catchment influences on water quality in the GBR and its catchments, including vegetation extent and clearing, riparian vegetation extent and clearing, floodplain wetland loss and modification, groundcover and gully density. Many of these datasets are based on the latest available information and many are generated as part of the P2R program.
- Significant adjustments to the catchment models for estimating pollutant sources, including the way that several processes are represented (for example streambank erosion), updated land use, better representation of STP DIN loads, catchment hydrology, and data inputs, resulting in refined estimates of end-of-catchment loads across the GBR. This is supported by improved validation of the catchment model and understanding of processes due to an increasing pool of knowledge. It must be noted that the modelling used to assess the costs of interventions is different to the version used to identify pollutant sources.
- Incorporation of updated land use and wetland extent data (to be released in May 2025), and incorporation of downstream wetlands, in the floodplain wetland hazard assessment.

- Use of field monitoring data for pesticide risk assessment rather than modelled data, providing more direct evidence of current risk conditions.
- Substantial increase in the representation of river inputs in the eReefs model, from 17 rivers in the previous assessment, to 63 individual outputs in the current model run. The distribution of loads is better represented with the increased number of rivers. This supports the ability to attribute pollutant exposure back to individual basins across the whole GBR.
- Use of a longer modelling period for the marine analysis; data spanning 12 years is now available instead of the four years available in the previous assessment. With more rivers modelled and over a longer climate period, there is a greater representation of the probability of a plume occurring in the longer climate period and coverage of a range of climate conditions.
- Testing of the marine model of pesticide risk for diuron.
- Incorporation of the current condition of ecosystems and trends over time to enable management responses for managing GBR water quality to be better defined, in terms of priorities for protection as well as increased effort in the areas of high pollutant exposure.
- Comprehensive review of management options for the different management responses, including close alignment with the review of the management practice adoption targets being conducted as part of the P2R program.

8.3 Limitations by assessment component

8.3.1 Freshwater wetland assessment limitations

Hazard assessment

The assessment of the exposure of floodplain wetlands to sediments, nutrients and pesticides has built on the approach taken in the 2017 assessment. However, several limitations remain:

- Natural or semi-natural, freshwater floodplain wetland systems include mosaic areas i.e. those areas identified as containing wetlands, but which are too small to map at the current state-wide wetland mapping scale of 1:100,000 to 1:50,000 in some coastal areas. Approximately 131,386 ha of land are mapped as mosaic areas containing freshwater floodplain wetlands or wetlands that are sub-dominant. Wetlands in these large areas are not included in the hazard assessment for wetlands and the condition of wetlands in these areas is unknown.
- The hazard assessment uses the pollutant weightings that were derived through an expert elicitation process almost ten years ago. While a rapid review of these weightings was undertaken for nutrients, sediments and pesticides with other sources, it is possible that expert opinion may have shifted regarding the weightings to be applied to some land uses based on new evidence. In addition, further distinction of nutrient forms (i.e. dissolved and particulate, nitrogen and phosphorus) would be beneficial to improve the specificity of the assessment.
- The composition of land uses within spatial units, which are used to determine hazard, varies among spatial units. Where the relative proportion of one land use is high, this will dominate the overall hazard outcome. For example, where there is a high proportion of conservation land use and a smaller area of a higher hazard land use, the hazard calculation will likely result in a minor or low hazard for the spatial unit. Such is the case for nutrient hazard exposure in the Mulgrave-Russell management unit. Additionally, the spatial units used to determine downstream hazard may occasionally extend beyond the downstream area, thereby attributing some hazard to wetlands unlikely to be affected, such as in the Shoalwater management unit.
- Where there are MUs with large areas exposed to a hazard but with only a small area of wetlands the relative GBR-wide exposed area is minimal.
- The wetland pre-clear mapping is a derived dataset, as there was no aerial survey or detailed inventory pre-clearing, and therefore there are limitations with the scale and accuracy of the data. Additionally, actual wetland loss between years is very difficult to determine and the wetland change methodology may sometimes attribute changes in vegetation loss as complete wetland loss, which

may not be correct. For example, a decline in vegetation cover might be classified as habitat loss, even though the wetland can still persist without it.

- An error was identified in the boundaries of Waterpark Creek management unit. This discrepancy primarily affected the exposure results for nutrients and sediments in Waterpark Creek, for which the result was adjusted in the water quality management response assessment to account for the misalignment. While the impact on other management units and on other pollutants is expected to be minimal, it is important to note this correction for future reference and interpretation.

Wetland condition

- The assessment of wetland ecosystem condition is based on the results of the P2R Wetland Condition Monitoring Program which monitors wetland aggregations in 27 of the 48 management units. For some management units, the condition assessment is based on very few monitoring sites which may not be representative of all wetlands in the area. There is no systematic pollutant monitoring or long-term research of pollutant presence and impacts to wetlands to draw on for this assessment, or to enable trend analysis.
- While the P2R Wetland Condition Monitoring Program is now well established (commenced in 2013), there is still limited data on the condition of floodplain wetlands or targeted research to enable quantification of the relationships between pollutant pressures, wetland condition and water quality impacts (and consequence) to inform a comprehensive and quantitative risk assessment at the GBR or regional scales. There is also limited data available on the generation, pathways and fate of potential pollutants in relation to floodplain wetlands, whether from sub-catchment, basin or GBR-wide perspectives. In some areas mapped as containing wetlands, the number, area and condition of wetlands is unknown. Additionally, some management units have few/small wetlands/aggregations and/or wetlands of high conservation value, and/or little to no condition data. There are also some area statistics missing, for example, information on the proportion of wetlands and the proportion of wetland area in the aggregation that is monitored in the East Burdekin Management Unit is unavailable with respect to key considerations guiding management focus in that region.
- The wetland condition assessment can be considered conservative as it penalises for higher pressures and poorer states.

8.3.2 Marine assessment limitations

DIN and fine sediment exposure

- Application of the eReefs 4 km output for some input layers results in large interpolation of data across the GBR. This coarse grid size is particularly limiting along the coastline, where shallow waters and resuspension events can dominate conditions, and where intertidal seagrass meadows are often located. This limitation is likely to result in underestimating the potential exposure of seagrass to TSS and DIN. This is also relevant to coral reefs, although there are comparably smaller areas of reefs in these very nearshore coastal waters. However, use of the finer resolution coral reef and seagrass mapping supports a better estimate of ecosystem exposure which is based on the area of ecosystems within each exposure category.
- Accounting for the overlap between rivers is challenging in this assessment where the results are defined by individual river footprints. While the degree of overlap between rivers was calculated and represented, it is difficult to account for it in a quantitative way. While it might be desirable to run the analysis for individual river footprints, these results may be misleading as they would not account for interactions between river footprints driven by flow, currents and wind condition which are very important in driving plume dynamics and would likely lead to an overestimate of exposure.
- The representation of 'anthropogenic' exposure builds on the same approach adopted in the 2017 assessment. However, the rigour of this approach is still heavily dependent on having a reasonable degree of confidence in the anthropogenic proportion of the catchment load estimates. This approach has lower confidence for some basins due to adjustments made to the catchment load inputs after they were incorporated into the eReefs marine model. These adjustments were most substantial for the pre-development estimates of DIN, and therefore most relevant to the

anthropogenic load estimates, for the basins in the Fitzroy and Burnett Mary regions (associated with the way that grazing was handled in the model). It is very likely that this has led to an overestimate of DIN exposure in these regions. *To address this issue, a similar approach to the review of the water quality targets (Waterhouse et al. 2025) was used and basins with relatively small anthropogenic loads were removed from the assessment. This could result in an underestimate of the exposure result for those basins with low anthropogenic loads. However, a sensitivity check of the analysis indicated that this is not a major concern because the areas of anthropogenic pollutant exposure were very low for these basins, and they would still fall within the Foundational management response category. The baseline load estimates incorporated into the assessment of pollutant sources (Section 3) are relatively stable as they are calibrated against monitoring data.* There are also limitations to the model for estimating urban diffuse loads which uses Event Mean Concentration data in the method.

- The nutrient and sediment assessment was conducted using average conditions, but over a long time period. Using averages does not fully account for the impact of large-scale events (e.g. those seen in 2010–2011) and most likely overestimates exposure in the drier years (e.g. 2014–2015). The approach of integrating the river footprints to represent a frequency of exposure accounts for this periodicity to some degree. *As in the 2017 assessment, it was concluded that most management decisions in the catchment are made on average conditions, and there is limited information to identify different management choices depending on extreme conditions at this stage.*
- It is still difficult to fully represent nutrients in the assessment as there is uncertainty in the current understanding of the relationship between end-of-catchment loads of nutrients (all forms) and measurements of Chl-*a* in the marine environment due to complex nutrient processing, which is affected by many factors. This applies to dissolved and particulate nutrients. Further effort is required to progress this understanding and generate high resolution datasets of nutrient conditions and links to riverine load inputs in the GBR. There is confidence in the relationship between DIN loads and Chl-*a*, used in this assessment, but quantitative correlations between phosphorus and particulate nutrients were too limited to be included here. These will improve as process data become available and the eReefs model is further developed.
- The ability to translate consequence factors into quantified spatial layers, and therefore calculate risk, is still relatively crude and requires considerably more effort to improve confidence in calculating ecological risk from degraded water quality to the GBR. This requires better understanding and quantification of the severity and effect of pressures on GBR coastal and marine ecosystems, which could be progressed to some extent through further interrogation of existing monitoring results (e.g. from the MMP, AIMS Long-term Monitoring Program, Seagrass-Watch and other relevant programs). This additional analysis was outside the scope of this project and was therefore not included. Consideration of cumulative impacts of multiple pressures is a major challenge and has not been considered here at all.
- The assessment does not include a specific measure of uncertainty, which would add value to interpretation of the results at smaller spatial scales.

Pesticide risk

- The marine modelling of pesticide exposure was limited to diuron for two wet seasons and a subsection of the GBR lagoon, whereas the actual pesticide profile in GBR waters includes multiple pesticides with varying toxicity profiles and environmental behaviours.
- Synergistic or cumulative effects of pesticides acting with other pollutants, or their interactions with other stressors such as climate change, have been demonstrated but are not captured here.

Specific limitations for some basins

There are several basins where particular limitations exist in the exposure assessment, and these have also been highlighted in the review of the water quality targets:

- **Herbert, DIN:** Substantial increase in adjusted loads mainly due to updates to the pre-development loads as a result of implementing the ‘reference’ values informed by Lewis et al. (2023). The 4 km x 4

km grid resolution constrains the ability to model discharge from the Herbert River into Hinchinbrook Channel. Further monitoring validation of the marine model in the Herbert River discharge footprint would be beneficial.

