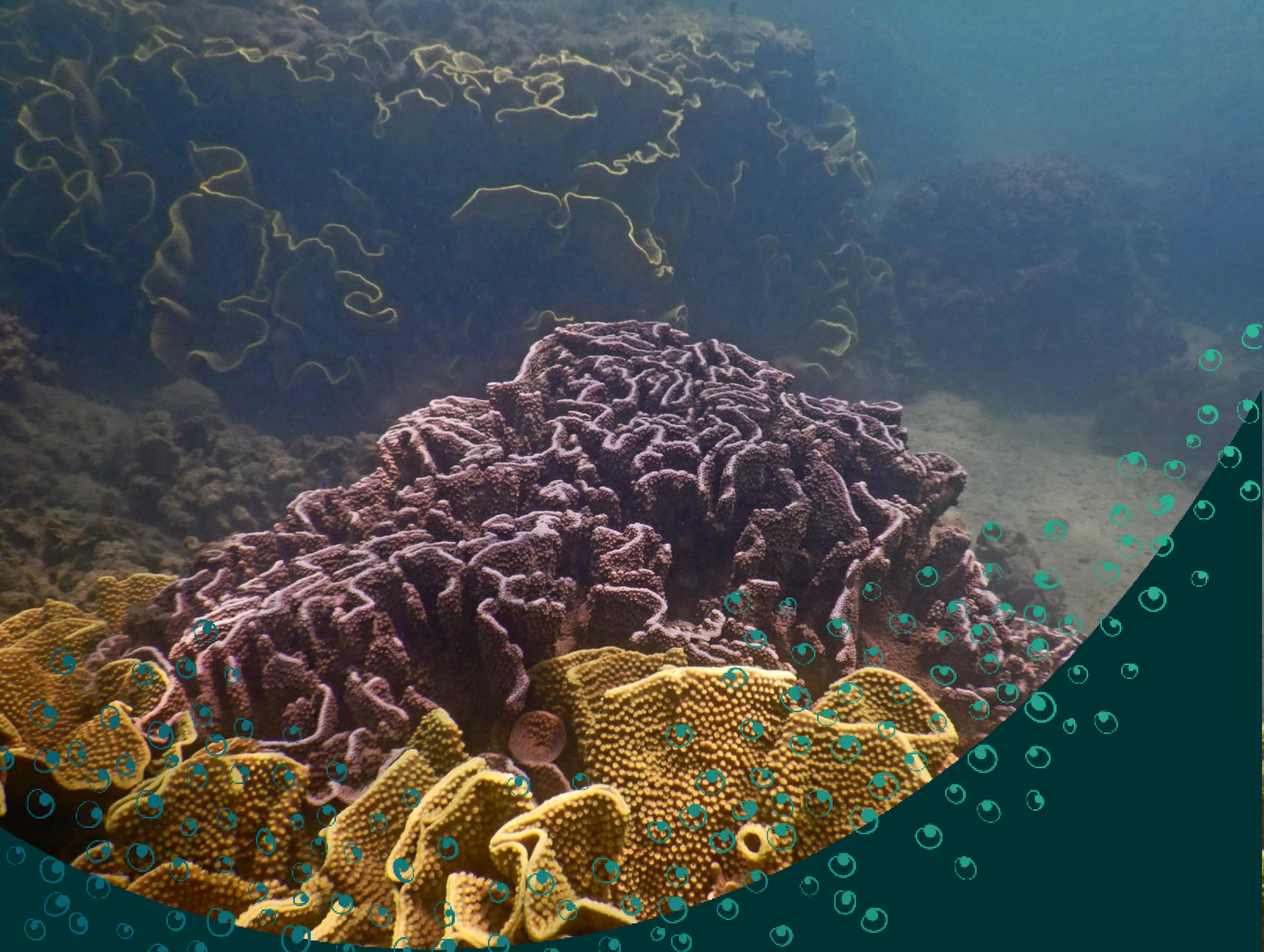

Interim water quality guidelines and related biological health indicators for corals of Hervey Bay, Great Sandy Strait, and Burnett-Baffle coast

Stage 3: Final Report

Queensland Government

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Photo credit: East Point Vernon *Turbinaria* corals. By Maria Zann.

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Hillyer KE, and Moss A, 2024. Interim water quality guidelines and related biological health indicators for corals of Hervey Bay, Great Sandy Strait, and Burnett-Baffle coast. Brisbane: The Department of the Environment, Tourism, Science and Innovation, Queensland Government.

12th December 2024

Version	Date	Description
1.0	12/12/24	Final version
2.0	13/06/25	Typo correction

Contents

Tables

Figures

Glossary of terms

AIMS   Australian Institute of Marine Science
ANZG   Australian and New Zealand Guidelines
Chl-a   chlorophyll a
COTS   crown of thorns starfish
DETSI   Department of Environment, Tourism, Science and Innovation
DIN   dissolved inorganic nitrogen
DOC   dissolved organic carbon
DON   dissolved organic nitrogen
DOP   dissolved organic phosphorus
EC   enclosed coastal
ERT   ecologically relevant targets
EV   environmental value
GBR   Great Barrier Reef
GSS   Great Sandy Strait
GBRCLMP   Great Barrier Reef Catchment Loads Monitoring Program
GBRMP   Great Barrier Reef Marine
GBRWHA   Great Barrier Reef World Heritage Area
GSMP   Great Sandy Marine Park
GV   guideline value
HAT   highest astronomical tide
HEV   high ecological value
JCU   James Cook University
LAT   lowest astronomical tide
LE   lower estuary
LOD   limit of detection
MMP   Marine Monitoring Program
ND   no data
NH_3 ammonia
NO_x nitrogen oxides
NTU   nephelometric turbidity units
OC   open coastal
PAH   polyaromatic hydrocarbon
PCB   polychlorinated biphenyl
PFAS per- and polyfluoroalkyl substances
PN   particulate nitrogen
PO_4 phosphate (dissolved inorganic phosphorus)
POC   particulate organic carbon
PP   particulate phosphorus
PPCP pharmaceuticals and personal care products
PSII herbicide   photosystem II inhibiting herbicide
SD   slightly disturbed
SST   sea surface temperature
TSS   total suspended solids
TV   trigger value
WQO   water quality objective

1 Non-technical summary

This coral project is undertaken in support of the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (Water Policy), subordinate legislation to the *Environmental Protection Act 1994* (EP Act). The report sets out interim water quality guidelines for the protection of coral health in the inshore Baffle, Burrum North, and Burrum South regions, which includes Hervey Bay and the Great Sandy Strait (GSS). These regions comprise a range of water types (Lower Estuary (LE)/Enclosed Coastal (EC), Open Coastal (OC)) and management intents (High Ecological Value, Slightly Disturbed). Guideline Values outlined in this document are interim being based on preliminary water quality monitoring data, and may be revised as more data becomes available. These values are percentiles which have been derived from a reference coral monitoring site in each region. This report also summarises background information related to water quality, the health of inshore coral communities in these regions, and indicators of coral health.

1.1 Threats to coral habitats

Coral reefs are faced with increased human impacts and are threatened globally. Increases in carbon dioxide and seawater temperatures can lead to a process called coral bleaching, which can result in coral death. Corals in cooler, high latitude habits have been suggested as possible climate refuges but are also likely to undergo greater temperature changes in the future. Changes in water quality can also influence coral health, such as increased levels of fine sediments, nutrients, pesticides, and other contaminants. On the Great Barrier Reef (GBR), human use of surrounding catchments has resulted in changes in the water loads of these pollutants and alterations to inshore environments, including to the health, abundance and diversity of coral species.

1.2 Coral habitats in the study area

The coral habitats of this project area fall within Gureng Gureng, Badtjala, and Gubbi Gubbi Country. They are located within the GBR Region but are predominately south of the boundary of Great Barrier Reef World Heritage Area (GBRWHA) and Great Barrier Reef Marine Park (GBRMP). The Great Sandy Marine Park (GSMP) covers much of the southern extent of the project area.

Being located in cooler waters, south of the majority of the GBR, the coral communities of the project area include tropical, sub-tropical, and temperate species. Inshore coral habitats comprise a variety of fringing (close to shore) and patch (isolated patches that vary in size) reef types. These coral habitats are subject to large variations in water clarity and suspended sediments associated with differing degrees of exposure to nearby rivers and floods. These coral habitats include a variety of hard (containing a skeleton of calcium carbonate) and soft corals (without a calcium carbonate skeleton), with differing community composition, and coral cover of the seabed.

1.3 Water quality in the study area

Water quality in the project area is primarily influenced by discharges from the surrounding major rivers, including the Mary River to the south, and the Burrum, Burnett, Kolan and Elliott rivers to the north. Key water quality issues for the Burnett Mary Region include excess total suspended sediment (TSS), dissolved nutrients, and pesticides. During flood events, inshore coral habitats are exposed to freshwater plumes and higher loads of these stressors, which may persist for weeks to months. Major flood events have occurred in the region in 2021-2022, 2012-2013, and 2010-2011. The study area was also exposed to widespread increases in seawater temperatures at a level predicted to result in severe coral bleaching in 2020, and to a lesser extent in 2018.

An initial three years of water quality sampling has been conducted regularly by Gidarjil Land and Sea Rangers (Gidarjil) at 15 nearshore coral sites within the study area between 2020-2022, with sampling six times per year. This period included both relatively dry (2020-2021), and wet years (2021-2022) when flooding was observed. An independent review noted some issues related to metadata, and to physical and chemical parameters; however, these data still offer useful baseline information that enabled the calculation of report card scores. Program improvements were proposed, and these initial data should be viewed as preliminary. Overall regional scores for this water quality sampling generally ranged between ‘Poor’ and ‘Good’. Flood events during 2021-22 were evident in overall scores for water quality indicators, including turbidity, and TSS. Monitoring has also been conducted at estuarine and coastal sites in the study area under the DETSI Central Ambient Monitoring Program since 1993. Analysis of change in measured water quality indicators during the 30-year period revealed most consistent change in surface water temperature, which has increased at multiple locations. Declining annual trends in water clarity and salinity have also been observed during the period in Hervey Bay, and the GSS.

Pesticide load monitoring conducted as part of the DETSI GBR Catchment Loads Monitoring Program revealed metolachlor, followed by diuron, and atrazine as posing the greatest potential risk to species. This risk varied over time and across monitored sites. Concentrations reported of individual pesticides between 2018 – 2023 typically fell below the relevant guideline level (95% species protection guidelines for moderately disturbed, PC95; ≥99% species for HEV and slightly disturbed); however, significant exceedances of PC95 did occur on occasion.

1.4 Trends in study area coral habitats

Coral surveys were conducted at 14 inshore coral sites by Gidarjil between 2020 - 2022, to identify trends in the cover and diversity of hard and soft corals, though not all reefs were surveyed in each year. Sites differed in hard and soft coral percentage cover, species dominance, species diversity, and juvenile density along persistent water quality gradients. Coral habitats in proximity to the Burrum and Burnett rivers were characterised predominantly by soft corals, whereas sites further north (Baffle region) and south (Hervey Bay) were characterised by higher cover of hard corals. Densities of hard corals was considered low, indicating limited recruitment success.

An independent review of the coral monitoring data noted some issues with the methodology applied; however, these data still offer useful baseline information that enabled the calculation of report card scores for hard and soft coral cover and juvenile hard corals for each site. Program improvements were proposed, and these data should be viewed as preliminary. ‘Good’ to ‘Very Good’ scores were consistently estimated for all years (2020 – 2022) for coral cover at sites in the Baffle (Pancake Creek), and Burrum North sub-regions (Hoffman’s Rocks, Barolin Rocks, and Four Mile Reef), whereas a decline in status has been observed at sites in the Burrum North sub-region (Burnett Heads, Burkitt’s Reef, Rifle Range Reef), and at both sites in the Burrum South sub-region (Point Vernon, and Pialba). Notably, at Point Vernon coral cover scores declined from ‘Very Good’ in 2020, to ‘Poor’ in 2022. Juvenile hard coral densities were scored as ‘Very Poor’ at the majority of sites.

1.5 Interim water quality guideline recommendations

The loss of live coral cover and decline in report card scores observed in the south of the study area (Burrum region) are of concern for coral health. Low numbers of juvenile corals observed across the study area are also an indicator of limited recruitment success and resilience to future stressors. With increased climate variability leading to more frequent exposure to thermal stress and flooding, it is critical that coral communities in already marginal environments are able to recover rapidly under ambient conditions, facilitating growth, repopulation and resilience to future stressors. Minimising local scale stressors, such as by maintaining and/or improving ambient water quality, in particular levels of nutrients, suspended sediments, and contaminants, will assist in ecological function and recovery.

In order to derive interim guidelines, reference sites were designated based on water quality indicator values observed over the recent coral site water quality monitoring during 2020 - 2022 by sub-region (Table 1). In each sub-region, this was by the site with the consistently lowest (i.e. best) median values over the period across key water quality indicators. These comprised Jensen's Rocks (Baffle sub-region), Four Mile (Burrum North), and Point Vernon (Burrum South). These were typically the most distant sites from the nearest major river mouth. Percentiles (20^{th}, 50^{th} and 80^{th}) were then calculated according to available physico-chemical indicator values at these reference sites. Regional percentiles are based on an average of the reference site percentiles. These guideline values are interim with a high degree of uncertainty, being based on a limited number of preliminary values, collected over one relatively dry year (2020-2021) and one wet year (2021-2022), where flooding was observed. Currently there is not sufficient monitoring data to generate an interim value for some indicators including secchi depth, sedimentation, total phosphorus, particulate nutrients, and some dissolved nutrients.

Notably, for some indicators reference site percentiles exceed the relevant designated Water Quality Objective for HEV open coastal waters in the study area or relevant Guideline Value, indicating a need for further monitoring to determine appropriate indicator values for coral health in these areas. It is suggested that the most conservative of the values be selected in these instances, as this would likely offer the highest degree of protection to coral health.

While this report canvasses toxicants (including insecticides, herbicides, fungicides and emerging contaminants), it does not seek to derive aquatic ecosystem guidelines for them. Reference is made to relevant guideline values developed under or in accordance with the toxicant derivation protocols set by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG), and toxicant policy established in state legislation and the Reef 2050 Water Quality Improvement Plan.

Table 1 Sub-regional interim water quality guidelines, exceedance of relevant regional Water Quality Objective (WQO)/Guideline Value (GV)/GBR Trigger Value indicated by orange highlight (where multiple water types present highest protection level selected). Standard error (SE), number of samples (N). Reference sites comprised Pancake Creek (Baffle sub-region, lower estuary), Ethel Rocks (Baffle sub-region, open coastal waters), Four Mile Reef (Burrum North, open coastal), and Point Vernon (Burrum South, open coastal).