- **Haughton, DIN:** The Burdekin River discharge footprint overlaps substantially with the Haughton River discharge footprint, which complicates Chl-*a* distribution for the Haughton in the spatial assessment. Further modelling / validation of the marine model in the Haughton River discharge footprint at times when the Burdekin is not flowing would assist in improving this understanding.
- **Proserpine, O’Connell, Pioneer, Plane, DIN:** There are large uncertainties in the Mackay Whitsunday region of the drivers of Chl-*a* concentrations. Importantly, the method has not specifically assessed end-of-catchment load reduction scenarios for phosphorus, which could be an important influence on Chl-*a* concentrations in the region. The interaction between turbidity, extended periods of resuspension (due to large tides and the local hydrodynamic regime), possible release of nutrients in the water column and complex water circulation with reduced flushing times particularly around the Whitsunday Islands may also influence the regional water quality but is not well understood. Further investigation of the drivers of nutrient enrichment in the region is required.
- **Fitzroy, DIN:** Better understanding of the sources of DIN from the Fitzroy basin would assist to clarify the likely anthropogenic influence of DIN loads in the region, especially potential nutrient sources from irrigated cropping areas.
- **Burnett Mary region, DIN:** There is limited empirical evidence about the impact of land-based nutrient inputs to the coastal and marine ecosystems, and there are no long-term monitoring datasets to validate the marine model. Better understanding of the sources of DIN from the basins in the Burnett Mary region would assist.
- **Normanby and Endeavour, fine sediment:** There is clear evidence of catchment disturbance from gully erosion, road and fire management in these basins and further investigation is required to quantify these inputs. The catchment model is currently being revised, with early indications that the loads for the Normanby and Endeavour basins were underestimated in previous assessments.
- **Limited or no pesticide data for some catchments,** e.g. the Cape York catchments, Mossman, Barron, Boyne, Calliope, Waterpark, Styx, and Baffle catchments had no data or only a couple of years of data. These catchments are usually associated with a low risk of pesticides. Shifts in land use and development need to be captured in monitoring data.

Marine ecosystem condition

- There are spatial limitations for the coral reef monitoring in the Marine Monitoring Program (MMP), with no sites in the Cape York or Burnett Mary regions. The condition data presented for the Cape York region is based on the AIMS Long-Term Monitoring Program which surveys sites in midshelf and offshore waters.
- Monitoring of inshore coral reef condition in the Cape York region is a priority need, especially in the context of increasing disturbances from climate change, and the need to protect the relatively good condition ecosystems in the region from a range of stressors.
- The extensive seagrass meadows in the central part of Hervey Bay (see Figure 4) are outside of the scope of the MMP, and are not currently routinely monitored (the MMP monitors sites in Rodds Bay and Urangan). This is a priority information need for these ecosystems in their own right, but in the context of this assessment, this information is needed for better understanding the influence of land-based runoff on these ecosystems and their connection to the GBR World Heritage Area.

8.3.3 Management options limitations

- **Data availability and quality:** There are variations in the supporting datasets in terms of sampling temporal and spatial frequency, methods, and spatial coverage of the assessment of water quality and cost effectiveness of management options. This impacts the direct alignment or comparison of some data sets between locations and industries.

- **Difficulties in linking land management changes to water quality improvements:** Improvements in management practices may take years to manifest in downstream water quality due to lag effects that have not been considered in this assessment.
- **Cumulative impacts from multiple land uses and processes:** Differentiating the contributions of agriculture, urban development, and natural erosion is challenging, and the cumulative benefits of implementing management actions is not well understood.
- **External factors and climate change:** Extreme weather events (cyclones, floods, droughts) can rapidly alter pollutant losses, making it difficult to assess management effectiveness. Rising temperatures, sea-level changes, and altered rainfall patterns and volumes may modify pollutant pathways and activate new sources of pollutants.
- **Historical influences:** Historical land-use practices may continue to influence water quality despite recent improvements, making it difficult to account for the drivers of exposure and condition in some locations, and therefore challenging to identify appropriate management options.

8.3.4 *Water quality management response assessment limitations*

- **Time lags:** The Management Response assessment does not fully account for the time lags between implementation of actions and measurable improvements in water quality and ecosystem condition. This is especially relevant when considering the different time scales of response for various pollutants and management interventions.
- **Multi-pollutant interactions:** The assessment addresses each pollutant type separately, potentially missing opportunities for integrated management approaches that could address multiple pollutants simultaneously.
- **Adaptive capacity considerations:** The assessment does not explicitly incorporate ecosystem adaptive capacity or resilience, which may influence the urgency and intensity of management responses required, particularly in the context of climate change.
- **Spatiotemporal scale issues:** There is potential mismatch between the scale at which management responses are defined (basin or management unit) and the scale at which management actions are implemented (property, sub-catchment), which may complicate translation of the framework into practical action.

The following aspects of the management response assessment are out of scope of this assessment but are important considerations for future work in informing water quality management strategies for the GBR:

- **Social and economic factors:** While the assessment identifies appropriate levels of management responses based on ecological factors, it does not comprehensively integrate socio-economic considerations that may influence implementation feasibility, acceptance, and cost-effectiveness of different management options.
- **Governance limitations:** The assessment does not address the institutional and governance arrangements required to implement the recommended management responses, particularly for responses requiring cross-jurisdictional coordination.
- **Resource constraints:** While the assessment identifies different levels of management response, it does not fully account for the practical resource constraints (financial, technical, human) that may limit implementation, particularly for areas requiring intensive management responses.
- **Stakeholder engagement:** The assessment does not detail the specific stakeholder engagement processes that would be required to implement different levels of management response, which is critical for successful implementation.
- **Traditional Owner integration:** While recognised as important, the assessment has not fully integrated Traditional Owner perspectives, knowledge, and governance structures into the management response categories.

8.4 Future research and information needs

To address the limitations of this project and improve future assessments, several key areas of research and information development are needed. These include:

- Improved representation of urban land use contributions to diffuse pollutant sources, PVP and possibly other land uses that rely on event mean concentration data.
- Further empirical research on wetland-floodplain-river processes and functioning within the GBR catchments to better understand pollutant exposure, transformations and impacts on freshwater ecosystems.
- Expanded monitoring of freshwater wetland condition across all management units to improve assessment confidence, particularly in areas with limited up-to-date data. Screening level wetland condition assessments in management units where monitoring does not occur, to validate the hazard assessment and provide condition data in those management units.
- Improved models of pesticide transport, transformation, and impact in both freshwater and marine environments, including expansion of the ms-PAF risk metric, need to include a wider range of pesticides. In addition, monitoring studies of pesticides are needed to validate the wetland hazard assessment and confirm condition assessments that use indirect indicators of water quality for freshwater wetlands at the frontline of pollutant inputs. This would contribute towards improved knowledge of exposure, consequence and therefore risk.
- Development of a characterisation and conceptual model of wetland ecological / sediment and geomorphic, deposition and mobilisation processes in sediment exposed management units to validate the wetland hazard assessment and indirect indicators of sediment inputs used in the P2R Wetland Condition Monitoring Program. This would also contribute towards improved knowledge of exposure, consequence and therefore risk.
- More specifically to the assessment itself, a detailed sensitivity analysis of the assumptions made in the assessment (e.g. equal weighting between coral reefs and seagrass in the marine sediment exposure assessment) would be valuable to assess the likely influence of these assumptions on the management response assessment and to identify priority areas for research.
- Implementation of research initiatives to address basin-specific data limitations identified above, e.g. understanding of nutrient sources and the role of particulate and bioavailable nutrients in the Fitzroy region.
- Better understanding of nutrient processing and transformation in marine environments to strengthen the links between catchment loads and marine ecosystem impacts, including sources and fate of phosphorus, and potential groundwater inputs.
- Research on the effectiveness and cost-effectiveness of different management interventions across different contexts to better inform management response prioritisation.
- Development of methodologies to better account for cumulative impacts and synergistic interactions between multiple stressors, including climate change.
- Research on effective governance models and stakeholder engagement approaches for implementing different levels of management response.
- Development of integrated approaches that incorporate socio-economic considerations into the management response framework.
- Enhanced monitoring of impacts associated with episodic very high and very low rainfall periods and waterway discharge events to capture time lags in responses as well as significant ecosystem change and resilience behaviours.
- Improved quantification of urban land use pesticide contributions and risk profiles.

In addition to these research and information needs, the assessment has highlighted the need for improved strategic planning to ensure alignment in the timing of the primary input datasets and processes, for example, the catchment modelling and review of the water quality and land management targets. Improved coordination and collaboration with relevant programs would also be beneficial, for example, closer link to Regional Report Card monitoring and use of datasets, particularly for freshwater and catchment indicators.

Despite these limitations, the current assessment provides a robust and scientifically defensible foundation for water quality management prioritisation in the GBR, based on the best available relevant information. The adaptive nature of the Management Response Decision Support Framework allows for adjustments as new information becomes available and understanding improves. To ensure that the water quality management response assessment remains relevant, it is recommended that it is updated within five years or following a major disturbance event that would be likely to have a significant influence on ecosystem condition.

9. References

- Abbott BN, Wallace J, Nicholas DM, Karim F, Waltham NJ (2020) Bund removal to re-establish tidal flow, remove aquatic weeds and restore coastal wetland services—North Queensland, Australia. *PLoS ONE* 15(1): e0217531.
- Adame MF, Arthington AH, Waltham N, Hasan S, Selles A, Ronan M (2019) Managing threats and restoring wetlands within catchments of the Great Barrier Reef, Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 29(5): 829–839. doi:10.1002/aqc.3096.
- Armour JD, Nelson PN, Daniells JW, Rasiah V, Inman-Bamber NG (2013) Nitrogen leaching from the root zone of sugarcane and bananas in the humid tropics of Australia. *Agriculture, Ecosystems & Environment*, 180: 68–78. <https://doi.org/10.1016/j.agee.2012.05.007>
- Arthington AH, Godfrey PC, Pearson RG, Karim F, Wallace J (2015) Biodiversity values of remnant freshwater floodplain lagoons in agricultural catchments: evidence for fish of the Wet Tropics bioregion, northern Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 25(3): 336–352.
- Ash AJ, McIvor JG, Corfield JP, Winter WH (1995) How land condition alters plant-animal relationships in Australia's tropical rangelands. *Agriculture, Ecosystems & Environment*, 56(2): 77–92. <http://www.sciencedirect.com/science/article/pii/0167880995006451>
- Ash AJ, O'Reagain PJ, McKeon GM, Stafford Smith DM (Eds.) (2000) *Managing climate variability in grazing enterprises: A case study of Dalrymple Shire, northeastern Australia*. Netherlands: Kluwer Academic Press.
- Australian and New Zealand Governments (ANZG) (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. *Australian and New Zealand Governments and Australian state and territory governments*. <http://waterquality.gov.au/anz-guidelines>
- Australian and Queensland governments (2018) Reef 2050 Water Quality Improvement Plan 2017–2022. State of Queensland. <https://www.reefplan.qld.gov.au>
- Australian and Queensland governments (2024a) Riparian Vegetation Extent Monitoring Methods, Reef Water Quality Report Card 2021 and 2022. State of Queensland, Brisbane.
- Australian and Queensland governments (2024b) Australian and Queensland governments, 2024, Catchment monitoring methods, Reef Water Quality Report Card 2021 and 2022, State of Queensland, Brisbane.
- Australian Pesticides and Veterinary Medicines Authority (APVMA) 2020 Appendix B of APVMA risk assessment manual, Australian Pesticides and Veterinary Medicines Authority 2019, Kingston, Australian Capital Territory.
- Bainbridge Z, Lewis S, Bartley R, Fabricius K, Collier C, Waterhouse J, Brodie J (2018) Fine sediment and particulate organic matter: A review and case study on ridge-to-reef transport, transformations, fates, and impacts on marine ecosystems. *Marine Pollution Bulletin*, 135: 1205–1220.
- Bainbridge Z, Lewis S, Stevens T, Petus C, Lazarus E, Gorman J, Smithers S (2021) Measuring sediment grain size across the catchment to reef continuum: Improved methods and environmental insights. *Marine Pollution Bulletin*, 168: 112339.
- Bainbridge Z, Olley J, Wilkinson S, Bartley R, Lewis S, Dougall C, Khan S, Kuhnert P, Burton J (2023) Refining fine sediment source identification through integration of spatial modelling, concentration monitoring and source tracing: A case study in the Great Barrier Reef catchments. *Science of The Total Environment*, 892: 164731.
- Bainbridge ZT, Lewis SE, Smithers SG, Kuhnert PM, Henderson BL, Brodie JE (2014) Fine suspended sediment and water budgets for a large, seasonally dry tropical catchment: Burdekin River catchment, Queensland, Australia. *Water Resources Research*, 50: 9067–9087.
- Bainbridge ZT, Lewis SE, Smithers SG, Wilkinson SN, Douglas GB, Hillier S, Brodie JE (2016) Clay mineral source tracing and characterisation of Burdekin River (NE Australia) and flood plume fine sediment. *Journal of Soils and Sediments*, 16(2): 687–706. <https://doi.org/10.1007/s11368-015-1282-4>