Indicator	Sub-region	Water type, management intent	WQO/GV 20th – 50th – 80th	Reference site percentile				
				20th	50th	80th	SE	N
Chl-a (µg/L)	Baffle	Baffle Creek, LE/EC, HEV	1 – 1 – 2	0.25	0.25	1.1	0.4	11
	Baffle	Baffle Creek, Open coastal, HEV	0.5 – 0.6 – 0.8	0.25	0.5	1.66	0.29	11
	Burrum North	HB1, Open coastal, HEV	0.5 – 0.6 – 0.8	0.25	0.25	2.14	0.57	11
	Burrum South	HB1, Open coastal, HEV	0.5 – 0.6 – 0.8	0.25	0.5	1.16	0.14	11
TSS (mg/L)	Baffle	Baffle Creek, LE/EC, HEV	ND	2.5	8	16	5.15	14
	Baffle	Baffle Creek, Open coastal, HEV	2 – 4 – 11	2.5	8.5	12	6.29	14
	Burrum North	HB1, Open coastal, HEV	2 – 4 – 11	2.5	9.5	14	1.88	14
	Burrum South	HB1, Open coastal, HEV	2 – 4 – 11	2.9	7	11.2	1.15	13
Turbidity (NTU)	Baffle	Baffle Creek, LE/EC, HEV	2 – 3 – 5	0.25	1.1	1.7	0.26	9
	Baffle	Baffle Creek, Open coastal, HEV	0 – 1 – 2	0.25	1.4	2.5	0.36	9
	Burrum North	HB1, Open coastal, HEV	0 – 1 – 2	0.25	0.7	2.6	0.32	9
	Burrum South	HB1, Open coastal, HEV	0 – 1 – 2	1.1	2.7	3.8	0.56	9
TN (µg/L)	Baffle	Baffle Creek, LE/EC, HEV	110 – 130 – 170	10	60	140	17.8	9
	Baffle	Baffle Creek, Open coastal, HEV	110 – 113 – 150	10	70	140	22.7	9
	Burrum North	HB1, Open coastal, HEV	110 – 113 – 150	10	70	170	23.9	9
	Burrum South	HB1, Open coastal, HEV	110 – 113 – 150	50	110	140	17.8	9
Ammonia N (NH_4) (µg/L)	Baffle	Baffle Creek, LE/EC, HEV	2 – 2 – 5	10.4	30	64.2	9.5	5
	Baffle	Baffle Creek, Open coastal, HEV	2 – 6 – 9	1.6	10	62	8.7	5
	Burrum North	HB1, Open coastal, HEV	2 – 6 – 9	1.4	20	36	5.4	5
	Burrum South	HB1, Open coastal, HEV	2 – 6 – 9	1.4	8	42	6.0	5
Dissolved oxygen (% saturation)	Baffle	Baffle Creek, LE/EC, HEV	95 - 100 - 105	96	99	101	12.7	11
	Baffle	Baffle Creek, Open coastal, HEV	90 – 95 – 100	95	99	102	7.4	13
	Burrum North	HB1, Open coastal, HEV	90 – 95 – 105	98	100	102	7.5	13
	Burrum South	HB1, Open coastal, HEV	90 – 95 – 105	89	98	105	7.6	13
pH	Baffle	Baffle Creek, LE/EC, HEV	7.9 – 8.1 – 8.3	8.0	8.1	8.2	1.2	10
	Baffle	Baffle Creek, Open coastal, HEV	8.1 – 8.2 – 8.4	8.1	8.2	8.2	0.9	12
	Burrum North	HB1, Open coastal, HEV	8.1 – 8.2 – 8.4	8.1	8.2	8.3	0.9	12
	Burrum South	HB1, Open coastal, HEV	8.1 – 8.2 – 8.4	8.0	8.2	8.3	0.9	12

Indicator	Sub-region	Water type, management intent	WQO/GV 20th – 50th – 80th	Reference site percentile				
				20th	50th	80th	SE	N
Total phosphorus (TP) (µg/L)	Baffle	Baffle Creek, LE/EC, HEV	6 – 9 – 13	ND	ND	ND	ND	-
	Baffle	Baffle Creek, Open coastal, HEV	6 – 10 – 14	ND	ND	ND	ND	-
	Burrum North	HB1, Open coastal, HEV	6 – 10 – 14	ND	ND	ND	ND	-
	Burrum South	HB1, Open coastal, HEV	6 – 10 – 14	ND	ND	ND	ND	-
Filterable reactive phosphorus (FRP) (µg/L)	Baffle	Baffle Creek, LE/EC, HEV	2 – 2 – 2	ND	ND	ND	ND	-
	Baffle	Baffle Creek, Open coastal, HEV	2 – 2 – 3	ND	ND	ND	ND	-
	Burrum North	HB1, Open coastal, HEV	2 – 2 – 3	ND	ND	ND	ND	-
	Burrum South	HB1, Open coastal, HEV	2 – 2 – 3	ND	ND	ND	ND	-
Secchi depth (m)	Baffle	Baffle Creek, LE/EC, HEV	1.3 - 2 - 2.5	ND	ND	ND	ND	-
	Baffle	Baffle Creek, Open coastal, HEV	>5.0	ND	ND	ND	ND	-
	Burrum North	HB1, Open coastal, HEV	Insufficient data	ND	ND	ND	ND	-
	Burrum South	HB1, Open coastal, HEV	Insufficient data	ND	ND	ND	ND	-
GBR mean annual Trigger Value								
Particulate nitrogen[1] (PN) (µg/L)	GBR	Enclosed coastal	-	ND	ND	ND	ND	-
		Open coastal	20	ND	ND	ND	ND	-
Particulate phosphorus[1] (PP) (µg/L)	GBR	Enclosed coastal	-	ND	ND	ND	ND	-
		Open coastal	2.8	ND	ND	ND	ND	-
Sedimentation[2] (mg/cm²/d)	GBR	Enclosed coastal	3	ND	ND	ND	ND	-
		Open coastal	3	ND	ND	ND	ND	-
Temperature[3] (ºC)	GBR	All	+1	20.2	24.9	26.5	1.06	41
Pesticides (species protected)	GBR	All	99%	ND	ND	ND	ND	-

[1]Seasonal adjustments for PN, and PP are approximately ± 20% of mean annual values

[2]Daily maximum of 15 mg/cm²/d

[3]Above long term average, percentiles are average values across reference sites over the period

2 Purpose and outputs

This document forms the Stage 3 Final Report, incorporating Stage 1 Literature Review and Stage 2 comments, to develop water quality guidelines and related biological health indicators for the coral habitats of the coastal waters of Hervey Bay, the Great Sandy Strait (GSS), and the Burnett-Baffle coast (project area; Figure 1). These are interim guideline values being based on preliminary water quality monitoring, with a high degree of uncertainty, at known coral sites.

The final project outputs and guideline values are intended to:

- Meet requirements for recognition as water quality guidelines under section 8 of the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (the Water Policy).
- Provide a technical basis for the development of aquatic ecosystem water quality objectives (WQOs) under schedule 1 of the Water Policy.
- Inform ongoing Australian and Queensland government commitments to protect and improve Great Barrier Reef values, including through the Reef 2050 water quality improvement plan.
- Support planning, resource allocation, licensing, and management initiatives in the region, notably the Great Sandy Strait Ramsar management requirements (i.e. Ramsar information sheet), Great Sandy Marine Park, Matters of National and State Environmental Significance, and decisions under the *Environmental Protection Act 1994.*

The purpose of Stage 1 is to:

- Identify key coral habitats in the project area by location, type/species, and significance.
- Summarise trends in coral coverage/composition/health, including relationships with climate and water quality.
- Scope and report on primary water quality indicators of relevance to corals.
- Scope and identify existing reports/resources that establish water quality guidelines for key indicators.
- Assess transferability of coral water quality indicators and guidelines from other regions/sources, and where appropriate provide advice/justification.
- Identify gaps in water quality data and related environmental information.

The purpose of Stage 2 is to:

- Identify water quality guidelines for key biological health and physio-chemical indicators of coral health.
- Comment on the effects of climate change and recommendations relating to climate change-associated water quality parameters.

The purpose of Stage 3 is to:

- Produce a final report with recommendations (this report).

Figure 1 Project area extent

3 Legislative context

Background on national water quality policy, Queensland water quality legislation, and related reef and regional initiatives is provided in Appendix 1. A summary follows: Under the Reef 2050 water quality improvement plan, end-of-catchment anthropogenic load reduction targets have been established for all mainland basins draining to the reef, including the Baffle, Kolan, Burnett, Burrum, and Mary basins. These include targets for dissolved inorganic nitrogen (DIN) and fine sediments (sediment fraction in water that measures less than 16 µm), which have been carried through as water quality objectives for reef catchments pursuant to section 11(6) of the Water Policy. Additionally, Environmental values (EV), water quality objectives (WQO) and accompanying mapping has been included under schedule 1 of the Water Policy for waters of the Mary and Burrum river basins, K'gari , Hervey Bay, and GSS; these include mapping of waters identified for high ecological value (HEV) level of protection in fresh, estuarine, and coastal/marine waters. As a GBR catchment, a Water Quality Improvement Plan (WQIP) has been prepared by the regional NRM body, the Burnett Mary Regional Group for the Burnett Mary Region (including Burnett-Baffle, Mary and Burrum basins), and includes basin-specific water quality targets and priorities.

Notwithstanding the above and other initiatives, to protect or restore the health and resilience of sensitive ecosystem values in the region (such as coral habitats), locally derived and ecologically-relevant water quality guidelines may be necessary. Given the extent of the project area and the variety of water bodies and their associated coral habitats, a one-size-fits-all approach is unlikely to be useful for setting ecologically relevant guidelines for coral health. As such, sub-regional guidelines according to current and past site conditions (e.g., water quality, flooding) and coral community composition (via the use of relevant site-specific indicators), are expected to facilitate improved health and/or protect the resilience of existing communities.

4 Coral habitats

4.1 Hard and soft corals

For the purposes of this study, ‘coral’ indicates hard corals, though soft corals are also present in the study area. Hard corals, also known as scleractinian and stony corals, produce a rigid skeleton made of calcium carbonate ($CaCO_3$) (Figure 2). Hard corals are the primary reef-building corals, those that form reefs are called hermatypic corals (Phylum: Cnidaria, Sub-phylum: Anthozoa). The group is highly diverse in the southern extent of the GBR ecoregion alone; 308 coral species are either confirmed or predicted to occur based on their known distributions (Veron J.E.N., Stafford-Smith M.G. 2016). Soft corals (Phylum: Cnidaria, Class: Octocorallia, Order: Alcyonacea) also known as ahermatypic coral, do not produce a rigid calcium carbonate skeleton and do not form reefs. However, soft corals may also serve as important refugia in areas of low seabed (benthic) habitat complexity (e.g. associated with low percentage hard coral cover).

Reef-forming (hermatypic) corals comprise a complex relationship between an animal host and internal symbiotic algae (dinoflagellates of the family Symbiodiniaceae) in addition to a diverse range of associated microorganisms (bacteria, fungi, viruses), as a whole termed the holobiont. This complex relationship enables the highly efficient recycling of nutrients from the algal photosymbionts to coral host (autotrophy), optimising growth in typical offshore reef environments (low nutrient, clear waters), within a given temperature range.

Figure 2 Soft corals (left) and hard coral (right, Acropora sp.) (photograph courtesy of Maria Zann)

4.2 Marginal coral habitats

Coral reefs are typically restricted to clear, tropical waters, however coral-dominated communities in eastern Australia cover a latitudinal range of >2,500 km, from the northern GBR to South West Rocks in NSW (Harriott and Banks 2002). Patterns of coral species richness and reef accretion show a general decline with increasing latitude; south of the GBR, coral species richness declines by 50%. A combination of abiotic and biotic factors likely drive differences between high latitude coral communities and tropical reefs, including temperature thresholds (reef formation is typically confined to regions with annual minimum temperatures of ≥18 °C), light limitation, aragonite saturation (a specific form of calcium carbonate and how easily it is dissolved), nutrient and sediment loads, larval dispersal, competition with macro-algae and other invertebrates, and availability of suitable settlement cues and algal symbionts (as reviewed in Abrego et al. 2021).

Inshore reefs occur within 20 km of the mainland coast where reef development may be influenced by continual or episodic terrigenous sediment inputs, fluctuating salinities, and reduced water quality through increased nutrient and pollutant delivery from urban and agricultural runoff (reviewed in Browne et al. 2012). Corals able to persist in these environments have developed morphological and/or physiological adaptations, primarily to high sediment loads and low levels of light. These adaptations include differences in colony growth form, increased mucous production, heterotrophic feeding, and sediment removal. However, freshwater run-off is a major cause of coral mortality on inshore reefs. Salinity tolerance thresholds are highly species-specific and are influenced by acclimatisation, but for sensitive species the lower limit may be between 26 – 30 ppt (~ 41 – 46 mS/cm conductivity) for exposure periods of 1 or more days (Berkelmans et al. 2012).

4.3 Drivers of change

Being highly locally adapted, when conditions rapidly fall outside of typical ranges (e.g. temperature, salinity, nutrients, light), coral symbioses start to dysfunction. If conditions persist or worsen, breakdown and loss of internal algal symbionts (coral bleaching) and/ or alterations in associated microorganisms (coral disease and syndromes) may occur. Climate change is a major driver of coral loss, with increasing water temperatures resulting in mass bleaching events on the GBR and globally (Hughes et al. 2003, 2017; Quigley and Baird 2024), with climate change considered the primary threat to the GBR (Waterhouse et al. 2024). The response of calcifying organisms to declining seawater pH from rising atmospheric CO_2 (ocean acidification, predicted near future levels pH 7.9 - 7.61), is also the subject of concern for future coral health and functionality (Eyre et al. 2018; Leung et al. 2022).

Local scale drivers, such as water quality (Section 5) can also significantly contribute to changes in coral reef health and may serve to alter ecological resistance and resilience to coral bleaching (Wooldridge 2009; Wooldridge and Done 2009). Water quality drivers may act over prolonged periods, and/or may be associated with acute events (e.g. floods, dredging), with inshore reefs more regularly and severely exposed compared to their offshore counterparts. Increased storminess due to climate change, with associated increases in the frequency and severity of disturbances from floods and storms, also affects capacity for recovery and resilience to future stressors. The combinations of water quality (including nutrients, light/sediments and pesticides) and climate change factors (including temperature and ocean acidification) are often additive and pose a greater threat to organisms than single stressors (Uthicke et al. 2024). The most detrimental effects are the combined effects of climate change and herbicides, and there is also evidence that climate change can interact with both nutrients and light reduction/sedimentation to cause additional stress, including reduced thermal tolerance (Uthicke et al. 2024).

At inshore reefs, land-based runoff will also result in impacts such as reduced light, increased macroalgal growth and disease (Waterhouse et al. 2024). In GBR catchments, historical and continuing land management and catchment modification impair water quality through extensive vegetation degradation, changed hydrology, increased erosion, and expansion of fertilised land uses, urban centres and coastal developments (Waterhouse et al. 2024). Pollutant loads from the catchment area to the GBR have increased from predevelopment loads by 1.4 to 5 times for fine sediments, and 1.5 to 3 times for dissolved inorganic nitrogen (with variations depending on basins); this has resulted in changes in the abundance and diversity of reef species and increases in macroalgal growth (Waterhouse et al. 2024).

Increased nutrient levels may facilitate the growth of macroalgae, which can compete for space on the seabed, directly smother corals, and cause disease, whilst also supporting outbreaks of the coral-feeding crown of thorns starfish (COTS; *Acanthaster planci*). Population outbreaks of COTS represent one of the most significant biological disturbances on coral reefs and remain one of the principal causes of widespread declines in live coral cover on the GBR (Caballes et al. 2024). Though it should be noted that COTS outbreaks have not been detected inshore of the Capricorn Group and are focussed further north in the GBR.

GBR inshore coral reefs are regularly monitored under the Marine Monitoring Program (MMP) and the Australian Institute of Marine Science's Long-Term Monitoring Program (LTMP). In the latest 2022 – 2023 report, GBR water quality guideline values for water clarity as measured by secchi depth, and the inorganic nitrogen nutrients nitrate/nitrite were not met in any region, with the exception of the Annan Endeavour focus region in Cape York (Gruber et al. 2024). Between 1995 and 2017, anthropogenic influenced riverine loads have reduced hard coral recovery rates, assessed in terms of coral cover, in inshore reefs of the central and southern GBR by between -12% to -27% (MacNeil et al. 2019). Among inshore and mid-shelf reefs, improvements of between 11% to 23% in the frequency of elevated sediments and/or high wet-season nutrient plume waters were therefore assessed as necessary to counteract future thermal stress expected by 2050 (MacNeil et al. 2019).

4.4 Indicators of change

Coral taxa and their life history stages (e.g. larvae, juvenile, adult) vary greatly in their ability to acclimate and persist under conditions of environmental stress. Using key indicators (e.g. coral cover, proportion of macroalgae, juvenile coral density), the status of coral communities can be rapidly characterised, such as to inform regional reef report card scores (Thompson et al. 2020). However, additional insights may also be generated via the use of coral traits (Table 2) to classify life history strategies (Darling et al. 2012). These strategies are primarily separated by colony morphology, growth rate, and reproductive mode:

- Competitive: large, branching, and plating coral species that grow quickly, occur at shallow depths, and reproduce by broadcast spawning. In the Indo-Pacific, this group includes the staghorn and bottlebrush corals in the genus *Acropora* and species of *Montipora, Pocillopora* and *Turbinaria*. This group is efficient at using resources and can dominate communities. Branching and plating corals often grow quickly into large, tree-like colonies, but they are typically only dominant in ideal environments.
- Weedy: reproduce by brooding and have smaller colony sizes. In the Indo-Pacific, this group includes branching *Porites* species, some species of *Pocillopora* and *Favia*. This group is a weedy or ruderal strategy of species that can opportunistically colonise recently disturbed habitats.
- Generalist: can do well in habitats where competition is limited by low levels of stress and includes *Montipora* and *Turbinaria* species.

- Stress tolerant: slow-growing species that reproduce by broadcast spawning and primarily have domed morphologies, large corallites, and high fecundity. Includes massive *Porites* species and many faviids (e.g. *Favia, Favites, Platygyra, Goniastrea*). Slow growth rates, longer generation times, large corallites (which promote energy storage), and high fecundity during episodic spawning events may all be advantageous traits in chronically harsh environments with, for example, low light or high sedimentation.

Typically, fast growing, branching coral taxa (e.g. *Acropora*) are considered sensitive to a range of environmental stressors, notably thermal stress; whereas slower growing, boulder forming groups (e.g. *Favia*) may be more resistant and better able to persist under changeable environments (Loya et al. 2001; Hughes et al. 2018). However, fast growing groups may also rapidly re-colonise if environmental conditions allow (Pratchett et al. 2020). High within- and between-species variability and flexibility (plasticity) also exists in features such as growth forms and feeding modes (Anthony and Fabricius 2000; Anthony and Connolly 2004). Survival of adult populations and their reproductive modes (e.g. brooding vs broadcast spawning) will in turn affect recruitment dynamics and recovery capacity (Hughes et al. 2019; Dietzel et al. 2020). Juvenile corals may also differ in their capacity to resist rapid environmental change relative to adult colonies (Álvarez-Noriega et al. 2018). As a result, community composition, reef structure, and resilience can relate both to site environmental exposure history (e.g. associated with previous disturbances), and current conditions (such as water quality).

Table 2 Example species traits relevant to life history strategies of hard corals (adapted from Darling et al. 2012)

Species trait	Description
Colony growth form	Branching, plating, massive, sub-massive, encrusting
Solitary colonies	Solitary or colonial
Reproductive mode	Brooding or broadcast spawning
Colony size	Dimensions, height, width
Corallite diameter	Average size of corallites
Depth range	Median depth reported
Fecundity	Number of eggs produced
Generation length	Number of years between generations
Growth rate	Average annual growth rate
Skeletal density	Average density of $CaCO_3$ skeleton
Symbiont richness	Richness of hosted algal symbiont genotypes

Coral biological indicators to changing water quality at the level of individual colonies, populations and communities have been studied via a range of techniques, from highly detailed molecular approaches to rapid *in situ* measurements (as reviewed in Cooper et al. 2009). The application and suitability of these indicators to water quality monitoring and coral health are outlined in Table 33. Effective indicators should be non-destructive, sensitive, and specific (to any given stressor or variable of interest), reflect function at a holistic level (i.e. holobiont vs single symbiotic partner), require little additional equipment and expertise, rapid, conducted *in situ*, and at low cost, enabling repeated sampling (both temporally and spatially). See, for instance, the bioindicator system proposed for water quality on inshore coral reefs of the GBR (Fabricius et al. 2012).

However, it should be noted that some indicators, such as low species richness, may also reflect natural conditions which have persisted for millennia (Browne et al. 2012). Further, shifts in community composition from diverse assemblages to those dominated by specialist coral species may also reflect alterations of available reef habitat as it approaches sea level, with associated alterations in wave activity and exposure, or may be associated with natural alterations in coastal processes and sediment delivery.

Table 3 Summary of coral reef bioindicators to changing water quality and utility to water quality monitoring. Potentially suitable indicators are highlighted in green (amended from Cooper et al. 2009; Fabricius et al. 2012).

Bioindicator	Stressor	Species / Family	Response	Application and suitability to WQ monitoring
Colony measures				
Gene expression	Heavy metals, sedimentation	*Diploria strigosa*	Up-regulation of 14 of 32 stress genes; Elevated expression of uPAR transcripts	Destructive, sensitive, specific, high cost
RNA/DNA ratio	Turbidity and light attenuation	*Porites* spp.	Increasing RNA/DNA ratio	Destructive, sensitive, high cost
Symbiont photophysiology	Herbicides	*Acropora formosa, Montipora digitata, Porites cylindrica, Seriatopora hystrix*	F_v/F_m reduced by 50%	Non-destructive, symbiont focus, low cost, *in situ*
Concentration of chlorophyll a	Dissolved inorganic nutrients (NH_4)	*Stylophora pistillata, S. hystrix*	Increases in chl-a (mg/g protein)	Destructive, symbiont focus, low cost
Density of symbionts	Dissolved inorganic nutrients (NH_4)	*S. pistillata, S. hystrix*	Increases in mean symbiont density (cells/mg protein)	Destructive, symbiont focus, low cost
Lipid content	Turbidity	*Goniastrea retiformis* and *P. cylindrica*	Lower lipid content	Destructive, intermediate cost
Tissue thickness	Light limitation, nutrient availability	*Porites* spp.	Mean tissue thickness (mm) nearshore > offshore	Destructive, intermediate cost
Surface rugosity	Light limitation, nutrient availability	*Porites* spp.	Mean tissue growth (mm/year) nearshore > mid-shelf > offshore	Destructive, intermediate cost
Coral growth	Light limitation, nutrient availability	*Porites* spp.	Mean skeletal density (g/cm^3) offshore > nearshore; Mean extension rate (mm/year) nearshore > offshore. Mean calcification rate (g/cm^2/year) nearshore > offshore	Destructive, intermediate cost
Coral growth	Dissolved inorganic nutrients	*S. pistillata*	Growth rates (mg/day) decreased by 25–60% during long-term nutrient exposure	Destructive, intermediate cost
Skeletal elemental and isotopic composition	Sewage	*Porites lobata*	$\delta^{15}N$ levels greater on reefs with sewage input	Destructive, specific, high cost
Partial mortality	River exposure	*Porites astreoides, Siderastrea siderea, Colpophyllia natans, Montastraea faveolata* and *Montastraea annularis*	Colonies with >50% partial mortality adjacent to river mouths > sites distant	Non-destructive, low cost, *in situ*
Population measures				

Bioindicator	Stressor	Species / Family	Response	Application and suitability to WQ monitoring
Macroalgae	Water quality gradient		Macroalgae strongly and consistently increase in abundance with increasing turbidity.	Non-destructive, low cost, *in situ*
Population structure	Water quality gradient (flood plume exposure)	*Acropora* spp.	High exposure low colony density (0.13/m^2), similar proportion across size classes. Low exposure greater colony density (2.46/m^2), population dominated (>73%) by juvenile size classes.	Non-destructive, low cost, *in situ*
Disease	Dissolved inorganic nutrients	*Gorgonia ventalina, M. annularis and Montastraea franksii*	Increased aspergillosis; and yellow band disease	Non-destructive, low cost, *in situ*
Disease	Dissolved organic carbon	*M. annularis, Agaricia tenuifolia* and *Porites furcata*	Species-specific responses; mortality increased over time	Non-destructive, low cost, *in situ*
Bioeroders	Water quality gradient	*Porites* spp.	Externally visible macro-bioeroders in the surface of living massive Porites corals and many sponges are heterotrophic filter feeders that increase in abundance with increasing loads of suspended food	Non-destructive, low cost, *in situ*
Community measures				
Larval supply and recruitment	Sedimentation	*Acropora digitifera*	Larval survival and settlement reduced in high (100 mg/L) and low (50 mg/L) sediments compared with controls (0 mg/L)	Non-destructive, low cost, *in situ*
Community composition	Water quality gradient	*Acropora* spp.	From reefs near the river to those >80 km (offshore), macroalgae cover river > offshore; octocoral offshore > river; and hard coral cover offshore > river; hard coral taxa offshore > river. *Acropora* percent cover to total hard coral cover ratio.	Non-destructive, low cost, *in situ*
Taxonomic richness	Water quality gradient		Taxonomic richness of hard corals 50% lower in region with high nutrient and sediment loads; decreased octocoral richness but increased macroalgae richness along water quality gradients from low to elevated levels of nutrients and sediments	Non-destructive, low cost, *in situ*, specialist knowledge required for identification > genus level
Max. depth of coral-reef development	Water quality gradient		5.0 m at coastal reefs to 25 m at offshore reefs	Non-destructive, low cost, *in situ*

5 Key water quality drivers

5.1 Sediments and water clarity

Both the concentration and type of suspended particles strongly determine water clarity and benthic irradiance at a given water depth (Fabricius 2011). Small grain particle fractions (clay <4 μm and silt <15.6 μm) remain suspended for prolonged periods, and are therefore more widely distributed, undergoing several cycles of deposition and resuspension. Small grain fractions also carry more bound nutrients and pesticides, absorb more light, and cause greater physiological stress and damage to corals than coarser sediment fractions. A meta-analysis of field- and lab-based approaches inclusive of all coral developmental stages, taxa, and geographic origins, revealed deposited sediment concentrations as low as 1 mg/cm^2/day, and suspended sediment concentrations as low as 3.2 mg/L can adversely affect corals (Tuttle and Donahue 2022). The same metanalysis revealed that physiological responses (e.g., reduced photosynthesis of symbionts) can occur as quickly as 12 h and 1 h after exposure to deposited sediment and suspended sediment, respectively. Lethal responses (i.e., tissue necrosis) occur at deposited sediment concentrations as low as 4.9 mg/cm^2/day and for exposure durations less than one day (22 h). Lethal responses can occur after exposure to suspended sediment concentrations as low as 3.2 mg/L and 12 h. Adults were found to be less sensitive to deposited sediment than immature coral stages; settlement rates significantly decline at 1.3 mg/cm^2/day deposited sediment and greater, and survival of coral juvenile recruits significantly declines at 13.8 mg/cm^2/day deposited sediment and greater.

The duration of sediment exposure regimes therefore has a major influence on associated coral communities and can be classed as: (1) persistent, (2) fluctuating, and (3) transitional (as reviewed in Zweifler (Zvifler) et al. 2021). Persistent turbid reefs are exposed to daily sustained suspended sediment loads above 5 mg/L, or 15 NTU, e.g. Paluma Shoals, a nearshore naturally turbid reef complex situated on the central GBR in Halifax Bay. The coral community is dominated by sediment-tolerant corals (e.g. *Montipora, Turbinaria, Goniopora, Porites, Galaxea, Millepora, Montastraea*) that typically inhabit high-energy settings (wind-wave and tidal currents) and have a high terrigenous sediment composition in their reef matrix (as opposed to calcium carbonate). Reefs considered to be fluctuating are exposed to episodic (daily to monthly) severe suspended sediment (>50 mg/L; >150 NTU) events interspersed by periods of often low turbidity or clear water (<5 mg/L; <15 NTU). The coral community is also dominated by sediment-tolerant corals that inhabit mixed energy settings and have some (but less than persistent) terrigenous sediments in their reef matrix. Transitional reefs exhibit a sustained or stepped change in turbidity over time (annual to decadal), often from clear water, or low turbidity, towards high turbidity levels. These reefs have experienced a recent (<100 years) increase in sediment exposure and will likely show evidence of reef depth compression and loss in coral cover and diversity, although the extent of this will depend on the original baseline and the rate of change in sediment exposure (Zweifler (Zvifler) et al. 2021).

In nearshore turbid reef areas (<10 m depth) at Paluma Shoals (central GBR, Halifax Bay), corals were found to exhibit clear preferences in their depth distributions (Morgan et al. 2016). Massive *Porites* spp. and large stands of foliose *Turbinaria* spp. inhabited deeper reefal areas (1.5 – 4 m lowest astronomical tide [LAT] and 1.5 – 3.5 m LAT, respectively). *Acropora* spp. and *Montipora* spp. dominated shallow water assemblages (<1.5 m LAT) and the relative abundance of encrusting taxa (mostly *Montipora* spp.) increases considerably towards sea level, whereas branching and tabular *Acropora* spp. were found to occupy a normally-distributed range between 0.5 – 2.5 m below LAT (maximum relative cover of 22% at 1 m below LAT). Highest mean coral cover (40 ± 36%) was recorded in shallow waters (<2 m below LAT) and decreased rapidly with depth to 4 m below LAT, closely following light attenuation under low-turbidity scenarios.

The GBR guideline trigger value is established at a maximum mean annual sedimentation rate of 3 mg/cm^2/day, and a daily maximum of 15 mg/cm^2/day (Great Barrier Reef Marine Park Authority 2010). This value is set with a low confidence, as more field data are needed. The value chosen is expected to guard against excessive coral recruit mortality and includes an uncertainty factor for higher organic content or small grain sizes. Hydrodynamic settings determine to what extent ecosystem stress is due to sedimentation and to what extent due to turbidity. In areas of low hydrodynamic energy, stress due to sedimentation will exceed the stress due to light attenuation. At high hydrodynamic energy where sediments tend to remain in suspension, the reverse is true.

5.2 Nutrients

The biological effects of nutrients on corals differ according to nutrient type and bioavailability, its form (i.e., dissolved or particulate), and between organic and inorganic. Dissolved inorganic nutrients (especially phosphate, nitrate, or ammonium) are highly bioavailable and therefore rapidly incorporated into benthic and pelagic food webs (within hours to days), and, thereafter, are found as particulate organic matter (especially as detritus, bacteria, phytoplankton and marine snow) (Fabricius 2011). In contrast, dissolved organic nutrients often occur in relatively high concentrations, with a large proportion not biologically available. Particulate organic matter is dominated by detritus and plankton, while particulate inorganic nutrients (PO_4, NO_x) are readily water soluble and are often bound to suspended sediment grains.

The direct effects of nutrient enrichment on corals primarily relate to altered symbiosis function, which results in lowered bleaching temperature thresholds and lower rates of calcification and growth, whereas indirect effects include altered availability of heterotrophic food sources, macroalgal densities and other space competitors (such as bioeroders), incidence of disease, and COTS outbreaks (Fabricius 2011; reviewed in D'Angelo and Wiedenmann 2014). In a meta-analysis of experimental studies, DIN above 10 µM was shown to have significant implications for reproductive success, as both larval survival and fertilization exhibited negative responses (Nalley et al. 2023).

Across the whole of the GBR, the relationships between the condition of reef biota (macroalgal cover versus coral and octocoral (soft corals, sea pens, sea fans and sea whips) species richness), water clarity and chlorophyll-a (chl-a) abundance were used to model water quality values (De'ath and Fabricius 2010). Critical levels of water quality parameters were considered >0.45 µg/L for chl-a and <10 m secchi disk depth for water clarity. Beyond these levels, macroalgal cover was found to rapidly increase and hard coral and phototrophic octocoral richness declined.

Critically, in the context of global drivers of change, inshore reef areas on the GBR with high run-off exposure risk (exceedance chl-a > 0.9 µg/L), displayed lower resistance to thermal stress during the 2002 and 1998 mass bleaching events and increased risk of bleaching (per unit increase in sea surface temperature, SST), reflecting an averaged lowering in upper thermal bleaching threshold of ~ 1.0 – 1.5 ºC (Wooldridge 2009; Wooldridge and Done 2009). Further, COTS larval development is optimal at 1.0 – 6.5 µg/L chl-a (Wooldridge and Brodie 2015). Reductions in end-of-river DIN concentrations between ~ 20 – 40% were therefore estimated as necessary to ensure the identified chl-a trigger threshold (> 0.8 µg/L) is not exceeded in any given year within the known central GBR COTS initiation zone (primary COTS outbreaks tend to occur on mid-shelf reefs in the north-central, Wet Tropics region) (Wooldridge and Brodie 2015). However, opportunistic COTS larvae may be more resilient to low food levels, with 0.1 µg/L chl-a considered as the critical limit (Wolfe et al. 2017).

5.3 Toxicants

Anthropogenic pollutants, such as pesticides, metals, pharmaceuticals, and sewage, can enter reef ecosystems through point sources (e.g. sewage outfalls), or nonpoint sources (as reviewed in van Dam et al. 2011). The persistence and dispersion of pollutants is dependent on their chemical composition and environmental conditions, such as water residence time and flushing rate. Highly soluble contaminants have the potential to be carried far offshore, and some pollutants may also be transported through the atmosphere and redeposited, impacting areas far from the site of application. The ecological impact of a toxicant is determined by the concentration of the chemical(s) in the environment, the duration and spatial extent of exposure, and the sensitivity of the exposed biota. The biological processes of early life stages of corals, including gamete fertilisation, larval settlement, and recruit survival, are chemically mediated and therefore sensitive to toxicants. Symbiont energy generation can also be negatively impacted by contaminants that target photosynthesis, such as PS II herbicides.

Fundamental data and establishment of water and sediment aquatic ecosystem guideline values for most pollutant groups in the GBR are lacking, most notably for coal, per- and poly-fluoroalkyl substances (PFAS), pharmaceutical, veterinary, and personal health care products and sunscreens (Chariton and Hejl 2024). This prevents any reliable assessment of spatial patterns, temporal trends, or exposure risk for ecosystems and biota. A systematic review and meta-analysis of chemical pollutants from land-based and atmospheric sources, comprising 13 metals, 18 pesticides, 5 polycyclic aromatic hydrocarbons (PAHs), a polychlorinated biphenyl (PCB), and a pharmaceutical, could not estimate thresholds for most combinations of pollutants and responses (Nalley et al. 2021). This was due to the diversity of pollutants, coral responses, and experimental approaches of the studies reviewed. Compared to metals and pesticides, the impacts of PAHs, PCBs, and pharmaceuticals on corals are considered even more understudied. However, within those studies that do exist, there is variability in the impacts to corals among life stages. Antifouling paints, coal dust and particles, heavy/trace metals and metalloids, marine debris, microplastics, pharmaceuticals, personal care products (PPCP), and petroleum hydrocarbons are all known to be present in the marine environment around the GBR, but are not routinely monitored (Kroon et al. 2020).