- Bartley R, Bainbridge ZT, Lewis SE, Kroon FJ, Wilkinson SN, Brodie JE, Silburn DM (2014) Relating sediment impacts on coral reefs to watershed sources, processes and management: A review. *Science of The Total Environment*, 468–469: 1138–1153. <https://doi.org/10.1016/j.scitotenv.2013.09.030>
- Bartley R, Hawdon A, Henderson A, Wilkinson S, Goodwin N, Abbott B, Baker B, Matthews M, Boadle D, Jarihani B (2018) *Quantifying the effectiveness of gully remediation on off-site water quality: preliminary results from demonstration sites in the Burdekin catchment (second wet season)*. Report to the National Environmental Science Program: Reef and Rainforest Research Centre Limited, Cairns (75 pp.)
- Bartley R, Keen RJ, Hawdon AA, Hairsine PB, Disher MG, Kinsey-Henderson AE (2008) Bank erosion and channel width change in a tropical catchment. *Earth Surface Processes and Landforms*, 33(14): 2174–2200. <https://doi.org/10.1002/esp.1678>
- Bartley R, Murray B (2024) Question 3.5 What are the most effective management practices (all land uses) for reducing sediment and particulate nutrient loss from the Great Barrier Reef catchments, do these vary spatially or in different climatic conditions? What are the costs and cost-effectiveness of these practices, and does this vary spatially or in different climatic conditions? What are the production outcomes of these practices? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water).
- Bartley R, Poesen J, Wilkinson S, Vanmaercke M (2020) A review of the magnitude and response times for sediment yield reductions following the rehabilitation of gullied landscapes. *Earth Surface Processes and Landforms*, 45: 3250–3279. doi:10.1002/esp.496
- Behr J, Possingham HP, Hoobin S, Dougall C, Klein C (2016) Prioritising catchment management projects to improve marine water quality. *Environmental Science & Policy*, 59: 35–43.
- Beutel TS, Tindall D, Denham R, Trevithick R, Scarth P, Abbott B, Holloway C (2014) Getting ground cover right: thresholds and baselines for a healthier reef. Report to the Reef Rescue Research and Development Program. Reef and Rainforest Research Centre Limited, Cairns (64 pp). ISBN: 978-1-925088-20-5.
- Bezzina A, Neelamraju C, Strauss J, Kaminski H, Roberts C, Glen J, Dias F (2022) CalcThemAll.PRM: Pesticide Risk Metric Calculations. R package. Water Quality Monitoring & Investigations, Department of Environment and Science, Queensland Government. <https://github.com/AlexWaterboyBezzina/CalcThemAll.PRM>
- Brodie JE, Kroon FJ, Schaffelke B, Wolanski EC, Lewis SE, Devlin MJ, Bohnet IC, Bainbridge ZT, Waterhouse J, Davis AM (2012) Terrestrial pollutant runoff to the Great Barrier Reef: An update of issues, priorities and management responses. *Marine Pollution Bulletin*, 65(4–9): 81–100. <https://doi.org/10.1016/j.marpolbul.2011.12.012>
- Brodie JE, Mitchell AW (2005) Nutrients in Australian tropical rivers: changes with agricultural development and implications for receiving environments. *Marine & Freshwater Research*, 56(3): 279–302.
- Brooks A, Daley J, Pietsch T (2024) Question 3.6 What is the effectiveness of gully and streambank restoration works in reducing sediment and particulate nutrient loss from the Great Barrier Reef catchments, does this vary spatially or in different climatic conditions? What are the costs and cost-effectiveness of these works, and does this vary spatially or in different climatic conditions? What are the production outcomes of these practices? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/3-5>
- Burford M, Huang J, Bainbridge Z, Burton J, Bahadori M, McCloskey G, Newham M (2024) Question 4.5 What are the primary biophysical drivers of anthropogenic dissolved nutrient export to the Great Barrier Reef and how have these drivers changed over time? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem

- condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/4-5>
- Burke L, Reynter K, Spalding M, Perry A (2011) Reefs at risk revisited. World Resources Institute, Washington DC, 114 pp. Available at www.wri.org.
- Caballes CF, Sambrook K, Pratchett MS (2024) Question 4.3 What are the key drivers of the population outbreaks of crown-of-thorns starfish (COTS) on the Great Barrier Reef, and what is the evidence for the contribution of nutrients from land runoff to these outbreaks? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/4-3>
- Carter AB, McKenna SA, Rasheed MA, McKenzie LJ, Coles RG (2016) Seagrass mapping synthesis: A resource for coastal management in the Great Barrier Reef World Heritage Area. Report for the Reef and Rainforest Research Centre, Cairns, QLD, Australia.
- Chamberlain D, Phinn S, Possingham H (2020) Remote sensing of mangroves and estuarine communities in central Queensland, Australia. *Remote Sensing* 12(1): 197.
- Chariton A, Hejl N (2024) Question 6.1 What is the spatial and temporal distribution and risk of other pollutants in the Great Barrier Reef ecosystems, and what are the primary sources? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/6-1>
- Chilcott CR, Sandral CJ, Aisthorpe JL, Paton CJ, McCallum BS (2005) Grazing Land Management - Fitzroy Basin Version Workshop Notes. Retrieved from North Sydney.
- Claassen R, Cattaneo A, Johansson R (2008) Cost-effective design of agri-environmental payment programs: U.S. experience in theory and practice. *Ecological Economics*, 65(4): 737–752. <http://dx.doi.org/10.1016/j.ecolecon.2007.07.032>
- Clayton PD, Fielder DP, Howell S, Hill CJ (2006) Aquatic Biodiversity Assessment and Mapping Method (AquaBAMM): a conservation values assessment tool for wetlands with trial application in the Burnett River catchment. Environmental Protection Agency, Brisbane, Queensland.
- Cleary A, Calley L, Charlton-Henderson S, Schultz T, Dean A, Kirk M, Orton J (2022) Reef sugarcane landholder characterisation report. Great Barrier Reef Foundation. Queensland, Australia.
- Coggan A, Hay R, Jarvis D, Eberhard R, Colls B (2022) Increasing uptake of improved land management practice to benefit environment and landholders: insights through a transaction cost lens. *Journal of Environmental Planning and Management*, 67(5): 1053–1076. <https://doi.org/10.1080/09640568.2022.2146310>
- Coggan A, Jarvis D, Emmerling M, Schirru E, Molinari B (2024) Question 7.1 What is the mix of programs and instruments (collectively and individually) used in Great Barrier Reef catchments to drive land management practices for Great Barrier Reef water quality benefits and how effective are they? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/7-1/>
- Coggan A, Thorburn PJ, Fielke SJ, Hay R, Smart JCR (2021) Motivators and barriers to adoption of Improved Land Management Practices. A focus on practice change for water quality improvement in Great Barrier Reef catchments. *Marine Pollution Bulletin*, 170: 112628. <https://doi.org/10.1016/j.marpolbul.2021.112628>
- Coles R, McKenzie L, De'ath G, Roelofs A, Long WL (2009) Spatial distribution of deepwater seagrass in the inter-reef lagoon of the Great Barrier Reef World Heritage Area. *Marine Ecology Progress Series*, 392, 57–68.

- Collier C (2013) Chapter 7: Review of the risks to seagrasses of the Great Barrier Reef caused by declining water quality. In: Assessment of the relative risk of water quality to ecosystems of the Great Barrier Reef: Supporting Studies. A report to the Department of the Environment and Heritage Protection, Queensland Government, Brisbane. TropWATER Report 13/30, Townsville, Australia.
- Collier C, Brown A, Fabricius K, Lewis S, Diaz-Pulido G, Adame F (2024) Question 3.2 What are the measured impacts of increased sediment and particulate nutrient loads on Great Barrier Reef ecosystems, what are the mechanism(s) for those impacts and where is there evidence of this occurring in the Great Barrier Reef? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water).
<https://reefwqconsensus.com.au/question/3-2>
- Collier C, Waycott M (2009) Drivers of change to seagrass distributions and communities on the Great Barrier Reef: Literature review and gaps analysis. Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited.
- Collier CJ, Devlin M, Langlois L, McKenzie LJ, Petus C, Teixeira da Silva E, McMahon K, Adams M, O'Brien K, Statton J, Waycott M (2015) Final report on Thresholds and indicators of declining water quality as tools for tropical seagrass management. A summary of findings from Project 5.3 Vulnerability of seagrass habitats in the GBR to flood plume impacts: light, nutrients, salinity. Reef and Rainforest Research Centre Limited, Cairns.
- Collier CJ, Uthicke S, Waycott M (2011) Thermal tolerance of two seagrass species at contrasting light levels: implications for future distribution in the Great Barrier Reef. *Limnology and Oceanography*, 56: 2200–2210.
- Collier CJ, Waycott M, McKenzie LJ (2012) Light thresholds derived from seagrass loss in the coastal zone of the northern Great Barrier Reef, Australia. *Ecological Indicators*, 23: 211–219.
<https://doi.org/10.1016/j.ecolind.2012.04.005>
- Connolly NM, Pearson RG (2007) The effect of fine sedimentation on tropical stream macroinvertebrate assemblages: a comparison using flow through artificial stream channels and recirculating mesocosms. *Hydrobiologia*, 592: 423–438.
- Cools J, Broekx S, Vandenberghhe V, Sels H, Meynaerts E, Vercaemst P, Huygens M (2011) Coupling a hydrological water quality model and an economic optimization model to set up a cost-effective emission reduction scenario for nitrogen. *Environmental Modelling & Software*, 26(1): 44–51.
<http://www.sciencedirect.com/science/article/pii/S1364815210001234>
- Coppo C, Brodie JE, Mellors J, Butler I, Sobotzick S (2014) Status of Coastal and Marine Assets in the Burnett Mary Region. In *TropWATER Report no. 14/36* (Issue 14). Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University.
- Coutts J, Roberts K (2003). Extension models and best practice in extension. In Invited paper, APEN Extension Conference (pp. 26-28).
- Creighton C, Waterhouse J, Day JC, Brodie J (2021) Criteria for effective regional scale catchment to reef management: A case study of Australia's Great Barrier Reef. *Marine Pollution Bulletin*, 173: 112882.
- Curnock MI, Nembhard D, Smith R, Sambrook K, Hobman EV, Mankad A, Chamberland E, Pert PL (2024) Finding common ground: Understanding and engaging with science mistrust in the Great Barrier Reef region. *PLOS ONE*, 19(8): e0308252.
- Darr SD, Pringle MJ (2017) Improving gully density maps for modelling water quality within Great Barrier Reef Catchments. In: Syme G, Hatton MacDonald D, Fulton B, Piantadosi J (Eds), MODSIM2017, 22nd International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, Hobart, pp. 1920–1926.