The ANZG is undertaking a rolling program of toxicant guideline updates for a range of industrial pollutants, pesticides and metals, across different water media (fresh, marine). This is either updating older (e.g. ANZECC 2000) guideline values, or deriving new toxicant guidelines for which no national water quality guidelines have previously existed. Refer to the ANZG website for further information. Accordingly, this report does not seek to develop aquatic ecosystem water quality guidelines for these toxicants.

6 Characteristics of Hervey Bay, GSS, and Burnett-Baffle Coast

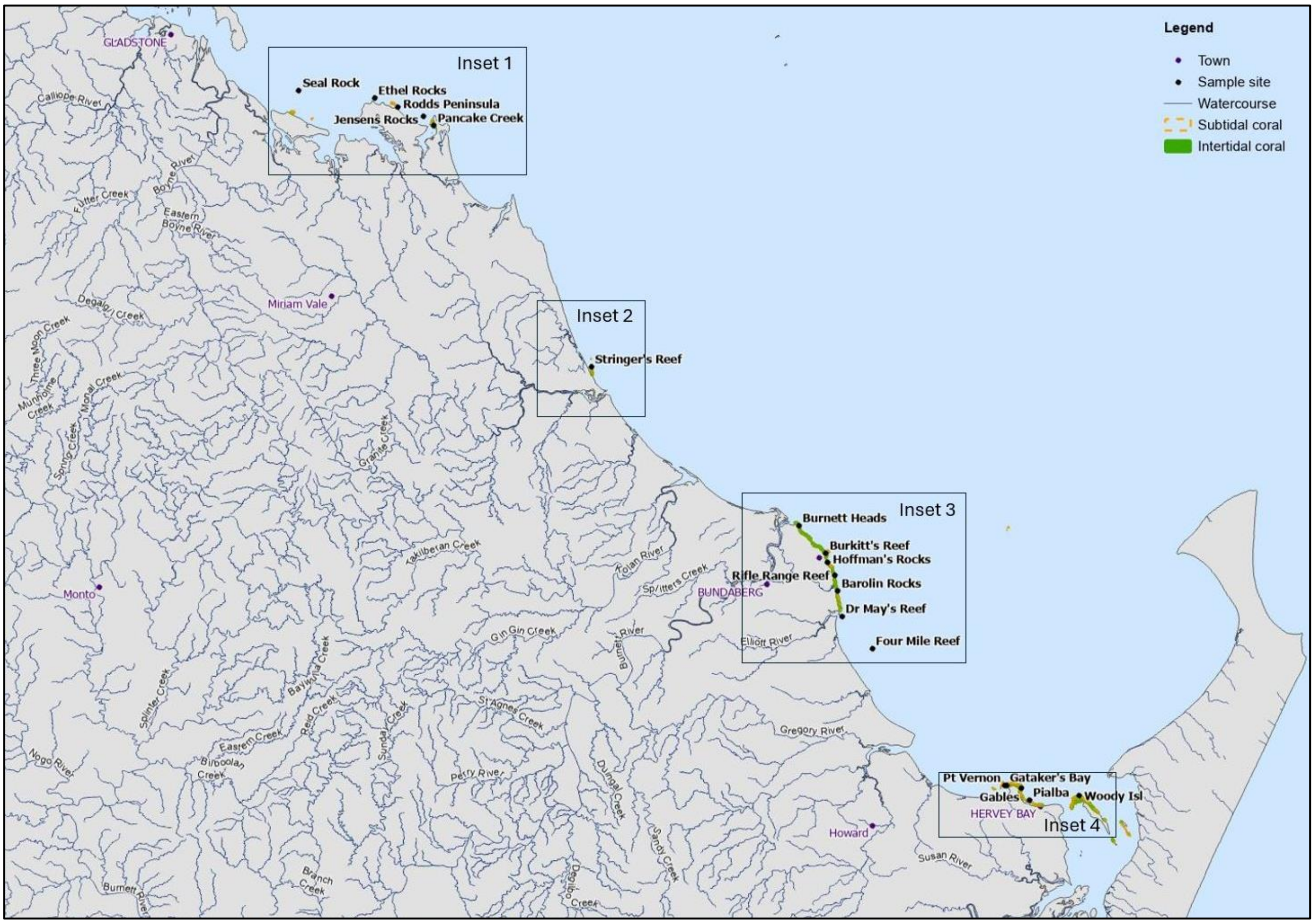
6.1 Coral sites of interest

Inshore coral habitats extend intermittently from the coastlines around Bundaberg, Woodgate, Burrum and Woongarra, down to Hervey Bay and the northern GSS (Figure 3). In the northernmost regions of the project area in the Baffle catchment (located inshore of the GBR Capricorn Bunker group), only a few known coral communities have been surveyed amongst the wider extent of rocky coastline. Mapped coral habitats and their full descriptors are provided in the Intertidal and Subtidal Ecosystems Mapping of Central Queensland. These habitats include intertidal coral (consolidation unassigned), and subtidal coral habitats (hard branching/ hard non-branching/ undifferentiated/ soft corals on consolidated/ unconsolidated substrates in shallow to deep water).

Annual monitoring has been conducted at 14 coral sites within the study area between 2019 to 2023 by Gidarjil Land and Sea Rangers (Gidarjil). Monitoring comprises surveys of coral cover, diversity, and recruitment, with methods closely resembling AIMS LTMP. Sites are located in four main areas (Figure 3), from the mouth of the Burnett River in the north, down to Four Mile Reef; and around Hervey Bay in the south.

Coral sites in the study area have also been surveyed intermittently, using a range of approaches by groups including: the regional Natural Resource Management (NRM) body (Burnett Mary Regional Group, BMRG), Butchulla Aboriginal Corporation, Banjima Native Title Aboriginal Corporation (BNTAC), and consultants. Unfortunately, much of this data is unpublished and/or not publicly accessible and, with losses of institutional memory, are increasingly challenging to access and utilise. Most research focus has been on a limited number of key sites around the Burrum River (Burkitt's Reef, Four Mile Reef, Barolin Rocks), and centred around Point Vernon, and Big Woody Island within Hervey Bay and the GSS (Zann 2012; Butler et al. 2013a, 2015a; Sommer et al. 2021).

Seven inshore sites in the Baffle Creek (Ethel Rocks, Pancake Creek and Stringer's Reef) and Burrum catchments (Barolin Rocks, Four Mile Reef, Pt. Vernon West and Pialba) have been surveyed as part of BMRG Reef System Repair Programs (2016 - 2018) (Project C160004) (Butler 2018). BMRG coral monitoring data (mainly single surveys conducted prior to 2010) and other relevant studies prior to 2014 are summarised in 'Status of Coastal and Marine Assets in the Burnett Mary Region' (Coppo et al. 2014). Citizen science, Reef Check Australia surveys have also been conducted in the GSMP, the most recent in June 2017, at six sites (Barolin Rocks, Burkitt's Reef, Big Woody Island, ESA Park, Gatakers Reef West, Round Island) (Welch, M., Salmond, J., Passenger, J., and Loder 2017).


Legend
Town
Sample site
Watercourse
Subtidal coral
Intertidal coral
GLADSTONE
Inset 1
Seal Rock
Ethel Rocks
Rodds Peninsula
Jensens Rocks
Pancake Creek
Calliope River
Boyne River
Futter Creek
Eastern Boyne River
Miriam Vale
Degalgil Creek
Three Moon Creek
Munholme Creek
Monal Creek
Spring Creek
Granite Creek
Inset 2
Stringer's Reef
Inset 3
Burnett Heads
Burkitt's Reef
Hoffman's Rocks
Rifle Range Reef
Barolin Rocks
Dr May's Reef
Four Mile Reef
BUNDABERG
Elliott River
Kolan River
Splitters Creek
Yandaran Creek
Monto
Gin Gin Creek
Burnett River
Splinter Creek
Baywulla Creek
Reid Creek
Eastern Creek
St Agnes Creek
Sunday Creek
Nogo River
Biroolan Creek
Perry River
Gregory River
Pt Vernon
Gatakers Bay
Gables
Pialba
Woody Isl
HERVEY BAY
Inset 4
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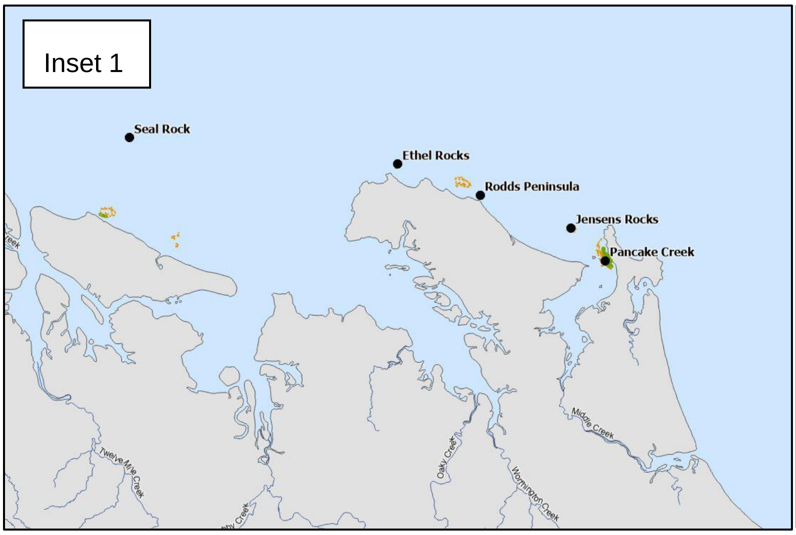
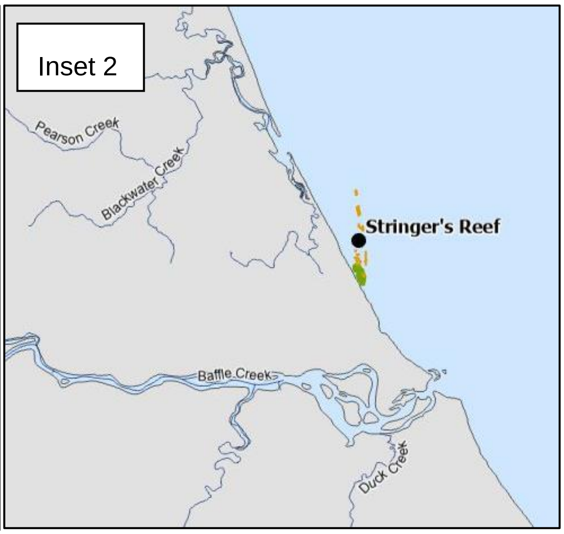
Burnett River
Degilbo Creek
Sandy Creek


Inset 1
Seal Rock
Ethel Rocks
Rodds Peninsula
Jensens Rocks
Pancake Creek
Middle Creek
Twelve Mile Creek
Oaky Creek
Worthington Creek


Inset 2
Pearson Creek
Blackwater Creek
Stringer's Reef
Baffle Creek
Duck Creek

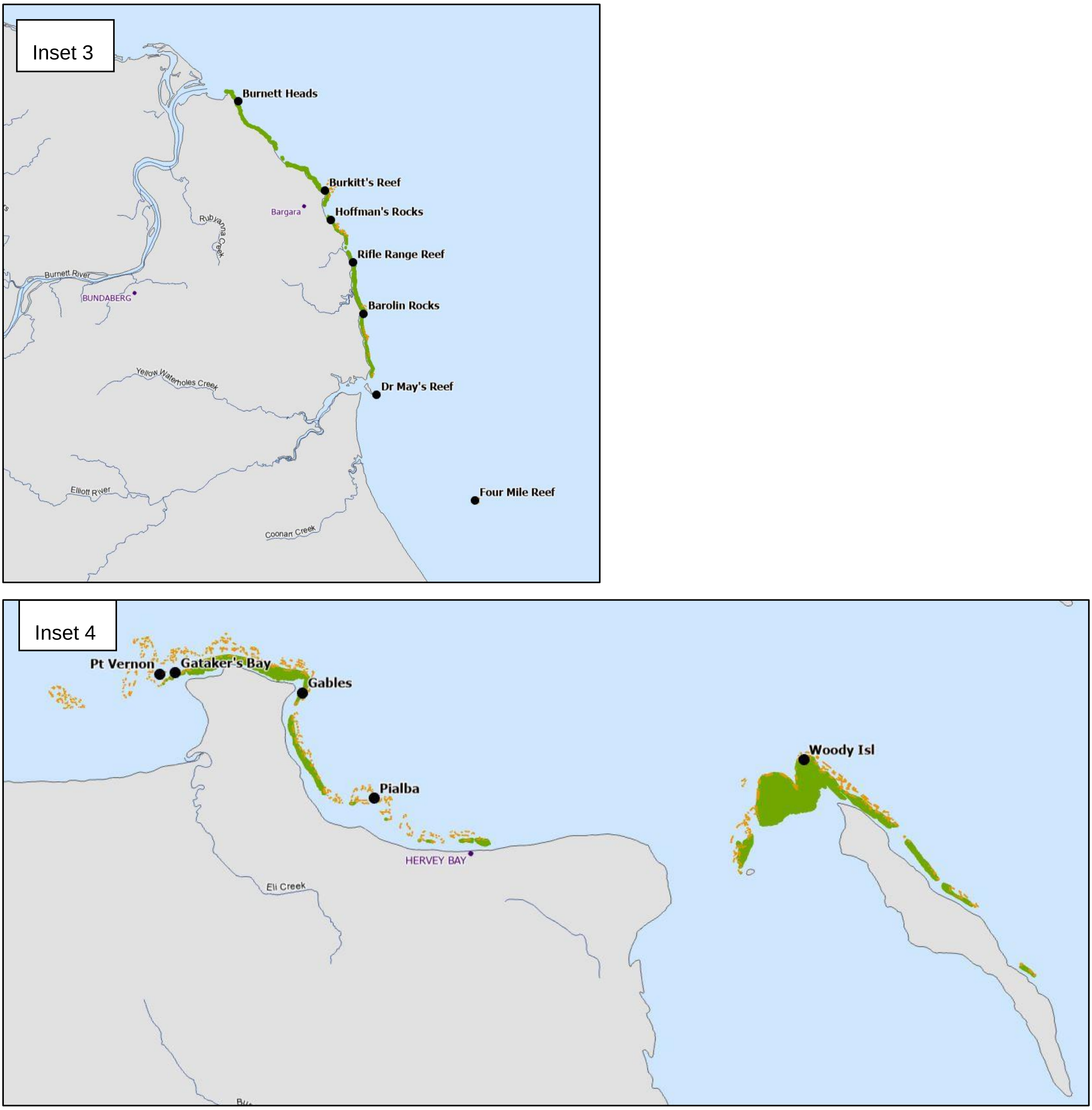


Figure 3 Coral habitats and recently monitored sites in the project area

6.1.1 Habitat types and condition

Inshore coral habitats in the study area are typified by exposure to a range of environmental conditions (e.g. wind/wave driven hydrodynamic energy, slope angle, depth, substrate consolidation, grain size and composition), and water quality (e.g. proximity to mainland, river mouths and flood events), and include both subtidal and intertidal examples. As high-latitude coral habitats, species composition includes tropical, sub-tropical and temperate examples. Sites recently surveyed within GSMP between 2019 and 2023 were characterised by moderate coral diversity (Olds et al. 2024). Coral dominance at reef sites was considered high, with individual reefs characterised by different genera, 19 of hard coral and 17 of soft coral. Live hard coral cover varied between reefs (exact data not reported, e.g. approximately 10% at Barolin Rocks, to 60% at Four Mile), and considered lower than GBR inshore reefs, but comparable to those of the Sunshine Coast and Moreton Bay Marine Park. Densities of juvenile corals also varied spatially, but densities of juvenile corals were considered low (exact data not reported), indicating limited potential recruitment success (Olds et al. 2024). Assessing hard and soft coral indicators resulted in an overall reef condition index score from 0 to 1 for each site, with the highest condition index (0.7) at Barolin Rocks, Hoffmans, Gatakers and Woody Island South. In contrast, Woody Island North and Eliott returned the lowest scores (0.4) of assessed sites.

Strong spatial variation in hard and soft coral cover, species dominance, diversity, and juvenile density was detected along persistent water quality gradients, from exposure to riverine plumes with associated sediment and nutrients (Olds et al. 2024). In the north, coral habitats ranged from those dominated by fast growing, branching corals at Pancake Creek (*Acropora*), and a variety of hard and soft coral taxa (Ethel Rocks), to those dominated by abundant macroalgae with a variety of hard coral taxa (Rodds Peninsula, Seal Rocks). Further south, three sites were dominated by hard coral cover, each with different dominant groups, Four Mile (*Pocillopora*), Pialba (*Turbinaria*) and Point Vernon (*Goniopora*). Remaining sites were largely dominated by soft corals, with some hard corals present. *Acropora* is typically considered a clear water specialist, as such it is usually confined to shallow, oligotrophic waters, located further offshore. Many species of *Pocillopora* are considered weedy and are able to rapidly recolonise areas following disturbance events, whereas *Turbinaria* and *Goniopora* are typically turbid generalists, and are highly successful at colonising sheltered habitats, exposed to higher levels of sedimentation and large fluctuations in turbidity (Darling et al. 2012).

Coral traits along spatial gradients of water quality at Hervey Bay coral sites were also recently examined (Sommer et al. 2021). Gradients of distance from the mainland and the Mary River were observed in species and functional composition, patterns in functional diversity, and trait abundance. These gradients persisted through time and were unaffected by recent flooding events. Nearshore reefs within Hervey Bay (Pialba, Point Vernon East, and West) were considered less functionally diverse, with co-occurring species more similar in their traits than expected by chance. The genera's *Goniopora, Turbinaria, Psammocora, Astrea*, and *Goniastrea* were more abundant at reefs closer to the mainland and closer to rivers, while *Acropora, Pocillopora*, and *Montipora* were more abundant further offshore. Species with foliose growth, large corallites, strong sediment-clearing ability, and those having separate sexes were more abundant at reefs closer to the mainland and to rivers. Hard coral species with poor ability to remove sediment, branching morphology, small corallites, fast development rates, hermaphroditic sexual pattern, brooding reproduction, and vertical symbiont transmission were associated with reefs more distant from the mainland and from rivers.


Figure 4 Examples of key coral genera in the study area, subtidal Turbinaria sp. (left); and intertidal Acropora sp. (right) (photographs courtesy of Maria Zann)

Surveys conducted during 2016 - 2018 in the Baffle sub-region at Ethel Rocks, Pancake Creek, and Stringer's Reef revealed a diverse array of communities (Butler 2018). Surveyed sites included low relief, encrusting, and diverse communities (40 hard and soft coral taxa) at Ethel Rocks, to lower diversity (19 taxa) but abundant communities located within the estuary at Pancake Creek, and those adjacent to Baffle Creek at Stringer's Reef, which supported much lower abundance and diversity (ca. 10% coral cover and 5 taxa) (Butler 2018).

Earlier surveys of inshore coral habitats in proximity to Hervey Bay by DeVantier (2010) described incipient reefs (i.e. with no apparent significant reef accretion present), mainly in subtidal patches. Living hard coral cover at these sites typically ranged between ca. 20 – 40%. Considerable partial mortality was observed on many corals, particularly the larger (older) colonies, which was attributed to sedimentation, overgrowth (e.g. by algae and encrusting fauna species), disease, and bleaching (DeVantier 2010) (Table 44). However, these sites were considered of significant ecological interest and value, with the richest individual site at Woody Island (31 species of hard coral) (DeVantier 2010). More extensive mapping revealed well-developed reefs (*sensu* van Woesik and Done 1997) at Pialba and eastward adjacent to the mainland (Zann 2012). The coral habitats at Gataker's Bay and Point Vernon were also considered notable for their high diversity and percentage coral cover (e.g. >85% from Gataker's Bay westward) (Zann 2012).

Table 4 Key characteristics of coral habitat sites surveyed around Hervey Bay (amended from DeVantier 2010)

Site name	Max depth (m)	Visibility (m)	Hard coral (% cover)	Dead hard coral (% cover)	Macroalgae (% cover)
Gatakers Bay	3	3	20	5	5
Point Vernon	3	3	30	5	5
Woody Island	6	4	30	3	2
Little Woody Island	15.5	4	10	2	1
Gables	4	3	30	5	1
Gatakers West	2	2	25	10	3
Gatakers West offshore	6	2	40	15	0
Point Vernon North	3	3	25	5	1

6.2 Water quality

6.2.1 River catchments

Water quality in the project area is primarily influenced by discharges from the Mary River to the south, and Burrum, Burnett, Kolan, and Elliott rivers to the north. Land use is dominated by grazing, forestry, and conservation, with areas of horticulture, sugarcane, and other cropping along the coastal floodplains of the Burnett and Mary rivers, and in smaller coastal catchments including the Burrum, and Baffle basins. Documented water quality issues in the region are typical of those affecting other GBR catchments, primarily TSS from grazing and stream bank erosion, dissolved nutrients from sugarcane, horticulture and urban land uses, and herbicides from sugarcane, horticulture, and cropping land uses, in addition to coastal development (Burnett Mary WQIP, 2019). Major coastal towns of the project area include Bundaberg, Hervey Bay, and Maryborough. The Mary River remains one of the highest priorities for the reduction of fine sediment and particulate nutrients in GBR catchments, with Reef 2050 Water Quality Improvement Plan 2025 water quality targets for end-of-catchment anthropogenic load reductions for fine sediment and particulate nutrients (high priority, 20%), DIN (moderate priority, 50%), and for pesticides to protect at least 99% of aquatic species (low priority) (end of basin load targets are under review at the time of writing, in accord with provisions of the *Environmental Protection Act*). The greatest risk posed to coral reefs from degraded water quality is considered to be from the Mary basin, followed by the Burrum and Burnett basins (Waterhouse et al. 2014)

Under the GBR Catchment Loads Monitoring Program (GBRCLMP) sediment, nutrient, and pesticide loads are also regularly monitored for GBR catchments and South East Queensland by Water Quality and Investigations, with data reported to Tahbil - Water Quality Data Portal. In terms of nutrients and sediment, for the most recent reporting period available (2020 – 2021), dry conditions persisted across the Burnett Mary region throughout, following on from much below-average rainfall in 2019 – 2020. This contributed to river discharge in all monitored catchments being below average, ranging from 1% of the long-term mean annual average in the Gregory River, to 21% in the Mary River. The Burnett River (120 GL), Gregory River (0.96 GL), Mary River (280 GL) and Tinana Creek (20 GL) end-of-catchment sites, all recorded their lowest discharge values since they have been monitored as a part of the GBRCLMP. The Gregory River and Tinana Creek sites have not exceeded their long-term mean annual average discharge since GBRCLMP monitoring began in 2018 – 2019, and 2013 – 2014, respectively. The Burnett River last exceeded its long-term mean annual average discharge in 2012 – 2013, and the Mary River in 2017 – 2018. Estimated end of catchment loads for TSS reflected the below-average rainfall experienced in the Burnett-Mary region during the period, <0.01 t/km^2 for the Burnett River, and 1.5 t/km^2 for the Mary River. Low river discharges were also reflected in low nutrient loads observed in the period, including dissolved inorganic nitrogen (DIN), Gregory River (0.15 t), Burnet River (2.7 t), and Mary River (52 t). Particulate phosphorus yields for the Burnett Mary region were among the smallest produced for this region since monitoring commenced. All four end-of-catchment sites in the region recorded their smallest estimated yield of particulate phosphorus, between 0.086 kg/km^2 in the Burnett River, and 2.6 kg/km^2 in the Mary River.

Pesticide targets under the Reef 2050 Water Quality Improvement Plan aim to reduce the risk posed by pesticides to aquatic organisms, with at least 99% of aquatic species protected at the end of catchment. The targets are ecologically relevant for the GBR and are necessary to ensure that broadscale land uses have no detrimental effect on the reef's health and resilience. The general policy framework for pesticides is to apply 99% species protection to reef waters and other waters identified as slightly disturbed (SD) or high ecological value (HEV). This highest species protection (99%) is also recommended under the ANZG framework for particular toxicants where bioaccumulation/biomagnification potential exists. For moderately disturbed waters, 95% species protection guidelines (PC95) is typically applied, however variations may apply according to local circumstances. Concentrations of 24 reference pesticides measured in water samples collected from GBRCLMP monitoring sites are used to calculate the daily percentage of species affected. Analysed pesticides include chlorpyrifos, fipronil, imidacloprid, haloxyfop, imazapic, metsulfuron-methyl, pendimethalin, metolachlor, ametryn, atrazine, terbuthylazine, tebuthiuron, simazine, diuron, terbutryn, hexazinone, metribuzin, 2,4-D, MCPA, fluroxypyr, triclopyr and isoxaflutole. Analysed pesticides include a range of groups including PSII inhibitors, insecticides, and herbicides with alternative modes of action. These data are then transformed to an average percentage of species protected in the aquatic ecosystem over a standardised wet season, termed the Pesticide Risk Metric.

The Pesticide Risk Metric is an estimate of the proportion of the aquatic ecosystem that is protected (or affected), from direct effects of pesticides expressed as a percentage. The most recent risk metric data reported are for the 2021 – 2022 period, with current and historically monitored sites located at Mary River (Churchill Street, Maryborough), Burrum River (Buxton boat ramp; historic, ceased in 2019), Gregory River (Jarrett's Road), Elliott River (Riverview boat ramp; historic, ceased in 2019), Burnett River (Quay Street Bridge, Bundaberg) and Baffle Creek (Newton Road; historic, ceased in 2019). Data is available at WQI Pesticide Reporting Portal. At current monitoring locations between 2017 – 2022, metolachlor (herbicide, very long chain fatty acids (VLCFA) synthesis inhibitor), consistently presented the greatest single risk to species at approximately 2%, followed by diuron (~ 1%; PSII inhibitor), and atrazine (~ <1%; PSII inhibitor), though this varied both temporally and spatially across sites. The cumulative risk of total pesticides also varied between sites and years, however on average the greatest risks to species in the region were at the Gregory River (~ 5%), the Mary River (~ 4%), and finally the Burnett River (~ 3%). Concentrations reported of individual pesticides between 2018 – 2023 typically fell below the relevant guideline level (95% species protection guidelines for moderately disturbed, PC95; ≥99% species for high ecological value and slightly disturbed). However, at the Gregory River site, recent levels of metolachlor have significantly exceeded this level (PC95 0.46 µg/L) on three occasions, most recently in November 2022 at 1.9 µg/L. In contrast, levels of diuron have exceeded this level (PC95 0.20 µg/L) on 10 occasions over the period, the highest being recorded in February 2022 at 0.47 µg/L.

Sampling of surface waters and sediment within seagrass habitats in Hervey Bay and the GSS, in addition to the Mary, Burrum, and Gregory rivers have been conducted over low, moderate, and high flow events between April 2002 and February 2004 (McMahon et al. 2005). Sampling revealed multiple herbicides associated with water and sediment. Diuron was the most abundant and widespread, exceeding marine water PC95 (0.59 µg/L) and PC99 (0.27 µg/L) within surface waters of the GSS catchment on one occasion at Pine Drain (Table 5). Default guideline values are not currently available for pesticides in sediment, and in some instances for seawater (as is the case for atrazine), however relatively high values for diuron were also observed within sediments in the Mary River and Hervey Bay (Table 6).

Table 5 Herbicide composition and concentration in surface waters following a rainfall event and moderate river flow in February 2003 and 2004, orange highlights indicate exceedance of marine water PC95/PC99 (adapted from McMahon et al. 2005)

Site	Date	Herbicide concentration (µg/L)				
		Diuron	Atrazine	Simazine	Flumeturon	Total
Burrum Heads	9-Feb-04	nd	nd	nd	nd	nd
Great Sandy Strait catchment						
Big Tuan Creek	6-Feb-03	0.05	0.01	nd	nd	0.06
	8-Feb-04	nd	nd	0.355	nd	0.355
Pine Drain	6-Feb-04	0.875	0.02	nd	<0.005	0.895
Booral (SG)	9-Feb-04	0.05	0.01	0.01	nd	0.07
Boonoroo (SG)	8-Feb-04	0.01	<0.005	0.025	nd	0.04
Kauri Creek (SG)	11-Feb-04	0.01	<0.005	0.01	nd	0.025
Mary River estuarine sites						
Upper Mary River	19-Feb-03	0.025	<0.005	0.045	nd	0.07
Maryborough	10-Feb-04	0.035	<0.005	0.025	nd	0.065
Hervey Bay						
Urangan (SG)	8-Feb-03	0.02	0.01	0.005	nd	0.035
nd = not detected. SG= seagrass site						

Table 6 Sediment herbicide concentrations of diuron and atrazine in April and December 2002 (adapted from McMahon et al. 2005)

Site	Herbicide concentration (µg/kg dry weight sediment)			
	Diuron		Atrazine	
	April	Dec	April	Dec
Burrum Heads	nd	nd	1.1	0.4
Mary River estuarine site				
Upper Mary River	0.4	1.5	nd	nd
Great Sandy Strait catchment				
Booral (SG)	0.1	nd	nd	0.4
Hervey Bay				
Lower Hervey Bay	–	nd	–	0.4
Dundowran (SG)	nd	0.2	nd	0.2
nd = not detected, − = no sample collected, SG= seagrass site				

6.2.2 Hervey Bay and the Great Sandy Strait

Hervey Bay is a large, shallow, coastal embayment, and considered inverse/hypersaline, with air temperature, wind direction and tidal regime responsible for salinity gradients in the bay (Gräwe et al. 2009, 2010). A recent drying trend, associated with droughts (1941 – 2000) and water extractions, has strengthened the inverse circulation and salinity flux out of the bay, with a reduction of precipitation by 13% and a reduction in river discharge by 23% (Gräwe et al. 2009, 2010). The Great Sandy Strait Ramsar Site is a sand passage estuary between the mainland and K'gari. Most of the area has saline water, although permanent or seasonal flows of fresh water occur into most estuaries in the system. Large inputs of fresh water and sediment occur during flooding relatively regularly, recent moderate/major flood events of the Mary River occurred in February 1992 and 1999, January 2011 and 2013, February 2013, January 2022, and February – March 2022.

The export of the freshwater (and associated contaminants) is strongly affected by the wind conditions at the time of the event; the 1992 and 1999 floods resulted in riverine freshwater flow restricted to an approximated 10 – 15 km narrow band along the western shore of Hervey Bay (Gräwe et al. 2010). The return in water quality to a pre-flood state had a typical decay time of 22 days, similar to a flushing time for the western bay due to SE winds. Northward through-flow in the GSS prevented an outflow of the Mary River discharge into the southern region of the strait, which pushes riverine water into the bay. In contrast, during more minor floods in 2008, fresh water remained in the northern part of the strait due to light winds (3 m/s). In this case, saline water in the bay acted as a barrier, preventing the transport of the fresh riverine water into Hervey Bay.

Modelling to assess potential contaminant mobilisation and hydrodynamics from the Mary River to receptors in the GSS, indicates that contaminants can remain localised to the Mary River for extended periods (weeks – months), under low wind and flow conditions (Johnstone et al. 2021). Winds (notably SE) coupled with high flows, have the potential to substantially reduce the residence time within the GSS, whereas NE winds may lead to longer residence times at the mouth of the Mary River and to the west of Big Woody Island. Under low flows, tidal processes are predominately responsible for most water movement and, consequently, sediments and associated contaminants originating from the Mary River are localised to the immediate region surrounding the river mouth.

6.2.3 Estuarine and coastal water quality

Monitoring of physical and chemical water quality indicators has been conducted since 1993 at multiple estuarine and coastal sites relevant to the study area under the Central Queensland Ambient Monitoring Program. Program details and data are available at: Water quality data and assessments. Monitored sites include the key rivers (Burnett, Gregory, Burrum, Mary, Elliott), Baffle Creek, Hervey Bay (a single point at Urangan jetty), and throughout the GSS (northernmost at East Woody Island). However, monitoring of the Elliott River ceased in 2010. These data provide a strong contextual background for ambient water quality conditions for key indicators in estuarine and river surface waters relevant to the wider study area. However, not all indicators are currently measured; notably, recent data for TSS, TN, and TP are lacking owing to sampling cost restraints.

For each catchment, a summary of key water quality indicator median values at 0.2 m depth are presented under typical conditions (1993 – 2023), and compared with Water Policy WQO, or draft objectives under the Burnett Mary WQIP plan (Table 7). As outlined in Section 7.1 and as per Australian & New Zealand Guidelines for Fresh & Marine Water Quality (ANZECC, 2000), for high ecological value (HEV) systems the management intent is no change to natural values. In this context, 'no change' means there should be no change to the natural range of values of any given indicator. For slightly to moderately disturbed systems, the median indicator value should be between the $20^{th}/80^{th}$ percentile of reference range. Estimated median values ≤$20^{th}/80^{th}$ percentile are highlighted in green; values ≤$80^{th}/20^{th}$ percentile orange; no set objective yellow; ↑/↓ indicate significant time trends in the median value of an indicator during the period.