- Davis A, Pearson R (2024) Question 1.4 How are the Great Barrier Reef's key ecosystem processes connected from the catchment to the reef and what are the primary factors that influence these connections? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/1-4>
- Davis A, Silburn M, Weber T, Star M (2024) Question 5.3 What are the most effective management practices for reducing pesticide risk from the Great Barrier Reef catchments, and do these vary spatially or in different climatic conditions? What are the costs of the practices, and cost-effectiveness of these practices, and does this vary spatially or in different climatic conditions? What are the production outcomes of these practices? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/5-3>
- Davis AM, Lewis SE, Bainbridge ZT, Glendenning L, Turner RDR, Brodie JE (2012) Dynamics of herbicide transport and partitioning under event flow conditions in the lower Burdekin region, Australia. *Marine Pollution Bulletin*, 65(4–9): 182–193. <https://doi.org/10.1016/j.marpolbul.2011.08.025>
- Davis AM, Lewis SE, Brodie JE, Benson A (2014) The potential benefits of herbicide regulation: A cautionary note for the Great Barrier Reef catchment area. *Science of the Total Environment*, 490: 81–92.
- Davis AM, Pearson R, Brodie JE, Butler B (2017) Review and conceptual models of agricultural impacts and water quality in waterways of the Great Barrier Reef catchment area. *Marine and Freshwater Research*, 68: 1–19.
- Department of Environment and Science (2022) *Reef Protection Regulations 2022*, Farming in Reef Catchments. Prescribed Methodology for sugarcane cultivation. Version 2. Office of the Great Barrier Reef, Environmental Policy and Programs, Department of Environment and Science, State of Queensland.
- Department of Environment and Science (2023a) Queensland Wetland Mapping Method - A Method to Provide Baseline Mapping of Wetland Extent and Extent Change in Queensland, Version 2.0. Queensland Government, Brisbane, Queensland.
- Department of Environment and Science (2023b) Land use mapping. Queensland Government website, accessed 27 February 2025. Available at: <https://www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/qlump>.
- Department of Environment and Science (2023c) Queensland Wetland Definition Guideline Version 2.0. Queensland Government, Brisbane, Queensland.
- Department of Environment and Science (2023d) Queensland Wetland Delineation and Mapping Guideline Version 2.0. Queensland Government, Brisbane, Queensland.
- Department of Environment and Science (2023e) Wetland Tracker Great Barrier Reef Catchment Wetland Condition Monitoring Program Construct Validity of Wetland Tracker Indicators – A Literature Review. Prepared by the Wetland Condition Science team, Ecosystem Survey & Mapping, Queensland Herbarium and Biodiversity Science, Department of Environment and Science.
- Department of Environment, Science and Innovation (2013) Pressures. WetlandInfo website, accessed 20 February 2025. Available at: <https://wetlandinfo.des.qld.gov.au/wetlands/management/pressures/>
- Department of Environment, Science and Innovation, (2022) Treatment system options, WetlandInfo website, accessed 20 June 2024. Queensland Government, Brisbane, Queensland. Available at: <https://wetlandinfo.des.qld.gov.au/wetlands/management/treatment-systems/for-agriculture/treatment-sys-nav-page/>
- Department of Environment, Science and Innovation (2022) Whole-of-System, Values-Based Framework, WetlandInfo website, accessed 14 May 2025. Queensland Government, Brisbane, Queensland. Available at: <https://wetlandinfo.des.qld.gov.au/wetlands/management/whole-system-values-framework/>

- Department of Environment, Tourism, Science and Innovation (2024a) Statewide Landcover and Trees Study – Methodology Overview v1.2. Queensland Government, Brisbane, Queensland.
- Department of Environment, Tourism, Science and Innovation (2024b) Biodiversity status of pre-clearing regional ecosystems v13.1. Queensland Government, Brisbane, Queensland.
- Department of the Environment, Tourism, Science and Innovation (DETSI) (2024c) Modelled estimates of dissolved inorganic nitrogen, fine sediment and particulate nutrients delivered from the Great Barrier Reef catchments. Catchment model V2.0, November 2024. Queensland Government, Brisbane, Queensland.
- Department of Environment, Tourism, Science and Innovation (DETSI) (2025) Identifying Options for Targeted Investment in Urban Water Management within the Great Barrier Reef Catchment. State of Queensland.
- Department of the Environment, Tourism, Science and Innovation (DETSI) (2025) Modelled estimates of dissolved inorganic nitrogen, fine sediment and particulate nutrients delivered from the Great Barrier Reef catchments. 2023 Baseline loads, Catchment model V3.0, final supplied March 2026. Queensland Government.
- Department of Natural Resources and Mines (2001) *Policy for Development and Use of Ponded Pastures*. Department of Natural Resources and Mines, Brisbane.
- Department of Primary Industries (2024) Review of Land Management Targets Reef 2050 Water Quality Improvement Plan. DRAFT 2.0. Summary Results Report. Management Practice Adoption of Rural Economic Development—Central, the Queensland Department of Primary Industries.
- Department of Science, Information Technology, Innovation and the Arts (2015) A landscape hazard assessment for wetlands in the Great Barrier Reef catchment. Queensland Government, Brisbane, Queensland.
- Devlin M, Lewis S, Davis A, Smith R, Negri A, Thompson M, Poggio M (2015) Advancing our understanding of the source, management, transport and impacts of pesticides on the Great Barrier Reef 2011–2015. A report for the Queensland Department of Environment and Heritage Protection. Tropical Water & Aquatic Ecosystem Research, James Cook University, Townsville, Australia.
- Devlin MJ, Brodie J (2005) Terrestrial discharge into the Great Barrier Reef Lagoon: nutrient behaviour in coastal waters. *Marine Pollution Bulletin*, 51(1-4): 9–22.
- Diaz-Pulido G, Reyes-Nivia C, Adame MF, Arthington AH, Collier C, Lovelock C (2024) Question 4.2 What are the measured impacts of nutrients on Great Barrier Reef ecosystems, what are the mechanisms for those impacts and where is there evidence of this occurring in the Great Barrier Reef? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/4-2/>
- Doole GJ (2012) Cost-effective policies for improving water quality by reducing nitrate emissions from diverse dairy farms: An abatement–cost perspective. *Agricultural Water Management*, 104: 10–20. <http://dx.doi.org/10.1016/j.agwat.2011.11.007>
- Dowie J (2024) Final Report Project Bluewater 2 (WQ-LB-005) Lower Burdekin. Report for the Reef Trust Partnership Water Quality Programs, DCCEE 30 May 2024.
- Duke JM, Dundas SJ, Messer KD (2013) Cost-effective conservation planning: Lessons from economics. *Journal of Environmental Management*, 125: 126–133. <https://doi.org/10.1016/j.jenvman.2013.03.048>
- Ebner BC, Fulton CJ, Donaldson J, Schaffer J (2016) Distinct habitat selection by freshwater morays in tropical rainforest streams. *Ecology of Freshwater Fish*, 25: 329–335. doi:10.1111/eff.12213
- Egan C (2024) *Fors - Rapid Hydrologic Flow Calibration Suite*. *Hydrology and Water Resources Symposium, HWRS 2024. 18-21 November, 2024. Engineers Australia, Melbourne, Australia*.

- Espinoza T, Collett S, Burns C (2024) Question 7.3 What are the critical success factors for greater Indigenous involvement in water quality decision making in the Great Barrier Reef region? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/7-3/>
- Fabricius K, Brown A, Songcuan A, Collier C, Uthicke S, Robson B (2024) Question 2.2 What are the current and predicted impacts of climate change on Great Barrier Reef ecosystems (including spatial and temporal distribution of impacts)? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/2-2/>
- Fabricius KE, Crossman K, Jonker M, Mongin M, Thompson A (2023) Macroalgal cover on coral reefs: Spatial and environmental predictors, and decadal trends in the Great Barrier Reef. *PLoS ONE* 18(1): e0279699.
- Fabricius KE, De'ath G, Humphrey CA, Zagorskis I, Schaffelke B (2013) Intra-annual variation in turbidity in response to terrestrial runoff on near-shore coral reefs of the Great Barrier Reef. *Estuarine, Coastal and Shelf Science*, 116: 57–65. <https://doi.org/10.1016/j.ecss.2012.03.010>
- Fabricius KE, Logan M, Weeks SJ, Brodie JE (2014) The effects of river run-off on water clarity across the central Great Barrier Reef. *Marine Pollution Bulletin*, 84(1–2): 191–200. <https://doi.org/10.1016/j.marpolbul.2014.05.012>
- Fabricius KE, Logan M, Weeks SJ, Lewis SE, Brodie JE (2016) Changes in water clarity in response to river discharges on the Great Barrier Reef continental shelf: 2002–2013. *Estuarine, Coastal and Shelf Science*, 173: A1–A15. <https://doi.org/10.1016/j.ecss.2016.03.001>
- Furnas M (2003) Catchments and Corals: Terrestrial Runoff to the Great Barrier Reef. Australian Institute of Marine Science, Townsville. 334 pp.
- Furnas M, Alongi D, McKinnon D, Trott L, Skuza M (2011) Regional-scale nitrogen and phosphorus budgets for the northern (14 S) and central (17 S) Great Barrier Reef shelf ecosystem. *Continental Shelf Research*, 31(19–20): 1967–1990.
- Furnas M, Mitchell A, Skuza M, Brodie J (2005) The other 90%: phytoplankton responses to enhanced nutrient availability in the Great Barrier Reef lagoon. *Marine Pollution Bulletin*, 51: 253–265.
- Furnas M, O'Brien D, Warne M (2013) Chapter 2: The Redfield Ratio and potential nutrient limitation of phytoplankton in the Great Barrier Reef. In: Assessment of the relative risk of water quality to ecosystems of the Great Barrier Reef: Supporting Studies. A report to the Department of the Environment and Heritage Protection, Queensland Government, Brisbane. TropWATER Report 13/30, Townsville, Australia.
- Gallen C, Thai P, Paxman C, Prasad P, Elisei G, Reeks T, Eaglesham G, Yeh R, Tracey D, Grant S, Mueller J (2019) *Marine Monitoring Program: Annual Report for inshore pesticide monitoring 2017–18. Report for the Great Barrier Reef Marine Park Authority*. Great Barrier Reef Marine Park Authority, Townsville, 118 pp.
- Garzon-Garcia A, Burton JM, Lewis SE, Bainbridge ZT, De Hayr RW, Moody PW, Brodie JE (2021) The bioavailability of nitrogen associated with sediment in riverine plumes of the Great Barrier Reef. *Marine Pollution Bulletin*, 173: 112910. <https://doi.org/10.1016/j.marpolbul.2021.112910>
- Gladstone Healthy Harbour Partnership (2023) Technical Report, Gladstone Harbour Report Card 2023 GHHP Technical Report No. 10. Gladstone Healthy Harbour Partnership, Gladstone. https://www.ghhp.org.au/files/ugd/5c25a1_8962ed685dab41429be153c2f0eb2378.pdf
- González-Pradas E, Villafranca-Sánchez M, Pérez-Cano V, Socias-Viciano M, Valverde-García A (1992) Soil adsorption of diuron: influence of NH₄Cl and organic matter additions. *Science of the Total Environment*, 123: 551–560.