Table 7 Summary of key water quality indicator median values at 0.2 m depth (1993 – 2023) by stream, and Water Policy WQO, or draft objectives under the Burnett Mary WQIP plan

Baffle Creek (HEV, Lower Estuary)	**Median ambient (low flow)**	**Min and Max (all flows)**	**WQIP draft objective to protect EV (20th, 50th, 80th)**
Turbidity (NTU)	↓2.55	0 – 136	2 – 3 – 5
TSS (mg/L)	10*	2.5 – 58.2*	No objective
Secchi depth (m)	2.4	0.05 – 4	1.3 – 2.0 – 2.5
Chl-a (µg/L)	↓0.73	0.1 – 22.0	1 – 1 – 2
TN (µg/L)	120	20 – 1900	110 – 130 – 170
TP (µg/L)	↓10	0 – 90	6 – 9 – 13
Temperature (°C)	↑24.63	16.6 – 31.2	No objective
Pesticides	ND	ND	No objective
* Indicates a limited and/or lack of recent data; ND No data for this site; # no set objective			

Burnett River (Slightly to moderately disturbed, Lower Estuary)	**Median ambient (low flow)**	**Min and Max (all flows)**	**WQIP draft objective to protect EV (20th, 50th, 80th)**
Turbidity (NTU)	3.1	0 – 232	<6
TSS (mg/L)	ND	ND	<15
Secchi depth (m)	↑1.85	0.05 – 7.2	>1.5
Chl-a (µg/L)	0.9	0.1 – 8.3	<2
TN (µg/L)	ND	ND	<200
TP (µg/L)	ND	ND	<20
Temperature (°C)	↑23.8	15.5 – 30.1	No objective
Pesticides	ND	ND	No objective
* Indicates a limited and/or lack of recent data; ND No data for this site; # no set objective			

Burrum River (Lower Estuary, BE1)	**Median ambient (low flow)**	**Min and Max (all flows)**	**WQO to protect EV (20th, 50th, 80th)**
Turbidity (NTU)	↓2	0 – 153	1 – 2 – 4
TSS (mg/L)	5.8*	1.87 – 14.2*	4 – 9 –13
Secchi depth (m)	2	0.05 – 3.8	1.8 – 2.9 – 4.3
Chl-a (µg/L)	0.88	0.1 – 45.3	0.6 – 0.8 –1.3
TN (µg/L)	ND	110 – 1000*	110 – 150 – 160
TP (µg/L)	ND	0 – 50*	6 – 10 – 14
Temperature (°C)	23.6	15.7 – 29.7	No objective
Pesticides	ND	ND	As per AWQG (2000)
* Indicates a limited and/or lack of recent data; ND No data for this site; # no set objective			

Mary River (Lower Estuary, GSS1)	Median ambient (low flow)	Min and Max (all flows)	WQO to protect EV (20th, 50th, 80th)
Turbidity (NTU)	↓4	0 – 451	1 – 2 – 4
TSS (mg/L)	ND	ND	4 – 9 –13
Secchi depth (m)	↑1.8	0.05 – 4.6	1.8 – 2.9 – 4.3
Chl-a (µg/L)	↓1.14	0.1 – 24.9	0.6 – 0.8 –1.3
TN (µg/L)	ND	110 – 1500*	110 – 150 – 160
TP (µg/L)	ND	10 – 310*	6 – 10 – 14
Temperature (°C)	23.99	15.9 – 30.1	No objective
Pesticides	ND	ND	As per AWQG (2000)
* Indicates a limited and/or lack of recent data; ND No data for this site; # no set objective			

Hervey Bay (HB1)	Median ambient (low flow)	Min and Max (all flows)	WQO to protect EV (20th, 50th, 80th)
Turbidity (NTU)	2	0 – 55	0 – 1 – 2
TSS (mg/L)	8.6*	2.4 – 23.6*	2 – 4 –11
Secchi depth (m)	↓2.8#	0.15 – 11	No objective
Chl-a (µg/L)	0.7	0.1 – 5.6	0.5 – 0.6 – 0.8
TN (µg/L)	120*	40 – 330*	110 – 130 – 150
TP (µg/L)	10*	0 – 50*	6 – 10 – 14
Temperature (°C)	↑23.78	15.5 – 29.4	No objective
Pesticides	ND	ND	As per AWQG (2000)
* Indicates a limited and/or lack of recent data; ND No data for this site; # no set objective			

GSS (GSS1)	Median ambient (low flow)	Min and Max (all flows)	WQO to protect EV (20th, 50th, 80th)
Turbidity (NTU)	↑1	0 – 24.5	1 – 2 – 4
TSS (mg/L)	4.1*	2 – 12.8*	4 – 9 –13
Secchi depth (m)	↓4.5	0.5 – 14.5	1.8 – 2.9 – 4.3
Chl-a (µg/L)	↓0.6	0.1 – 5.4	0.6 – 0.8 –1.3
TN (µg/L)	120*	30 – 680*	110 – 150 – 160
TP (µg/L)	10*	0 – 60*	6 – 10 – 14
Temperature (°C)	↑24.16	16.4 – 28.9	No objective
Pesticides	ND	ND	As per AWQG (2000)
* Indicates a limited and/or lack of recent data; ND No data for this site; # no set objective			

Under typical conditions, upward and downward trends through time were observed in indicators relevant to both local/regional and global scale stressors. Of the measured indicators, temperature showed the most widespread and consistent change over the 30-year monitoring period. Significant annual temperature increases were observed at these monitored sites in the Burnett River (0.2%), Baffle Creek (0.2%), Elliott River (0.3%), GSS (0.2%), and Hervey Bay (0.2%).

Annual changes in water clarity were also observed over the monitoring period, improving at the slightly to moderately-disturbed Burnett River site (1%). Improvement was also observed at the Mary River site (1.3%), coupled with a decline in turbidity (-2.8%) and chl-a (-1.5%). In contrast, the Hervey Bay site saw declining annual trends for water clarity (-0.8%), coupled with a decline in specific conductivity (-0.04%). At East Woody Island in the GSS, a declining annual trend in clarity (-0.7%) and specific conductivity (-0.03%) was also observed, coupled with an increasing trend for turbidity (+2.5%). Larger annual declines in specific conductivity were estimated when high-flow data are also included for GSS and Hervey Bay. This trend of declining specific conductivity is also apparent across additional monitored sites further south of the study area throughout the GSS (Figure 5). As such, these relatively long-term changes could be associated with localised alterations in freshwater inputs into GSS and Hervey Bay under typical conditions, and more frequent and severe flood events during the period. Major flood events have occurred in the region in 2021-2022, 2012-2013, and 2010-2011 (See Appendix, Stream Discharge for discharge plots available for nearby streams).

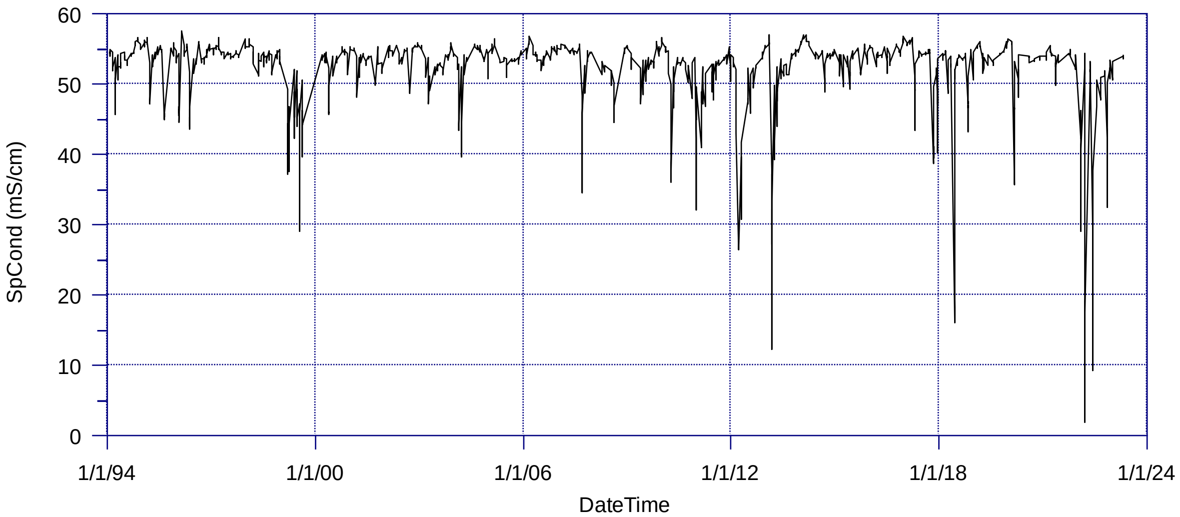


Figure 5 Change in specific conductivity with time across monitored sites in the GSS (all flows)

6.2.4 Coral site water quality

An initial three years of water quality surveys have been conducted alongside coral surveys at 15 coral sites within GSMP between November 2020 – 2022 by Gidarjil, six times per year. At each site, physicochemical parameters including temperature, conductivity, salinity, dissolved oxygen, pH, turbidity, chl-a, and phycocyanin have been measured *in situ*. Measurements were taken at ~ 1 m depth, and 1 m above the seabed. Water samples were also collected for physical and chemical analyses, including TSS, chl-a, and dissolved, particulate, and total nutrients. An independent review noted some quality issues related to the methods applied, however these data do offer useful baseline information and enabled the calculation of preliminary report card scores for water quality though with a high degree of uncertainty (Thompson et al. 2023). Program improvements were proposed, and these data should be viewed as preliminary.

Report card scores were based on comparison to adjacent Water Quality Objectives (WQO) under the Water Policy (expressed as 20th, 50th, 80th percentiles), based on management intent and desired state of the water type to which annual median or mean values are compared. Sites range from high ecological value (HEV), slightly to moderately disturbed (SMD) and moderately disturbed (MD), in enclosed coastal and open coastal water types. Scores for the Baffle sub-region were 'Very Poor' or 'Poor' in all three years for all indicators except turbidity (Thompson et al. 2023). The Burrum region had a mix of scores, but the majority were 'Moderate', 'Good', or 'Very Good'. This large sub-regional difference is mainly due to the large differences in WQO available for the Baffle and Burrum sub-regions (e.g., Baffle is being scored against much more stringent values than Burrum), rather than actual *in situ* water quality differences during monitoring. Overall regional scores generally ranged between 'Poor' and 'Good'. Flood events during 2021 - 2022 water years (1 Sept to 31 Aug the following year) were evident in overall scores for turbidity and TSS, which both scored 'Poor' in this year in contrast to higher scores in 2020 - 2021 and 2022 - 2023, chl-a scores were 'Moderate' in 2021 - 2022 and improved to 'Good' in 2022 - 2023.

GBR Water Quality Guidelines describe the concentrations and trigger values for chl-a, water clarity, sediment, particulate nutrients, and pesticides that have been established as necessary for the protection and maintenance of marine species and ecosystem health of the GBR in various water types (Great Barrier Reef Marine Park Authority 2010). If exceeded, these trigger values (TV) identify the need for management responses. Of these indicators, chl-a and TSS were measured during monitoring at the coral sites. At the two sites in enclosed coastal waters, annual mean values for chl-a did not exceed the GBR trigger value (TV 2 µg/L ; Table 6). However, the TV for TSS (TV 15 mg/L) was exceeded in flood years at Seal Rock in 2021 - 2022 ($\bar{x}_{TSS}$ 27.3 mg/L), and 2022 - 2023 ($\bar{x}_{TSS}$ 26.3 mg/L), and at Pancake Creek in in 2021 - 2022 ($\bar{x}_{TSS}$ 22.2 mg/L).

At the majority of sites located in open coastal waters, mean values recorded over the period exceeded TV for both chl-a (TV 0.45 µg/L) and TSS (TV 2 mg/L) (Table 8 and 9). The highest values were observed in the flood year 2021 - 2022 for chl-a at Burkitt's Reef ($\bar{x}_{chl\text{-}a}$ 2.87 µg/L), and for TSS at Barolin Rocks ($\bar{x}_{TSS}$ 24.8 mg/L). However, even in non-flood years, GBR TV set for open coastal waters were still exceeded. Less stringent values set for enclosed coastal waters are likely to be more applicable in this region, particularly for TSS.

Table 8 Monitoring data for chl-a (µg/L) by site and water type, relative to GBR trigger values for enclosed coastal (EC TV 2 µg/L) open coastal (OC 0.45 µg/L) according to water year, exceeds TV (OC) indicated by orange fill and (EC) bold, adapted from (Thompson et al. 2023). Number of samples (N), Median (Med), standard deviation (SD).

Sub-region	Site	Water type	2020-2021				2021-2022				2022-2023			
			N	Mean	Med	SD	N	Mean	Med	SD	N	Mean	Med	SD
Baffle	Seal Rocks	EC	3	1.25	1.45	0.79	6	0.87	0.53	0.91	2	0.69	0.69	0.09
	Pancake Creek	EC	3	1.16	0.50	1.36	6	0.55	0.55	0.19	2	0.83	0.83	0.81
	Ethel Rocks	OC	3	1.18	1.25	0.68	6	0.94	0.89	0.40	2	1.10	1.10	1.20
	Jensens Rocks	OC	3	0.83	0.95	0.28	6	0.88	1.00	0.35	2	0.71	0.71	0.27
	Stringers Reef	OC	3	0.33	0.25	0.13	6	0.83	0.88	0.52	2	0.25	0.25	0.00
Burrum North	Burnett Heads	OC	4	0.82	0.93	0.27	6	1.33	1.21	0.90	2	1.15	1.15	1.27
	Burkitt's Reef	OC	4	0.85	0.71	0.57	5	**2.87**	1.93	2.30	2	0.49	0.49	0.16
	Hoffmans Rocks	OC	3	0.47	0.25	0.38	6	1.26	1.50	0.62	2	0.34	0.34	0.12
	Rifle Range Reef	OC	3	**2.55**	2.20	2.49	6	1.26	1.48	0.62	2	0.25	0.25	0.00
	Barolin Rocks	OC	3	1.73	1.90	1.27	6	0.92	0.55	0.82	2	0.42	0.42	0.01
	Dr May's Reef	OC	3	0.57	0.48	0.20	6	1.88	1.34	1.10	2	0.36	0.36	0.16
	Four Mile	OC	3	1.72	1.10	1.85	6	0.91	0.79	0.54	2	0.25	0.25	0.00
Burrum South	Pt. Vernon	OC	3	0.97	0.95	0.08	6	0.77	0.69	0.59	2	0.78	0.78	0.74
	Pialba	OC	3	0.99	1.00	0.46	6	0.82	0.49	0.91	2	0.95	0.95	0.99

Table 9 Monitoring data for TSS (mg/L) by site and water type, relative to GBR trigger values for enclosed coastal (EC TV 15 mg/L) open coastal (OC TV 2 mg/L) according to water year, exceeds TV indicated by orange fill and (EC) bold, adapted from (Thompson et al. 2023). Number of samples (N), Median (Med), standard deviation (SD).

Sub-region	Site	Water type	2020-2021				2021-2022				2022-2023			
			N	Mean	Med	SD	N	Mean	Med	SD	N	Mean	Med	SD
Baffle	Seal Rocks	EC	6	5.7	4.8	3.6	6	**27.3**	21.8	20.7	2	**26.3**	26.3	25.1
	Pancake Creek	EC	6	4.4	3.8	2.2	6	**22.2**	16.5	16.6	2	13.6	13.6	2.9
	Ethel Rocks	OC	6	12.8	3.8	19.4	6	12.5	12.8	5.6	2	7.8	7.8	1.8
	Rodds Peninsula	OC	6	7.8	4.8	7.5	6	13.5	13.3	5.3	2	12.1	12.1	2.0
	Jensens Rocks	OC	6	6.0	4.3	4.6	6	**21.1**	20.3	13.9	2	7.0	7.0	3.5
	Stringers Reef	OC	6	4.4	3.9	2.4	6	12.4	9.5	9.7	2	9.8	9.8	6.7
Burrum North	Burnett Heads	OC	6	5.4	5.8	2.5	6	13.9	7.6	12.9	2	14.5	14.5	4.2
	Burkitt's Reef	OC	6	4.6	3.8	2.5	5	9.6	9.5	4.5	2	11.5	11.5	0.7
	Hoffmans Rocks	OC	6	3.5	2.8	1.8	6	13.9	14.0	7.1	2	11.0	11.0	2.8
	Rifle Range Reef	OC	5	3.7	2.5	2.2	6	19.0	15.5	16.4	2	11.3	11.3	0.4
	Barolin Rocks	OC	5	3.7	2.5	2.4	6	**24.8**	18.3	23.1	2	13.4	13.4	4.1
	Dr May's Reef	OC	6	6.0	2.5	6.9	6	**19.3**	17.3	15.2	2	10.3	10.3	1.1
	Four Mile	OC	6	4.8	3.3	3.0	6	10.4	9.0	5.1	2	11.0	11.0	1.4
Burrum South	Pt. Vernon	OC	5	4.0	3.0	2.3	6	**20.0**	10.9	17.9	2	8.5	8.5	2.8
	Pialba	OC	5	3.6	3.0	1.5	6	13.6	10.8	9.1	2	10.3	10.3	0.5

6.2.5 Coral site event data

Following flooding in 2011, significant water quality changes were detected at inshore coral sites in Hervey Bay, which persisted for approximately 14 weeks (Butler et al. 2013a). Salinity dropped from 35 ppt to 31.5 ppt, and nutrient levels (TN and TP) were elevated to 2 – 3 times their historical average. Flood plume exposure and associated water quality changes were greatest at Hervey Bay sites (Pt. Vernon West and East) and Burkitt's Reef, with the lowest exposure at Four Mile Reef, which is located a greater distance from shore and in deeper water (Table 10).