- Grant S, Thompson K, Paxman C, Elisei G, Gallen C, Tracey D, Kaserzon S, Jiang H, Samanipour S, Mueller J (2018) Marine Monitoring Program: Annual report for inshore pesticide monitoring 2016-2017. Report for the Great Barrier Reef Marine Park Authority. Great Barrier Reef Marine Park Authority, Townsville, 128 pp.
- Great Barrier Reef Marine Park Authority (GBRMPA) (2010) Water quality guidelines for the Great Barrier Reef Marine Park. Great Barrier Reef Marine Park Authority, Townsville, Queensland.
- Great Barrier Reef Marine Park Authority (GBRMPA) (2024) Great Barrier Reef Outlook Report 2024. Great Barrier Reef Marine Park Authority, Townsville, Queensland.
- Grech A, Sheppard J, Marsh H (2011) Informing species conservation at multiple scales using data collected for marine mammal stock assessments. *PloS ONE*, 6(3): e17993.
- Greiner R, Patterson L, Miller O (2009) Motivations, risk perceptions and adoption of conservation practices by farmers. *Agricultural Systems*, 99(2–3): 86–104. <https://doi.org/10.1016/j.agsy.2008.10.003>
- Gribben PE, Jongen R, Ferguson A, Marzinelli EM, Verges A, Kendrick GA (2022) Inclusion of sediment processes in restoration strategies for Australian seagrass ecosystems. Report to the National Environmental Science Program Marine and Coastal Hub. University of New South Wales. <https://www.nespmarinecoastal.edu.au/wp-content/uploads/2023/08/Project-1.8-Final-report.pdf>
- Gruber R, Waterhouse J, Petus C, Howley C, Lewis S, Moran D, James C, Logan M, Bove U, Brady B, Choukroun S, Connellan K, Davidson J, Mellors J, O’Callaghan M, O’Dea C, Shellberg J, Tracey D, Zagorski I (2024) Great Barrier Reef Marine Monitoring Program Inshore Water Quality Monitoring: Annual Report 2022–23. Great Barrier Reef Marine Park Authority, Townsville, Queensland. 298 pp.
- Guerschman JP, Scarth PF, McVicar TR, Renzullo LJ, Malthus TJ, Stewart JB, Trevithick R (2015) Assessing the effects of site heterogeneity and soil properties when unmixing photosynthetic vegetation, non-photosynthetic vegetation and bare soil fractions from Landsat and MODIS data. *Remote Sensing of Environment*, 161: 12–26.
- Hall TJ, McIvor JG, Reid DJ, Jones P, Macleod ND, McDonald CK, Smith DR (2014) A comparison of stocking methods for beef production in northern Australia: Pasture and soil surface condition responses. *Rangeland Journal*, 36(2): 161–174.
- Hart BT, Burgman M, Grace M, Pollino C, Thomas C, Webb JA, Allison GA, Chapman M, Duivenvoorden L, Feehan P, Lund L, Carey JM, McCrea A (2005) Ecological Risk Management Framework for the Irrigation Industry. Land and Water Australia, Canberra (Technical Report).
- Hassett (2022) Land Condition Assessment Tool. Data analysis—March 2020 to March 2022. Queensland Government, Brisbane, Queensland.
- Hay R, Eagle L, Saleem MA (2019) Social marketing’s role in improving water quality on the Great Barrier Reef. *Asia Pacific Journal of Marketing and Logistics*, 31(5): 1308–1343. <https://doi.org/10.1108/APJML-08-2018-0318>
- Herd N, Butcher M, Bowmaker K, Wilson L (2022) Behavioural insights for practice change in sugarcane: A framework to inform practice change strategies in the Mackay Whitsunday and Lower Burdekin sugarcane regions. Great Barrier Reef Foundation Reef Trust Partnership. Queensland.
- Hillyer KE, Moss A (2025) Interim water quality guidelines and related biological health indicators for corals of Hervey Bay, Great Sandy Strait, and Burnett-Baffle coast. Brisbane: Department of the Environment, Tourism, Science and Innovation, Queensland Government, Brisbane, Queensland.
- Hook SE, Smith RA, Waltham N, Warne M St J (2024) Pesticides in the Great Barrier Reef catchment area: Plausible risks to fish populations. *Integrated Environmental Assessment and Management*, 20(5): 1256–1279.
- Howley C, Shellburg J (unpublished) Uncertainty in Sediment Budgets and Loads for Cape York Peninsula Catchments: Observations of On-ground Reality vs. Model Outputs. Cape York Water Partnership

- observations document prepared for C2O Consulting for consideration regarding Targets and Spatial Management Prioritisation for the GBR.
- Hunt LP (2008) Safe pasture utilisation rates as a grazing management tool in extensively grazed tropical savannas of northern Australia. *The Rangeland Journal*, 30(3): 305–315.
- Hunt LP, Mclvor JG, Grice AC, Bray SG (2014) Principles and guidelines for managing cattle grazing in the grazing lands of northern Australia: stocking rates, pasture resting, prescribed fire, paddock size and water points – a review. *The Rangeland Journal*, 36(2): 105–119. <https://doi.org/10.1071/RJ13070>
- Jakeman T, Snow V, Verburg K, Western A, Whitehead P, Sondoss E (2024) *Paddock and Catchment Modelling Program Review. Review Team Report 31/05/24.*
- James J (2021) Principles for establishing greater trust between scientists and farmers: A synthesis of NESP Tropical Water Quality Hub research. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns (63 pp). <https://nesptropical.edu.au/wp-content/uploads/2022/08/v20220317-Project-6.6-Synthesis-Report.pdf>
- Johns C, Tilden JD, Sutcliffe T, Vandergragt ML (2022) Wetland Tracker: Great Barrier Reef catchment wetland condition monitoring program, Field Methods Guide and Workbook. Department of Environment and Science, Brisbane, Queensland.
- Kanakis K, Bickle M, Erbacher J (2024) Understanding the perceptions of producers: A tool for the extension toolbelt. *Rural Extension & Innovation Systems Journal*, 20(1): 55-59.
- Kealley MJ, Quirk MF (2016) Smartcane BMP - understanding drivers and building momentum for best management practice uptake in the Queensland sugarcane industry. *Proceedings of the International Society of Sugar Cane Technologists*, 29: 445–453.
- King N (2021) Banana best management practices Environmental Guidelines for the Australian Banana Industry – V3. Australian Banana Growers’ Council, in conjunction with Queensland’s Department of Agriculture and Fisheries (DAF) and Horticulture Innovation Australia Ltd (HIA). https://abgc.org.au/wp-content/uploads/2021/11/BMP-Review-V3_WEB-VERSION.pdf
- King OC, van de Merwe JP, Brown CJ, Warne MSJ, Smith RA (2022) Individual and combined effects of diuron and light reduction on marine microalgae. *Ecotoxicology and Environmental Safety*, 241: 113729.
- Koci J, Sidle RC, Kinsey-Henderson AE, Bartley R, Wilkinson SN, Hawdon AA, Hogarth L (2020) Effect of reduced grazing pressure on sediment and nutrient yields in savanna rangeland streams draining to the Great Barrier Reef. *Journal of Hydrology*, 582: 124520.
- Larcombe P, Ridd PV, Prytz A, Wilson B (1995) Factors controlling suspended sediment on inner-shelf coral reefs, Townsville, Australia. *Coral Reefs*, 14: 163–171.
- Lewis KA, Tzilivakis J, Warner DJ, Green A (2024b) The Pesticide Properties Database (PPDB). Agriculture & Environment Research Unit (AERU), University of Hertfordshire. <https://sitem.herts.ac.uk/aeru/ppdb/>
- Lewis S, Bainbridge Z, Smithers S (2024a) Question 3.1 What are the spatial and temporal distributions of terrigenous sediments and associated indicators within the Great Barrier Reef? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/3-1/>
- Lewis S, Bartley R, Bainbridge Z, Wilkinson S, Burton J, Bui E (2015) Burdekin sediment story. James Cook University, Townsville, Australia.
- Lewis SE, James C, Bainbridge Z (2023) Water quality signatures of pristine and near-pristine landscapes in the Great Barrier Reef Catchment Area (Vol. 23). TropWATER, James Cook University.
- Lise W, van der Veeren RJHM (2002) Cost-effective nutrient emission reductions in the Rhine River Basin. *Integrated Assessment*, 3(4): 321–342. doi:10.1076/iaij.3.4.321.13582

- Lockie S, Lawrence G, Dale AP, Taylor BM (2002) "Capacity for Change": Testing a model for the inclusion of social indicators in Australia's National Land and Water Resources Audit. *Journal of Environmental Planning and Management*, 45(6): 813–826. <https://doi.org/10.1080/0964056022000024352>
- Lough JM, Lewis SE, Cantin NE (2015) Freshwater impacts in the central Great Barrier Reef: 1648–2011. *Coral Reefs*, 34: 739–751.
- MacKinnon M, Herbert B (1996) Temperature, dissolved oxygen and stratification in a tropical reservoir, Lake Tinaroo, North Queensland, Australia. *Marine and Freshwater Research*, 47(7): 937–949. doi:10.1071/MF9960937
- MacLeod ND, Mclvor JG (2006) Reconciling economic and ecological conflicts for sustained management of grazing lands. *Ecological Economics*, 56(3): 386–401. <http://www.sciencedirect.com/science/article/pii/S0921800905004295>
- MacLeod ND, Mclvor JG (2008) Quantifying production-environment tradeoffs for grazing land management - A case example from the Australian rangelands. *Ecological Economics*, 65(3): 488–497. <http://www.sciencedirect.com/science/article/pii/S0921800907004065>
- Mahaney W, Wardrop D, Brooks R (2004) Impacts of sedimentation and nitrogen enrichment on wetland plant community development. *Plant Ecology*, 175: 227–243.
- McCloskey G, Baheerathan R, Dougall C, Ellis R, Bennett F, Waters D, Darr S, Fentie B, Hateley L, Askildsen M (2021a) Modelled estimates of dissolved inorganic nitrogen exported to the Great Barrier Reef lagoon. *Marine Pollution Bulletin* 171: 112655.
- McCloskey GL, Baheerathan R, Dougall C, Ellis R, Bennett FR, Waters D, Askildsen M (2021b) Modelled estimates of fine sediment and particulate nutrients delivered from the Great Barrier Reef catchments. *Marine Pollution Bulletin*, 165, 112163.
- Mclvor J (2012) Sustainable management of the Burdekin grazing lands – A technical guide of options for stocking rate management, pasture spelling, infrastructure development and prescribed burning to optimise animal production, profitability, land condition and water quality outcomes. State of Queensland.
- Mclvor JG, Williams J, Gardener CJ (1995) Pasture management influences runoff and soil movement in the semi-arid tropics. *Australian Journal of Experimental Agriculture*, 35(1): 55–65. <https://doi.org/10.1071/EA9950055>
- McKenzie L, Collier CJ, Waycott M (2012a) Reef Rescue Marine Monitoring Program: Inshore seagrass, annual report for the sampling period 1st September 2010–31st May 2011, 230 pp. Fisheries Queensland, Cairns.
- McKenzie L, Collier C, Waycott M, Unsworth R, Yoshida R, Smith N (2012b) Monitoring inshore seagrasses of the GBR and responses to water quality. Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 9–13 July 2012. Mini-Symposium 15b – Seagrasses and seagrass ecosystems. Available at: www.icrs2012.com/proceedings/manuscripts/ICRS2012_15B_4.pdf.
- McKenzie L, Pineda M-C, Grech A, Thompson AA (2024a) Question 1.2/1.3/2.1 What is the extent and condition of Great Barrier Reef ecosystems, and what are the primary threats to their health? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). https://reefwqconsensus.com.au/question/1-2_1-3_2-1/
- McKenzie LJ, Collier CJ, Langlois LA, Brien H, Yoshida RL (2024b) Marine Monitoring Program: Annual Report for Inshore Seagrass Monitoring 2022–23. Report for the Great Barrier Reef Marine Park Authority, Great Barrier Reef Marine Park Authority, Townsville. 178 pp.