Table 10 Water quality data collected between Jan – Feb 2011 from plume water near reef study sites in Hervey Bay (adapted from Butler et al. 2013b). Ranges from all depths for TSS, TN, and TP are shown from samples taken at 0.2 m water depth.

Parameter	Reef Site							
	Burkitt's Reef		Four Mile Reef		Pt. Vernon W		Pt. Vernon E	
Depth (m HAT)	5		10		5		5	
Distance from mainland (km)	0.5		5.0		0.4		0.25	
Sample date	18-Jan-11	6-Feb-11	18-Jan-11	6-Feb-11	19-Jan-11	31-Jan-11	19-Jan-11	31-Jan-11
Salinity range (ppt)	31.2–33.7	na	31.2–34.3	na	29.4–31.2	32.3	29.8–30.1	32.1
Turbidity range (NTU)	9.0–13.6	na	<1	na	3.6–16.9	9.9–12.6	7.4–23.4	7.5–9.9
TSS (mg/L)	79	35	12	14	18	35	24	34
TP (µg/L)	25	14	8	6	12	20	22	15
TN (µg/L)	230	180	130	110	180	190	280	180
DOsat (%)	86.8–91.1	na	101.5–115.4	na	97.7–105.8	91.4–93.8	104.7–106.7	94.6–100.3
Temperature (°C)	26.73–26.84	na	26.76–26.98	na	27.46–28.12	26.45–26.46	27.79–28.29	26.35–26.46
na = not measured								

Following the repeated flood events in January and February 2013, water quality was altered within Hervey Bay for up to six months post-flooding (Butler et al. 2015a) (Table 11). Submarine groundwater caused hypo-saline conditions to persist for a further four months. As in previous flood events, sites differed in exposure to the flood plume, which was most prolonged in Hervey Bay at Pt. Vernon West relative to the other surveyed coral sites.

Table 11 Comparison in extremes of flood plume water quality parameters and duration below normal salinity or above environmental guidelines measured at East Woody Island (GSS) in 2011 and 2013 and inshore coral habitats (Pt. Vernon West, Pt. Vernon East and Pialba) of Hervey Bay in 2013 (adapted from Butler et al. 2015b). Maximum values for TSS, TN, and TP for samples taken from 0.8m water depth.

Parameter	GSS (East Woody Island) 2011	Duration (weeks)	GSS (East Woody Island) 2013	Duration (weeks)	Hervey Bay 2013	Duration (weeks)
Salinity (ppt.)	31.3	<16	17.2	<8	14.1	7 + 20
Turbidity (NTU)	11	<12	3.9	<4	na	na
TSS (mg/L)	na	na	11	<12	131	24
TN (µg/L)	360	20+	250	<8	750	8
TP (µg/L)	18	<8	30	<8	65	11
na = not measured						

6.3 Trends in coral communities

6.3.1 2020 – 2022 coral monitoring

The benthic community composition of coral sites varied by region, north of the Burnett River (Baffle sub-region), south of the Burnett River (Burrum North sub-region), and around Hervey Bay (Burrum South sub-region) (Thompson et al. 2023). In the Baffle sub-region, coral sites typically had a higher proportion of the hard coral genus, *Acropora,* the exception being Stringer's Reef where corals had a higher proportion of the hard coral *Porites*, though in very low cover. Monitored coral sites in the Burrum North sub-region were dominated by soft corals, most notably the genus *Cladiella*, with low hard coral cover. Two exceptions were Dr May's (low overall cover), and Four Mile Reef (dominated by hard corals, with a high proportion of the genus *Pocillopora*). In the Burrum South sub-region, Pialba had a community composition dominated by the hard coral genus, *Turbinaria*, while at Point Vernon the community was largely the hard coral genus, *Goniopora*. The density of juvenile hard corals in the region was very low suggesting limited larval supply, the highest number being observed in the Baffle region.

Change (increases and decreases) in coral cover between years was observed, though caution is required in interpreting changes in the coral cover in this data set as there is substantial variability in estimates among years (Thompson et al. 2023) (Table 12). Between 2020 - 2021, declines in hard and soft coral cover were estimated in the Burrum North sub-region, at Burnett Heads and Dr May's. More widespread declines were observed at sites in the Burrum region (North and South sub-regions) between 2021 - 2022, with moderate levels of coral cover loss on reefs south of the Burnett River attributed to the 2022 floods. The density of juvenile corals (count/transect area) also declined at most reefs monitored in 2022, though this was not statistically significant due to small sample sizes.

Table 12 Changes in hard and soft coral cover (%) and juvenile density (count/transect area). Data are predicted values from individual models run for each indicator at each reef. Coloured cells indicate values that were statistically (p<0.05) greater (green) or lower (red) than observed in the previous year. Adapted from (Thompson et al. 2023).

Sub-region	**Reef**	Hard coral cover (%)			Soft coral cover (%)			Juvenile density		
		2020	2021	2022	2020	2021	2022	2020	2021	2022
Baffle	Seal Rocks	9.9		13.9	0.3		1.2			
	Ethel Rocks	21.7	31	28.7	16.9	14.3	14.8	1.23	2.21	
	Rodds Peninsula	7.7	14.3	4.5	7.7	5.9	12.1	0.34	0.08	
	Pancake Creek	57.4	50.5	60.7	0	0	0.1	1.87	1.68	
Burrum North	Burnett Heads	3.5	1.7		28.3	5		0.31	0.25	
	Burkitt's Reef	4.7	9.5	1.1	38	19.5	3.9	0.41	0.37	0
	Hoffmans Rocks	0.5	1.0	0.7	60.5	67.1	67.7	1.77	0	1.01
	Rifle Range Reef	6.1	7.9	4.0	42.9	35.1	39.8	0.75	0	0
	Barolin Rocks	5.7	8.3	3.0	58.9	53.8	57.4	1.11	1.53	0.3
	Dr May's Reef	2.2	0.7	0.5	2.4	0.8	0.9	0.09	0.09	0.05
	Four Mile Reef	49.7	45.5	65	0	0	0	0.32	0.85	0
Burrum South	Point Vernon	70.9	41.2	26.7	1.7	1.1	3.1	1.21	1.37	0.69
	Pialba Reef	40.3	56.4	36.7	14.8	2.9	8.6	1.5	0.17	0.71

Report card scores based on hard and soft coral cover and juvenile hard corals have been estimated with methods consistent with the Reef Report Card (Thompson et al. 2023) (Table 13). 'Good' to 'Very Good' scores for coral cover were consistently estimated for all years (2020 – 2022) at Pancake Creek, Hoffmans Rocks, Barolin Rocks, and Four Mile Reef, whereas a decline in status has been observed at Burnett Heads, Burkitt's Reef, Rifle Range Reef, Point Vernon, and Pialba. Notably, Point Vernon declined from 'Very Good' in 2020, to 'Poor' status in 2022. Pancake Creek was the only site that showed improvement in coral cover scores over the period from 'Good' to 'Very Good'. Scores of 'Very Poor' were consistently observed at Seal Rocks, Stringer's Reef, and Dr May's Reef. Overall, coral cover for the region scored 'Moderate', declining from 'Very Good' in the southern region, but improving from 'Poor' in the northern region. At all sites and in all years, juveniles were scored as 'Very Poor', with exception of Point Vernon in 2020, scored as 'Moderate'.

Table 13 Report card scores for Coral Cover and Juvenile hard corals estimated using methods consistent with the Reef Report Card. Colours use represent report card categories as explained in section 3.2.4: red = 'Very Poor', orange = 'Poor', yellow = 'Moderate', light green = 'Good' and dark green = 'Very Good'. Adapted from (Thompson et al. 2023)

Sub-region	**Reef**	Coral Cover			Juveniles		
		2020	2021	2022	2020	2021	2022
Baffle	Seal Rocks	0.14		0.19	0.13		
	Ethel Rocks	0.5	0.6	0.59	0.11	0.19	
	Rodds Peninsula	0.21	0.27	0.22	0.03	0.01	
	Pancake Creek	0.77	0.67	0.81	0.16	0.15	
	Stringers Reef	0.14			0		
Burrum North	Burnett Heads	0.42	0.09		0.03	0.02	
	Burkitt's Reef	0.56	0.45	0.04	0.04	0.03	0
	Hoffmans Rocks	0.81	0.91	0.91	0.19	0	0.09
	Rifle Range Reef	0.65	0.56	0.59	0.07	0	0
	Barolin Rocks	0.86	0.83	0.8	0.14	0.19	0.04
	Dr May's Reef	0.06	0.02	0.02	0.01	0.01	0.01
	Four Mile Reef	0.66	0.61	0.86	0.03	0.09	0
Burrum South	Point Vernon	0.99	0.56	0.39	0.52	0.12	0.06
	Pialba	0.73	0.81	0.59	0.13	0.01	0.06
Baffle		0.35	0.51	0.45	0.09	0.12	
Burrum North		0.57	0.5	0.54	0.07	0.05	0.02
Burrum South		0.86	0.68	0.49	0.32	0.12	0.06
Region		0.57	0.55	0.5	0.03	0.02	0.01

6.3.2 Post flood surveys

Hard coral cover was considered very low at Woody Island North in 2022, where *Acropora* corals were noted as recently dead and covered with turf algae (Olds et al. 2024). In contrast, previous surveys at the site recorded live coral cover ~30 – 60% in 2010 – 2013 (Butler et al. 2015a), and 40 – 50% in 2014 – 2017 (Welch, M., Salmond, J., Passenger, J., and Loder 2017), though data are not directly comparable as methods in each study differed.

A ~40% reduction in total coral abundance (48% to 30%) before and after the flooding event of 2011, was observed at key sites within Hervey Bay (Pialba, Point Vernon West, Point Vernon East), GSS (Big Woody Island) and the

Bundaberg Coast (Burkitt's Reef, Four Mile Reef) (Butler et al. 2013a). Changes were not consistent amongst reefs, for example, there was an 89% reduction in coral cover at Pt. Vernon East, whereas no changes were recorded at Big Woody and Four Mile Reef. Variation was significantly correlated with distance from the mainland, with decreasing flood impacts observed with increasing distance from the mainland, up to a distance of 700 m. Impacts corresponded with the severity and duration of flood plume exposure, which was greater at more sheltered, shallow, mainland reefs (i.e., Point Vernon West, Point Vernon East, and Burkitt's Reef), relative to more exposed sites (i.e., Four Mile Reef, Big Woody). In 2011, species richness was variable among reefs and pre- and post-flood, and no overall significant reductions in species richness were observed. Post-flood changes in percentage cover at Pt. Vernon, Pialba, Burkitt's and Pt. Vernon West were driven primarily by losses of the two most abundant and widespread genera, the hard coral, *Goniopora* (Pre: 7.88%; Post: 2.61%) and the octocoral, *Cladiella* (Pre: 22.21%; Post: 9.91%). Hard coral genera typically considered more sensitive to disturbance, *Pocillopora, Montipora,* and *Acropora,* showed increased relative abundance overall. However, these groups were initially present in low abundances and restricted to Four Mile and Big Woody reefs, which were not significantly flood-impacted. Following the floods in 2013, total hard and soft coral abundance across sites further declined to 21.2%, from approximately 29.5% after the floods in 2011 (Butler et al. 2015a). In contrast to the flood events in 2011 and 2022, repeat events in 2013 resulted in observed declines in coral total abundance across all surveyed coral sites. However, as in previous years, losses were inconsistent among the reefs. Declines in total abundance varied from −21.5% (Four Mile) to −83.8% (Pt. Vernon East), with mortality from flood impacts found to be significantly negatively correlated with distance from the nearest river.

Analyses of historical hard coral abundance and community structure at a sub-set of key Hervey Bay reef sites (Pt. Vernon West, Pialba, Four Mile Reef and Big Woody) has also been undertaken via reef matrix cores with uranium-thorium dating (Butler 2015). Cores revealed that inshore corals have existed in Hervey Bay for at least 6,500 years. Depending on proximity to the mainland, reef geomorphology varied spatially from solid, vertical relief reefs offshore to simple, non-accreting, nearshore coral communities. Historical coral diversity was low (13 genera) and coral communities alternated cyclically (~1600 years) between those dominated by *Acropora,* and those dominated by genera considered stress tolerant, such as *Goniopora* and *Turbinaria*. This periodicity is similar to lunar, solar, and thermohaline cycles, as well as millennial-scale ENSO cycles, specifically with a positive correlation between total coral abundance and high-frequency of El Niño events. ENSO effects differed depending on distance from the mainland (Butler 2015). Away from the mainland, dry El Niño conditions resulted in generally higher abundances of coral and of the rapid growing but stress-sensitive *Acropora*, while low frequencies of El Niño events (La Niña periods) resulted in reduced total coral and increased relative abundances of the more stress-tolerant corals, such as *Goniopora* and *Turbinaria*. In contrast, nearer the mainland, El Niño conditions resulted in increased abundances of stress-tolerant coral, while La Niña conditions unexpectedly resulted in higher abundance of *Acropora,* perhaps as a result of lower levels of thermal stress and bleaching. The contrast between the currently low and historically high relative abundances of *Acropora* at Four Mile Reef and the replacement of a recently-colonised novel coral community suggests the possibility of anthropogenic influence. However, stress-tolerant assemblages have previously occurred naturally in Hervey Bay and are also likely part of a cyclicity of coral communities over the millennia.

7 Water quality guideline application for the project area

7.1 Regional and sub-regional guideline values for enclosed and open coastal waters

The study area presented here extends across levels of aquatic ecosystem protection, (sub-)regions, and water types to which the Queensland Water Quality Guidelines (QWQG) (2009) are meant to apply. Levels of protection range from high ecological value (HEV) (GSS), to slightly to moderately disturbed systems. QWQG guidelines have been developed based upon Australian & New Zealand Guidelines for Fresh & Marine Water Quality (ANZECC, 2000).

For HEV systems the management intent is no change to natural values, this includes physico-chemical, biological and habitat attributes. This may be tested by assessing for change to the 20th, 50th and 80th percentiles of the natural values of a given indicator. If all three remain unchanged, the overall range is deemed to have experienced no change. For slightly to moderately disturbed systems, the median value of physico-chemical indicators should be between the $20^{th}/80^{th}$ percentile of reference range. In contrast to freshwater systems that experience a range of flows, estuarine and coastal systems are less variable, with only short periods of high flow events. QWQG guidelines are largely based on data collected during ambient periods and therefore generally appropriate under these conditions.

Relevant values for QWQG for the South East Region are summarised in Table 14, for estuaries (lower) and marine waters (enclosed coastal and open coastal). Part of the study area also extends north into the QWQG Central Region, with GBR Water Quality Guideline values applying to open coastal environments (Section 7.3.2).

Table 14 Regional and sub-regional GV for key physio-chemical indicators and percentile value (20th, 50th, 80th percentile). Units are µg/L unless stated otherwise.

Indicator	**QLD SE region (slightly to moderately disturbed systems)**		**HEV (GSS)**	**QLD Central region (slightly to moderately disturbed systems)**
	Open coastal	Enclosed/Lower estuary	Enclosed/Lower estuary	Enclosed/Lower estuary
TN	140	200	110 – 115 – 160	200
TP	20	20	6 – 10 – 14	20
Chl-a	1.0	2.0	0.6 – 0.8 – 1.3	2.0
Turbidity (NTU)	1	6	1 – 2 – 4	6
Secchi (m)	5.0	1.0	1.8 – 2.9 – 4.3	1.5
TSS (mg/L)	10.0	15.0	4 – 9 – 13	15.0

7.2 Water Quality Objectives under the Water Policy

Aquatic ecosystem WQOs under the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (EPP) differ across the project area by water type, degree of human disturbance, and level of protection/management intent (Table 15). Baffle Creek and the Burnett River are not currently scheduled under Water Policy, but have draft interim WQO to protect aquatic ecosystem EV under the Burnett River Water Quality Improvement Plan (WQIP).