- McKenzie LJ, Collier CJ, Langlois LA, Yoshida RL, Uusitalo J, Waycott M (2022) Marine Monitoring Program: Annual Report inshore seagrass monitoring 2020-21. Great Barrier Reef Marine Park Authority. <https://elibrary.gbrmpa.gov.au/jspui/handle/11017/3930>
- McKenzie-Mohr D (2008) Fostering Sustainable Behaviour: Beyond Brochures. *International Journal of Sustainability Communication*, 3: 108–118.
- Mellors JE (2003) Sediment and nutrient dynamics in coastal intertidal seagrass of north eastern tropical Australia. PhD Thesis. James Cook University, Townsville.
- Mercurio P, Eaglesham GK, Parks S, Kenway M, Beltran V, Flores F, Müller JF, Negri AP (2018) Contribution of transformation products towards the total herbicide toxicity to tropical marine organisms. *Scientific Reports*, 8(1): 4808. <https://doi.org/10.1038/s41598-018-23153-4>
- Mercurio P, Müller JF, Eaglesham GK, Flores F, Negri AP (2015) Herbicide persistence in seawater simulation experiments. *PLOS ONE*, 10(8): e0136391. <https://doi.org/10.1371/journal.pone.0136391>
- Mercurio P, Müller JF, Eaglesham GK, O'Brien JW, Flores F, Negri AP (2016) Degradation of herbicides in the tropical marine environment: Influence of light and sediment. *PLOS ONE* 11(11), e0165890. <https://doi.org/10.1371/journal.pone.0165890>
- Michie S, van Stralen MM, West R (2011) The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implementation Science*, 6: 42. doi: 10.1186/1748-5908-6-42.
- Mitchell C, Brodie JE, White I (2005) Sediments, nutrients and pesticide residues in event flow conditions in streams of the Mackay Whitsunday Region, Australia. *Marine Pollution Bulletin*, 51(1–4): 23–36. <https://doi.org/10.1016/j.marpolbul.2004.10.036>
- Moore S, Jenner A, McIntosh T, Markey-Towler B, Pickering JA (2021) Utilising behavioural science to create practice change in agriculture: A case study with the Queensland sugarcane industry. *42nd Australian Society of Sugar Cane Technologists Conference 2021, ASSCT 2021*, 42: 325–331.
- Moran D, Robson BJ, Gruber RK, Waterhouse J, Logan M, Petus C, Howley C, Lewis SE, Tracey D, James C, Mellors J, Bove U, Davidson J, Glasson K, Jaworski S, Lefèvre CD, Macadam A, Shanahan M, Vasile R, Zagorskis I, Shellberg JG (2022) Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2020-2021. Report for the Great Barrier Reef Marine Park Authority. *Great Barrier Reef Marine Park Authority*. <https://hdl.handle.net/11017/3931>
- Murphy T, Dougall C, Burger P, Carroll C (2013) Runoff water quality from dryland cropping on Vertisols in Central Queensland, Australia. *Agriculture, Ecosystems & Environment*, 180: 21–28.
- Murray-Prior R, Schultz T, Long P (2024) Question 7.2 What are the behavioural (attitudinal), economic, social and cultural factors that hinder or enable the uptake of management practices that aim to improve water quality outcomes for the Great Barrier Reef? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/7-2/>
- Navarro J, Hadjikakou M, Ridoutt B, Parry H, Bryan BA (2021) Pesticide Toxicity Hazard of Agriculture: Regional and Commodity Hotspots in Australia. *Environmental Science & Technology*, 55: 1290–1300.
- Negri AP, Taucare G, Neale P, Neelamraju C, Kaminski H, Mann RM, Warne MSJ (2024) Question 5.1 What is the spatial and temporal distribution of pesticides across Great Barrier Reef ecosystems? What are the (potential or observed) ecological impacts in these ecosystems? What evidence is there for pesticide risk? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/5-1/>
- Neil DT, Orpin AR, Ridd PV, Yu B (2002) Sediment yield and impacts from river catchments to the Great Barrier Reef lagoon. *Marine and Freshwater Research*, 53: 733–752.

- Neldner VJ, Wilson BA, Dillewaard HA, Ryan TS, Butler DW, McDonald WJF, Richter D, Addicott EP, Appelman CN (2023) Methodology for survey and mapping of regional ecosystems and vegetation communities in Queensland. Version 7.0. Updated December (2023). Queensland Herbarium, Department of Environment, Science and Innovation, Brisbane, Queensland.
- O'Reagain P, Bushell J, Holloway C, Reid A (2009) Managing for rainfall variability: effect of grazing strategy on cattle production in a dry tropical savanna. *Animal Production Science*, 49(2): 85–99.
- O'Reagain P, Bushell JJ, Holmes B (2011) Managing for rainfall variability: Long-term profitability of different grazing strategies in a northern Australian tropical savanna. *Animal Production Science*, 51(3): 210–224. <https://doi.org/10.1071/AN10106>
- Orr DM, O'Reagain PJ (2011) Managing for rainfall variability: impacts of grazing strategies on perennial grass dynamics in a dry tropical savanna. *The Rangeland Journal*, 33(2): 209–220.
- Pandolfi JM, Bradbury RH, Sala E, Hughes TP, Bjorndal KA, Cooke RG, McArdle D, McClenachan L, Newman MJ, Paredes G, Warner RR, Jackson JB (2003) Global trajectories of the long-term decline of coral reef ecosystems. *Science*, 301(5635), 955–958.
- Pearson RG, Arthington AH, Godfrey PC (2010) Ecosystem health of wetlands of the Great Barrier Reef Catchment: Tully-Murray floodplain case study, Reef and Rainforest Research Centre for the Australian Government's Marine and Tropical Sciences Research Facility, Cairns, Queensland.
- Pearson RG, Connolly NM, Boyero L (2015) Ecology of streams in a biogeographic isolate—the Queensland Wet Tropics, Australia. *Freshwater Science*, 34(2): 797–819.
- Pearson RG, Godfrey PC, Arthington AH, Wallace J, Karim F, Ellison M (2013) Biophysical status of remnant freshwater floodplain lagoons in the Great Barrier Reef catchment: A challenge for assessment and monitoring. *Marine and Freshwater Research*, 64(3): 208–222.
- Peña-Arancibia JL, van Dijk AI, Guerschman JP, Mulligan M, Bruijnzeel LAS, McVicar TR (2012) Detecting changes in streamflow after partial woodland clearing in two large catchments in the seasonal tropics. *Journal of Hydrology*, 416: 60–71. <https://doi.org/10.1016/j.jhydrol.2011.11.036>
- Pettit N, Jardine T, Hamilton S, Sinnamon V, Valdez D, Davies P, Douglas M, Bunn S (2012) Seasonal changes in water quality and macrophytes and the impact of cattle on tropical floodplain waterholes. *Freshwater and Marine Research*, 53: 788–800.
- Petus C, Collier C, Devlin M, Rasheed M, McKenna S (2014) Using MODIS data for understanding changes in seagrass meadow health: A case study in the Great Barrier Reef (Australia). *Marine Environmental Research*, 98: 68–85.
- Pickering JA, Hong J, Hong D, Kealley MJ (2017) Applying behavioural science to the Queensland sugar cane industry and its relationship to the Great Barrier Reef. *Rural Extension and Innovation Systems Journal*, 13(2): 1–10. <https://www.apen.org.au/static/uploads/files/reis-2017-1302-r1-wfaudpxsqodb.pdf>
- Pickering JA, McIntosh T, Moore S, Priwitzer S, Haanterä K, Preston G, Hong J, Win Law I, Simmons E, Ruzsicska N, Kealley MJ (2019) Project Cane Changer: Using behavioural science to create practice change. *41st Annual Conference - Australian Society of Sugar Cane Technologists 2019*, 41: 101–107. https://www.assct.com.au/component/assct/search-result?search_cat=title&filter_search=PROJECT%20CANE%20CHANGE&publisher=any&Itemid=0
- Prosser IP, Wilkinson SN (2024) Question 4.4 How much anthropogenic dissolved nutrient (nitrogen and phosphorus species) is exported from Great Barrier Reef catchments? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/4-4/>
- Puignou Lopez O, Lewis SE, James CS, Davis AM, Mackay SJ (2025) Hydrology of the Great Barrier Reef catchment area along a latitudinal gradient: implications for estimating discharge. *Journal of Hydrology: regional studies*, 61: 102603.

- Ramsay I, Sudarjanto G, Claus S, Clech-Goods C, Munns T (2020) Great Barrier Reef Point Source Metadata Collection Project. Brisbane: Department of Environment and Science, Queensland Government, Brisbane, Queensland.
- Ramsay I, Sudarjanto G, Pambrun V, Barry E (2024) Leading Practice Review of Sewage Treatment Plant Environmental Management in Queensland. Brisbane: Department of Environment, Science and Innovation, Queensland Government, Brisbane, Queensland.
- Rasheed MA, Bryant CV, Reason CL, York P, Cleguer C, Shrubshall H, Hoffman L (2023) *Towards water quality and monitoring guidelines for the health of seagrass and associated mega-fauna in the Burnett Mary Region. JCU publication 26/63, Centre for Tropical Water & Aquatic Ecosystem Research.*
- Rasiah V, Armour JD, Moody PW, Pattison AB, Lindsay S, Florentine S (2009) Characterising and improving the deteriorating trends in soil physical quality under banana. *Soil Research*, 47(6): 574–584.
- Reid MA, Sayer CD, Kershaw AP, Heijnis H (2007) Palaeolimnological evidence for submerged plant loss in a floodplain lake associated with accelerated catchment soil erosion (Murray River, Australia). *Journal of Paleolimnology*, 38(2): 191–208. doi: 10.1007/s10933-006-9067-9.
- Robson B, Brown A, Uthicke S (2024) Question 4.1 What is the spatial and temporal distribution of nutrients and associated indicators within the Great Barrier Reef? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/4-1/>
- Roebeling PC, Webster AJ, Biggs J, Thorburn P (2007) Financial-economic analysis of current best management practices for sugarcane, horticulture, grazing and forestry industries in the Tully-Murray catchment. Report to the Marine and Tropical Sciences Research Facility (MTSRF), Reef and Rainforest Research Centre (RRRC), Cairns, Australia.
- Rolfe J, Star M, Curcio A (2020) Can extension programs improve grazing management in rangelands: a case study in Australia's Great Barrier Reef catchments. *The Rangeland Journal*, 42(6): 447-459.
- Roth CH (2004) A framework relating soil surface condition to infiltration and sediment and nutrient mobilization in grazed rangelands of northeastern Queensland, Australia. *Earth Surface Processes and Landforms*, 29(9): 1093–1104. <https://doi.org/10.1002/esp.1104>
- Rust S, Star M (2018) The cost effectiveness of remediating erosion gullies: a case study in the Fitzroy. *Australasian Journal of Environmental Management*, 25(2): 233–247.
- Ryan PA (1991) Environmental effects of sediment on New Zealand streams: a review. *New Zealand Journal of Marine and Freshwater Research*, 25(2): 207–221.
- Scarth P, Röder A, Schmidt M, Denham R (2010) Tracking grazing pressure and climate interaction-the role of Landsat fractional cover in time series analysis. In Proceedings of the 15th Australasian remote sensing and photogrammetry conference, Alice Springs, Australia (Vol. 13). Published by the Remote Sensing and Photogrammetry Commission of the Spatial Sciences Institute Canberra.
- Schaffer JR, Hamann M, Rowe R, Burrows DW (2015) Muddy waters: the influence of high suspended-sediment concentration on the diving behaviour of a bimodally respiring freshwater turtle from north-eastern Australia. *Marine and Freshwater Research*, 67(4): 505–512.
- Schindler DW (1977) The evolution of phosphorus limitation in lakes. *Science*, 195: 260–262.
- SETAC (1997) SETAC Technical Issue Paper (TIP): Environmental risk assessment. Pensacola, SETAC, 4 pp.
- Shaw M, Ellis RJ, Silburn DM, Hateley LR, Waters DK (2014) Combined monitoring and modeling at paddock and catchment scales to predict the effects of herbicide management on water quality entering the Great Barrier Reef. *Abstracts of Papers of the American Chemical Society*, 248.
- Shaw M, Silburn DM, Rojas-Ponce S, Lewis SE, Davis A (2013) Herbicide degradation on Queensland cropping soils and crop residue. Half-lives measured in a controlled environment: Report to the Reef Rescue Water

Quality Research & Development Program. *State of Queensland*.

<https://www.reefrescueresearch.com.au/research/all-projects/23-final-reports/178-rrrd038-final-report-3.html>

Skerratt J, Baird ME, Mongin M, Ellis R, Smith RA, Shaw M, Steven ADL (2023) Dispersal of the pesticide diuron in the Great Barrier Reef. *Science of the Total Environment*, 879: 163.

Sluggett R (2024) Final Report (WQ-MW-004) Project Bluewater 2 Mackay. Report for the Reef Trust Partnership Water Quality Programs, DCCEEW 31 May 2024.

Smith RA, Middlebrook R, Turner RDR, Huggins RL, Vardy S, Warne M St J (2012) Large-scale pesticide monitoring across Great Barrier Reef catchments – Paddock to Reef Integrated Monitoring, Modelling and Reporting Program. *Marine Pollution Bulletin*, 65(4–9): 117–127.

<https://doi.org/10.1016/j.marpolbul.2011.08.010>

Smith RA, Warne M St J, Mengersen K, Turner RDR (2017) An improved method for calculating toxicity-based pollutant loads: Part 1. Method development. *Integrated Environmental Assessment and Management*, 13(4): 746–753. <https://doi.org/10.1002/ieam.1854>

Sobtzick S, Cleguer C, Hagihara R, Marsh H (2017) *Distribution and abundance of dugong and large marine turtles in Moreton Bay, Hervey Bay and the southern Great Barrier Reef. A Report to the Great Barrier Reef Marine Park Authority*. James Cook University Technical Report 17/21. Townsville, Queensland.

Spillsbury FD, Warne M St J, Backhaus T (2020) Risk assessment of pesticide mixtures in Australian rivers discharging to the Great Barrier Reef. *Environmental Science & Technology*, 54(22): 14361–14371.

<https://doi.org/10.1021/acs.est.0c04066>

Star M, Hasan S, Smart J, Wegscheidl C (2024) Question 4.8 What are the measured costs, and cost drivers associated with the use of natural/near natural wetlands, restored, treatment (constructed) wetlands and other treatment systems in Great Barrier Reef catchments in improving water quality? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/4-8/>

Star M, Rolfe J, Farr M, Poggio M (2021) Transferring and extrapolating estimates of cost-effectiveness for water quality outcomes: Challenges and lessons from the Great Barrier Reef. *Marine Pollution Bulletin*, 171: 112870. <https://doi.org/10.1016/j.marpolbul.2021.112870>

State of Queensland (Department of Environment Science and Innovation) (2023) Biodiversity status of pre-clearing and 2021 remnant regional ecosystems - Queensland series. Version 6.13 edn.

Sutcliffe T, Hudson S, Johns C, Vandergragt ML (2022) Wetland Tracker: Great Barrier Reef catchment wetland condition monitoring program, Part 2: Desktop Methods Guide. Department of Environment and Science, Brisbane, Queensland.

Taucare G, Bignert A, Kaserzon SL, Thai P, Mann RM, Gallen C, Müller JF (2022) Detecting long temporal trends of photosystem II herbicides (PSII) in the Great Barrier Reef lagoon. *Marine Pollution Bulletin*, 177: 113490. <https://doi.org/10.1016/j.marpolbul.2022.113490>

Templeman M, McDonald S (2024) Question 5.2 What are the primary sources of pesticides that have been found in Great Barrier Reef ecosystems and what are the key factors that influence pesticide delivery from source to ecosystem? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/5-2/>

Ten Napel M, Wallace R, Neelamraju C, Ferguson B, Huggins R, Orr D, Simpson S, Strauss J, Anderson L, Roberts C, Welk K, Fisher S, Turner RDR, Mann RM (2019a) *Great Barrier Reef Catchment Loads Monitoring Program Report Summary 2016–2017*, Department of Environment and Science, Brisbane, Australia.

- Ten Napel M, Wallace R, Neelamraju C, Ferguson B, Huggins R, Orr D, Simpson S, Strauss J, Anderson L, Roberts C, Welk K, Fisher S, Huggins R, Turner RDR, Mann RM (2019b) *Great Barrier Reef Catchment Loads Monitoring Program Report Summary 2017–2018*, Department of Environment and Science, Brisbane, Australia.
- Thompson A, Davidson J, Logan M, Thompson C (2024) Marine Monitoring Program Annual Report for Inshore Coral Reef Monitoring: 2022–23. Report for the Great Barrier Reef Marine Park Authority. Great Barrier Reef Marine Park Authority, Townsville. 149 pp.
- Thompson AA, Davidson J, Logan M, Thompson C (2023) Marine Monitoring Program Annual Report 2021–22 for Inshore Coral Reef Monitoring. Great Barrier Reef Marine Park Authority, Townsville. 151 pp.
- Thorburn P, Verburg K, Farr M, Weber T, Vilas M, Connolly C, Eccles R (2024) Question 4.6 What are the most effective management practices for reducing dissolved nutrient losses (all land uses) from the Great Barrier Reef catchments, and do these vary spatially or in different climatic conditions? What are the costs of the practices, and cost-effectiveness of these practices, and does this vary spatially or in different climatic conditions? What are the production outcomes of these practices? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/4-6/>
- Thornton CM, Elledge AE (2022) Leichhardt, land clearing and livestock: the legacy of European agriculture in the Brigalow Belt bioregion of central Queensland, Australia. *Animal Production Science*, 62(11): 913–925. <https://doi.org/10.1071/AN21468>
- Tilden JD, Leigh C, Johns C, Ellison T, Huurdeman V, Vandergragt ML (2023) Great Barrier Reef catchment wetland condition monitoring program: Construct validity of Wetland Tracker indicators – a literature review. Department of Environment and Science, Brisbane, Queensland.
- Tilden JD, Vandergragt ML (2022) Great Barrier Reef catchment wetland condition monitoring program: tracking the condition of freshwater wetlands. Department of Environment and Science, Brisbane, Queensland.
- Townsend SA, Edwards CA (2003) A fish kill event, hypoxia and other limnological impacts associated with early wet season flow into a lake on the Mary River floodplain, tropical northern Australia. *Lakes & Reservoirs: Research & Management*, 8(3-4): 169–176.
- Trevithick R, Scarth P, Tindall D, Denham R, Flood N (2014) Cover under trees: RP64G Synthesis Report. Department of Science.
- Udy JW, Dennison WC (1997) Physiological responses of seagrasses used to identify anthropogenic nutrient inputs. *Marine and Freshwater Research*, 48(7): 605–614.
- Udy JW, Dennison WC, Long WJL, McKenzie LJ (1999) Responses of seagrass to nutrients in the Great Barrier Reef, Australia. *Marine Ecology Progress Series*, 185: 257–271.
- US EPA (U.S. Environmental Protection Agency) (1998) Guidelines for Ecological Risk Assessment. EPA/630/R-95/002F. Risk Assessment Forum, Washington DC, USA.
- Uthicke S, Fabricius K, Brown A, Molinari B, Robson B (2024) Question 2.4 How do water quality and climate change interact to influence the health and resilience of Great Barrier Reef ecosystems? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/2-4/>
- Vandergragt ML, Warne MSJ, Borschmann G, Johns CV (2020) Pervasive pesticide contamination of wetlands in the Great Barrier Reef catchment area. *Integrated Environmental Assessment and Management*, 16(6): 968–982.
- Verhoeven JTA, Arheimer B, Yin C, Hefting MM (2006) Regional and global concerns over wetlands and water quality. *Trends in Ecology and Evolution*, 21(2): 96–103. doi: 10.1016/j.tree.2005.11.015.

- Wallace J, Waltham N, Burrows D, McJannet D (2015) The temperature regimes of dry season waterholes in tropical northern Australia: potential impacts on fish refugia. *Freshwater Science*, 34(2): 663–678. doi: 10.1086/681278.
- Waltham N, Motson K, Molinari B (2024) Question 4.7 What is the efficacy of natural/near-natural wetlands, restored, treatment (constructed) wetlands and other treatment systems in Great Barrier Reef catchments in improving water quality (nutrients, fine sediments and pesticides)? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/4-7/>
- Wang G, Jian M, Lu X, Wang M (2013) Effects of sediment load and water depth on the seedbanks of three plant communities in the National Natural Wetland Reserve of Lank Xingkai, China. *Aquatic Botany*, 106: 35–41.
- Warne M St J, Neale PA, Macpherson MJ (2023) A Pesticide Decision Support Tool to guide the selection of less environmentally harmful pesticides for the sugar cane industry. *Environmental Science and Pollution Research*, 30(49): 108036-108050.
- Warne M St J, Neelamraju C, Strauss J, Smith RA, Turner RDR, Mann RM (2020) Development of a method for estimating the toxicity of pesticide mixtures and a Pesticide Risk Baseline for the Reef 2050 Water Quality Improvement Plan. Department of Environment and Science, Queensland Government, Brisbane, Queensland.
- Water Quality & Investigations (2020) Great Barrier Reef Catchment Loads Monitoring Program: Loads and yields for sediment and nutrients, and Pesticide Risk Metric results (2018–2019) for rivers that discharge to the Great Barrier Reef, Department of Environment and Science, Brisbane, Australia.
- Water Quality & Investigations (2021) Great Barrier Reef Catchment Loads Monitoring Program: Loads and yields for sediment and nutrients, and Pesticide Risk Metric results (2019–2020) for rivers that discharge to the Great Barrier Reef, Department of Environment and Science, Brisbane, Australia.
- Water Quality & Investigations (2023) Great Barrier Reef Catchment Loads Monitoring Program: Loads and yields for sediment and nutrients, and Pesticide Risk Metric results (2020–2021) for rivers that discharge to the Great Barrier Reef, Department of Environment and Science, Brisbane, Australia.
- Water Quality & Investigations (2024a) Great Barrier Reef Catchment Loads Monitoring Program: Program Design (methods) document, Department of the Environment, Tourism, Science and Innovation, Brisbane, Australia.
- Water Quality & Investigations (2024b) Tahbil - Water Quality Data Portal. [website]. Queensland Government, Brisbane. <https://apps.des.qld.gov.au/water-data-portal/>
- Water Quality & Investigations (2024c) Great Barrier Reef Catchment Loads Monitoring Program: Loads and yields for sediment and nutrients, and Pesticide Risk Metric results (2021–2022) for rivers that discharge to the Great Barrier Reef, Department of Environment, Science and Innovation, Brisbane, Australia.
- Water Quality & Investigations (2024d) Great Barrier Reef Catchment Loads Monitoring Program: Loads and yields for sediment and nutrients, and Pesticide Risk Metric results (2022–2023) for rivers that discharge to the Great Barrier Reef, Department of Environment, Tourism, Science and Innovation, Brisbane, Australia.
- Waterhouse J, Brodie J, Coppo C, Tracey D, da Silva E, Howley C, Petus C, McKenzie L, Lewis S, McCloskey G, Higham W (2016) Assessment of the relative risk of water quality to ecosystems of the eastern Cape York NRM Region, Great Barrier Reef. A report to South Cape York Catchments. TropWATER Report 16/24, Townsville, Australia. TropWATER (JCU). 105 pp.
- Waterhouse J, Lewis S, Mongin M, Skerratt J, Pineda MC, McCloskey G, Darr S, Sambrook K (2025) Review of the Great Barrier Reef Water Quality Targets. Commonwealth of Australia and Queensland Government. https://www.reefplan.qld.gov.au/_data/assets/pdf_file/0028/429904/gbr-water-quality-targets.pdf

- Waterhouse J, Molinari B, Star M, Weber T, Waltham N, Motson K (2024c) Synthesis of evidence of the effectiveness of wetlands in water quality improvement, costs and cost-drivers in the Great Barrier Reef catchment area. Report prepared for the Great Barrier Reef Foundation. Brisbane, Queensland. 110 pp. <https://www.barrierreef.org/uploads/Wetlands-Synthesis-Report-FINAL.pdf>
- Waterhouse J, Pearson R, Lewis S, Davis A, Waltham N (2023) Great Barrier Reef Ecohydrology. In Oceanographic Processes of Coral Reefs (pp. 105–125). CRC Press.
- Waterhouse J, Pineda M-C, Sambrook K, Newlands M, McKenzie L, Davis A, Pearson R, Fabricius K, Lewis S, Uthicke S, Bainbridge Z, Collier C, Adame F, Prosser I, Wilkinson S, Bartley R, Brooks A, Robson B, Diaz-Pulido G, Reyes C, Caballes C, Burford M, Thorburn P, Weber T, Waltham N, Star M, Negri A, Warne M St J, Templeman S, Silburn M, Chariton A, Coggan A, Murray-Prior R, Schultz T, Espinoza T, Burns C, Gordon I, Devlin M (2024a) 2022 Scientific Consensus Statement: Conclusions In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/conclusions/>
- Waterhouse J, Pineda M-C, Sambrook K, Newlands M, McKenzie L, Davis A, Pearson R, Fabricius K, Lewis S, Uthicke S, Bainbridge Z, Collier C, Adame F, Prosser I, Wilkinson S, Bartley R, Brooks A, Robson B, Diaz-Pulido G, Reyes C, Caballes C, Burford M, Thorburn P, Weber T, Waltham N, Star M, Negri A, Warne M St J, Templeman S, Silburn M, Chariton A, Coggan A, Murray-Prior R, Schultz T, Espinoza T, Burns C, Gordon I, Devlin M (2024b) 2022 Scientific Consensus Statement: Summary. In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/summary/>
- Waterhouse J, Brodie J, Tracey D, Smith R, Vandergragt M, Collier C, Petus C, Baird M, Kroon F, Mann R, Sutcliffe T, Waters D, Adame F (2017a) Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 3: The risk from anthropogenic pollutants to Great Barrier Reef coastal and marine ecosystems. State of Queensland.
- Waterhouse J, Schaffelke B, Bartley R, Eberhard R, Brodie J, Star M, Thorburn P, Rolfe J, Ronan M, Taylor B, Kroon F (2017b) 2017 Scientific Consensus Statement: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 5: Overview of key findings, management implications and knowledge gaps. State of Queensland.
- Wätzold F, Schwerdtner K (2005) Why be wasteful when preserving a valuable resource? A review article on the cost-effectiveness of European biodiversity conservation policy. *Biological Conservation*, 123(3): 327–338. <http://www.sciencedirect.com/science/article/pii/S0006320704004793>
- Wegscheidl C, Trendell P, Coutts J (2015) Evaluating the role of extension in helping to improve water quality in the Great Barrier Reef. *Rural Extension Farming Systems Journal*, 11(1): 1–10.
- Wetland Condition Science Team (2024) Wetland Condition Monitoring Program for the Great Barrier Reef Catchment Area. Queensland Government, Brisbane, Queensland. <https://storymaps.arcgis.com/stories/304abfa55a4a4156a5d12de69cd3318f>
- Wetzel RG (2001) Limnology: lake and river ecosystems. 3rd ed. Elsevier Academic Press, USA. 985 pp.
- Wilkinson S, Hairsine PB, Bartley R, Brooks A, Pietsch T, Hawdon A, Shephard B (2022) *Gully and Stream Bank Toolbox. A technical guide for gully and stream bank erosion control programs in Great Barrier Reef catchments*. 3rd Edition. Commonwealth of Australia. 112 pp.
- Wilkinson SN, Murray B, Prosser IP (2024) Question 3.4 What are the primary biophysical drivers of anthropogenic sediment and particulate nutrient export to the Great Barrier Reef and how have these drivers changed over time? In Waterhouse J, Pineda M-C, Sambrook K (Eds) 2022 Scientific Consensus Statement on land-based impacts on Great Barrier Reef water quality and ecosystem condition. Commonwealth of Australia (Department of Climate Change, Energy, the Environment and Water). <https://reefwqconsensus.com.au/question/3-4/>

- Williams A, James J, Prichard P (2021) Developing an Extension Model of Practice and empower extension practitioners. *Rural Extension & Innovation Systems Journal*, 17(1): 10-20.
- Zann M (2024) Intertidal and Subtidal Ecosystems Mapping for Central Queensland. Department of Environment, Science and Innovation.
- Zedler JB, Kercher S (2004) Causes and consequences of invasive plants in wetlands: Opportunities, opportunists, and outcomes. *Critical Reviews in Plant Sciences*. 23(5): 431–452.
doi:10.1080/07352680490514673.

Version History

Preliminary Methods

Date	Document Version	Document Revision History	Document Author / Reviser and organisation
March 2024	1.0	Draft methods prepared and reviewed by ISP at their meeting on 1 March 2024	Jane Waterhouse, Megan Star, Bianca Molinari, Maria Vandergragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook
April 2024	1.1	Draft methods revised to incorporate comments from ISP and Contract Managers	Jane Waterhouse, Megan Star, Bianca Molinari, Maria Vandergragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook

Full Report

Date	Document Version	Document Revision History	Document Author / Reviser and organisation
June 2024	0.1	Working draft of report framework and methods, incorporating material above	Jane Waterhouse, Megan Star, Bianca Molinari, Maria VanderGragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook
July 2024	0.2	Working draft of report framework and methods, including responses to ISP comments from June 2024 meeting	Jane Waterhouse, Megan Star, Bianca Molinari, Maria VanderGragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook
March 2025	0.3	Draft report	Jane Waterhouse, Megan Star, Bianca Molinari, Maria VanderGragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook, Severine Choukroun, Dieter Tracey, Stephen Lewis
March 2025	0.4	Draft report – Sections 1-5 for ISP	Jane Waterhouse, Megan Star, Bianca Molinari, Maria VanderGragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook, Severine Choukroun, Dieter Tracey, Stephen Lewis
March 2025	0.5	Draft report – all sections for ISP	Jane Waterhouse, Megan Star, Bianca Molinari, Maria VanderGragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook, Severine Choukroun, Dieter Tracey, Stephen Lewis
March 2025	0.6	Draft report – internal adjustments following submission to ISP on 25 March	Jane Waterhouse, Megan Star, Bianca Molinari, Maria VanderGragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook,

Date	Document Version	Document Revision History	Document Author / Reviser and organisation
		2025 and integration of ISP and policy feedback.	Severine Choukroun, Dieter Tracey, Stephen Lewis
April 2025	0.7	Draft report for peer review addressing ISP and policy feedback.	Jane Waterhouse, Megan Star, Bianca Molinari, Maria VanderGragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook, Severine Choukroun, Dieter Tracey, Stephen Lewis
April 2025	0.8	Draft report – internal adjustments and peer review feedback from Roger Shaw, Bob Spiers and Britta Schaffelke.	Jane Waterhouse, Megan Star, Bianca Molinari, Maria VanderGragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook, Severine Choukroun, Dieter Tracey, Stephen Lewis
May 2025	1.0	Final Report	Jane Waterhouse, Megan Star, Bianca Molinari, Maria VanderGragt, Catherine Leigh, Terri Sutcliffe, Rachael Smith, Katie Sambrook, Severine Choukroun, Dieter Tracey, Stephen Lewi
June 2025	1.1	Final Report with minor edits	Jane Waterhouse, Katie Sambrook, Rachael Smith,
September 2025 (released November 2025)	1.2	Final Report with minor edits including update to Table 22 to correct minor errors and Table 26 to improve clarity following review of associated communication products by OGBR&WH.	Jane Waterhouse, Rachael Smith, Katie Sambrook
December 2025 (not released)	1.3	Final Report with corrections to Section 2.2.2 and Appendix 2 Table 8 to correct terminology including amendment of wording from ‘wetland loss’ to ‘wetland loss and modification’. Clarification of reference to ‘natural unmodified wetlands’ when comparing current and historical extent.	Maria VanderGragt, Terri Sutcliffe
August 2026	2.0	Final Report version 1.3 with additional adjustments to the report copyright attribution, recognition of updated pollutant load information and corrections to Section 2.2.4 regarding gully density for the Belyando catchment (and associated regional interpretation).	Jane Waterhouse, Katie Sambrook, Rachael Smith, Maria VanderGragt, Terri Sutcliffe