Table 15 Project area aquatic ecosystem WQOs under Water Policy, with 20th, 50th and 80th percentiles of existing water quality, and Burnett River WQIP.

Indicator	**Burnett River**	**Burrum River (BE1)**	**Hervey Bay (HB1)**	**GSS (GSS1)**	**Baffle Creek**	**Baffle Creek**
	Open coastal	Lower estuary	Open coastal	Lower estuary	Lower estuary	Open coastal
	Slightly to moderately disturbed	High ecological value	High ecological value	High ecological value	High ecological value	High ecological value
Turbidity (NTU)	<2	1 – 2 – 4	0 – 1 – 2	1 – 2 – 4	2 - 3 - 5	0 – 1 – 2
TSS (mg/L)	<11	4 – 9 – 13	2 – 4 – 11	4 – 9 – 13	ND	2 – 4 – 11
Chl-a (µg/L)	<0.8	0.6 – 0.8 – 1.3	0.5 – 0.6 – 0.8	0.6 – 0.8 – 1.3	1 - 1 - 2	0.5 – 0.6 – 0.8
Total nitrogen (TN) (µg/L)	<150	110 – 115 – 160	110 – 113 – 150	110 – 115 – 160	110 - 130 - 170	110 – 113 – 150
Oxidised N (µg/L)	<2	2 – 2 – 3	2 – 2 – 2	2 – 2 – 3	2 - 2 - 2	2 – 2 – 2
Ammonia N (µg/L)	<9	2 – 7 – 10	2 – 6 – 9	2 – 7 – 10	2 - 2 - 5	2 – 6 – 9
Organic N (µg/L)	<140	100 – 100 – 150	98 – 100 – 140	100 – 100 – 150	100 - 130 - 160	98 – 100 – 140
Total phosphorus (TP) (µg/L)	<14	6 – 10 – 14	6 – 10 – 14	6 – 10 – 14	6 - 9 - 13	6 – 10 – 14
Filterable reactive phosphorus (FRP) (µg/L)	<3	2 – 2 – 3	2 – 2 – 3	2 – 2 – 3	2 - 2 - 2	2 – 2 – 3
Dissolved oxygen (% saturation)	90 – 105	90 – 95 – 105	90 – 95 – 105	90 – 95 – 105	95 - 100 - 105	90 – 95 – 100
pH	8.1 – 8.4	8.1 – 8.2 – 8.4	8.1 – 8.2 – 8.4	8.1 – 8.2 – 8.4	7.9 - 8.1 - 8.3	8.1 – 8.2 – 8.4
Secchi depth (m)	>5.0	1.8 – 2.9 – 4.3	Insufficient data	1.8 – 2.9 – 4.3	1.3 - 2 - 2.5	>5.0

7.3 GBR waters

7.3.1 Basin-specific ecologically relevant targets

Ecologically relevant targets (ERT) attempt to define the anthropogenic pollutant load reductions that would be required to meet the GBR WQG, which are set at a standard considered to be suitable to maintain reef ecosystem health (Brodie and Lewis 2014). Final anthropogenic load targets for reef waters are identified in the Reef 2050 water quality improvement plan, and GBR DIN and TSS load targets are listed under the Water Policy (currently under review). ERT were set for all the basins in the Burnett Mary region for the main pollutants addressed in the Reef

Water Quality Improvement Plan targets. Basin-specific ERT for Baffle Creek, Kolan, Burnett, Burrum and Mary rivers were later derived using a consistent approach for the full GBR region, using the eReefs hydrodynamic, sediment transport, and biogeochemical model and monitoring data (Brodie et al. 2017) (Table 16). Where possible, recent basin-specific ERT are set based on an ecological outcome in the GBR, based on GBR Water Quality Guidelines.

ERT load reductions for each GBR catchment have been established based on targets for improved coral diversity versus macroalgae via lowering of dissolved nitrogen loads (both dissolved organic and inorganic nitrogen, DON and DIN), with the assumption that reductions are mostly applicable to DIN, where average chl-a concentration in the water column does not exceed the GBR WQG value for open coastal waters (chl-a <0.45 μg/L, all years, all waters within river footprints) (Brodie et al. 2017). Based on this model, proposed basin-specific water quality targets are compared to the regional Burnett Mary WQIP for fine sediment, DIN, PN and PP reduction. Regional NRM WQIP target reductions are set equally, or higher than those for proposed ERT load reductions, namely for Burnett River DIN (proposed 70%, WQIP 50%; 62 t/yr by 2025).

Table 16 Great Barrier Reef River Basins End-of-Basin Load Water Quality Objectives to be achieved by 2025, under Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (annual average loads)

River basin	Target reduction anthropogenic DIN (%)	Anthropogenic DIN (t/yr) objective	Target reduction anthropogenic fine sediment (%)	Anthropogenic fine sediments (kt/yr) objective
Baffle	50	16	20	42
Kolan	50	34	20	6
Burnett	70	57	20	341
Burrum	50	93	20	14
Mary	50	181	20	536

7.3.2 GBR Water Quality Guidelines

GBR Water Quality Guidelines describe the concentrations and trigger values for sediment, nutrients, and pesticides that have been established as necessary for the protection and maintenance of marine species and ecosystem health of the GBR in various water types (Great Barrier Reef Marine Park Authority 2010) (Table 17). It is important to note that the levels of contaminants identified in these guidelines are not targets, but rather guideline trigger values that, if exceeded, identify the need for management responses. These guidelines include levels of particulate nutrients (PN, PP), chl-a, and sedimentation, which complement other nutrient forms (e.g. TN, TP), all of which are included as WQO under the Water Policy (Section 7.2). Note that as environmental values and WQO are scheduled, relevant GBR guidelines and local GBR water quality data are reviewed and locally adapted into the Water Policy schedule documents where necessary, in consultation with GBRMPA.

The Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP) 2025 water quality pesticide target is to protect at least 99% of aquatic species at the end-of-catchment, applying across all catchments (Australian Government and Queensland governments, 2018). A guideline trigger level for sea temperature is set at increases of no more than 1ºC above the long-term average.

Table 17 Mean annual guideline trigger values for GBR WQ and water body types (Great Barrier Reef Marine Park Authority, 2010)

Indicator	Enclosed coastal	Open coastal	Midshelf	Offshore
Secchi depth (m)[1]	1.0/1.5	10	10	17
Chl-a (µg/L)[2]	2.0	0.45	0.45	0.4
TSS (mg/L)[3]	5.0/15	2.0	2.0	0.7
PN (µg/L)[3]	-	20	20	17
PP (µg/L)[3]	-	2.8	2.8	1.9
Sedimentation[4]	3 $mg/cm^2/d$	3 $mg/cm^2/d$	3 $mg/cm^2/d$	3 $mg/cm^2/d$

[1]At shallower depths secchi will be visible on the seafloor. Guideline trigger values for water clarity decrease by 20% for areas with > 5 m tidal ranges.

[2]Chlorophyll values are ~40% higher in summer and ~30% lower in winter than mean annual values.

[3]Seasonal adjustments for SS, PN, and PP are approximately ± 20% of mean annual values

[4]Daily maximum of 15 $mg/cm^2/d$

7.4 Other relevant guidelines

7.4.1 Ecologically relevant water quality guidelines for Moreton Bay & estuaries 2022

This Healthy Land and Water project aimed to develop Ecologically Relevant Water Quality Guidelines for Moreton Bay. It was noted that the relationship between water quality and indicators of coral condition must first be established at a given site. Key proposed indicators relevant to coral health included total muddy area, and coral area extent (>20%), condition and function. Guidelines or targets relevant to coral were limited to annual median values of turbidity <3 NTU, secchi disk depth >2.0 m, and TP <0.02 mg/L.

8 Interim guidelines for coral health

The study area comprises three key regions, each with differing levels of aquatic ecosystem protection, water types, environmental conditions and associated coral communities; these comprise north of the Burnett River (Baffle sub-region), south of the Burnett River (Burrum North sub-region), and around Hervey Bay (Burrum South sub-region).

Flood events during 2021 - 2022 were evident in coral site monitoring of water quality and report card scores for turbidity and TSS, which both scored ‘Poor’ in this year in contrast to higher scores in 2020 - 2021 and 2022 - 2023, chl-a scores were ‘Moderate’ in 2021 - 2022 and improved to ‘Good’ in 2022 - 2023 (Thompson et al. 2023). However, between sub-regions, differences in WQO available for the generation of scores resulted in large differences, which were not reflective of *in situ* differences in water quality. Therefore, it is informative to derive sub-regional guideline values tailored to reflect community values, management goals and local conditions of an ecosystem of interest, derived using percentiles of reference site data. Based on available water quality data collected during 2020 - 2023, GBR trigger values for open coastal waters are likely too stringent to be relevant to coral habitats in the study area, which are typically subject to higher levels chl-a and turbidity. However, values set for enclosed coastal waters are more consistent with environmental conditions at the majority of sites; chl-a (TV 2.0 µg/L) was not typically exceeded by annual mean values over the period with exception of two sites in Burrum North (Rifle Range Reef and Burkitt’s Reef). Values set for TSS (TV 15 mg/L) were only exceeded at multiple sites in the flood affected 2021 - 2022, and at one site in the Baffle sub-region (Seal Rocks) in 2022 - 2023.

Coral sites in the Burrum Region in particular have been subjected to recent losses in live coral cover due to floods in 2011, 2013 and 2022, and exposure to extended periods of hyposaline flood waters. Changes in calculated coral cover report card indicator scores over the monitoring period between 2020 - 2023 were most notable in Burrum South, at the Point Vernon site which declined from ‘Very Good’ in 2020, to ‘Poor’ status in 2022 (Thompson et al. 2023). Low levels of juvenile hard corals were noted at all monitored sites across the study area, resulting in a ‘Very Poor’ score in most years and indicating limited resilience to future stressors.

To derive interim sub-regional guidelines for coral health, reference sites were selected based on median indicator values observed over the monitoring period by sub-region and water type. Noting that this period included one relatively dry (2020-2021), and wet year where flooding was observed (2021-2022). Reference sites comprised Pancake Creek (Baffle sub-region, lower estuary), Ethel Rocks (Baffle sub-region, open coastal waters), Four Mile Reef (Burrum North, open coastal), and Point Vernon (Burrum South, open coastal). Percentiles (20^{th}, 50^{th} and 80^{th}) were calculated according to indicator values at these sites. Interim values outlined in Table 18 are therefore based on a limited number of preliminary coral site water quality data collected between 2020 - 2022. An independent review noted some quality issues related to the methods applied to the coral site water quality monitoring, however the data do offer useful baseline information, noting a high degree of uncertainty (Thompson et al. 2023). Program improvements were proposed, and these data should be viewed as preliminary.

Currently there is not sufficient monitoring data to generate a preliminary value for some indicators including secchi depth, sedimentation, total phosphorus, particulate nutrients and some dissolved nutrients. Notably, for some indicators reference site percentiles exceed designated WQOs for HEV open coastal waters, and further data is necessary to determine appropriate indicator values for coral health in these areas. It is suggested that the lowest of the two values be selected in these instances, as this would likely offer the highest degree of protection to coral health. Relating indicator data by water year in each sub-region to these interim values (Table 19), noting that reference sites are also included in these regional values, the majority of values fell below the 80th percentile. Higher values were observed in the 2021 – 2022 period for TSS and turbidity in both the Burrum and Baffle sub-regions. Values for total nitrogen collected in September 2022 and November 2022 were excluded in percentile calculations, due to potential contamination noted in these samples.

Table 18 Sub-regional reference site interim percentiles for physical chemical indicators from coral site monitoring between 09/2020 to 11/2022, exceedance of relevant regional WQO/GV/GBR TV indicated by orange highlight (where multiple highest protection selected). In this instance it is recommended to select the most conservative value. Standard error (SE), number of samples (N). Reference sites comprised Pancake Creek (Baffle sub-region, lower estuary), Ethel Rocks (Baffle sub-region, open coastal waters), Four Mile Reef (Burrum North, open coastal), and Point Vernon (Burrum South, open coastal).

Indicator	Sub-region	Water type, management intent	WQO/GV 20th – 50th – 80th	Reference site percentile				
				20th	50th	80th	SE	N
Chl-a (µg/L)	Baffle	Baffle Creek, LE/EC, HEV	1 – 1 – 2	0.25	0.25	1.1	0.4	11
	Baffle	Baffle Creek, Open coastal, HEV	0.5 – 0.6 – 0.8	0.25	0.5	1.66	0.29	11
	Burrum North	HB1, Open coastal, HEV	0.5 – 0.6 – 0.8	0.25	0.25	2.14	0.57	11
	Burrum South	HB1, Open coastal, HEV	0.5 – 0.6 – 0.8	0.25	0.5	1.16	0.14	11
TSS (mg/L)	Baffle	Baffle Creek, LE/EC, HEV	ND	2.5	8	16	5.15	14
	Baffle	Baffle Creek, Open coastal, HEV	2 – 4 – 11	2.5	8.5	12	6.29	14
	Burrum North	HB1, Open coastal, HEV	2 – 4 – 11	2.5	9.5	14	1.88	14
	Burrum South	HB1, Open coastal, HEV	2 – 4 – 11	2.9	7	11.2	1.15	13
Turbidity (NTU)	Baffle	Baffle Creek, LE/EC, HEV	2 – 3 – 5	0.25	1.1	1.7	0.26	9
	Baffle	Baffle Creek, Open coastal, HEV	0 – 1 – 2	0.25	1.4	2.5	0.36	9
	Burrum North	HB1, Open coastal, HEV	0 – 1 – 2	0.25	0.7	2.6	0.32	9
	Burrum South	HB1, Open coastal, HEV	0 – 1 – 2	1.1	2.7	3.8	0.56	9
TN (µg/L)	Baffle	Baffle Creek, LE/EC, HEV	110 – 130 – 170	10	60	140	17.8	9
	Baffle	Baffle Creek, Open coastal, HEV	110 – 113 – 150	10	70	140	22.7	9
	Burrum North	HB1, Open coastal, HEV	110 – 113 – 150	10	70	170	23.9	9
	Burrum South	HB1, Open coastal, HEV	110 – 113 – 150	50	110	140	17.8	9
Ammonia N (NH_4) (µg/L)	Baffle	Baffle Creek, LE/EC, HEV	2 – 2 – 5	10.4	30	64.2	9.5	5
	Baffle	Baffle Creek, Open coastal, HEV	2 – 6 – 9	1.6	10	62	8.7	5
	Burrum North	HB1, Open coastal, HEV	2 – 6 – 9	1.4	20	36	5.4	5
	Burrum South	HB1, Open coastal, HEV	2 – 6 – 9	1.4	8	42	6.0	5
Dissolved oxygen (% saturation)	Baffle	Baffle Creek, LE/EC, HEV	95 - 100 - 105	96	99	101	12.7	11
	Baffle	Baffle Creek, Open coastal, HEV	90 – 95 – 100	95	99	102	7.4	13
	Burrum North	HB1, Open coastal, HEV	90 – 95 – 105	98	100	102	7.5	13
	Burrum South	HB1, Open coastal, HEV	90 – 95 – 105	89	98	105	7.6	13
pH	Baffle	Baffle Creek, LE/EC, HEV	7.9 – 8.1 – 8.3	8.0	8.1	8.2	1.2	10
	Baffle	Baffle Creek, Open coastal, HEV	8.1 – 8.2 – 8.4	8.1	8.2	8.2	0.9	12
	Burrum North	HB1, Open coastal, HEV	8.1 – 8.2 – 8.4	8.1	8.2	8.3	0.9	12

Indicator	Sub-region	Water type, management intent	WQO/GV 20th – 50th – 80th	Reference site percentile				
				20th	50th	80th	SE	N
	Burrum South	HB1, Open coastal, HEV	8.1 – 8.2 – 8.4	8.0	8.2	8.3	0.9	12
Total phosphorus (TP) (µg/L)	Baffle	Baffle Creek, LE/EC, HEV	6 – 9 – 13	ND	ND	ND	ND	-
	Baffle	Baffle Creek, Open coastal, HEV	6 – 10 – 14	ND	ND	ND	ND	-
	Burrum North	HB1, Open coastal, HEV	6 – 10 – 14	ND	ND	ND	ND	-
	Burrum South	HB1, Open coastal, HEV	6 – 10 – 14	ND	ND	ND	ND	-
Filterable reactive phosphorus (FRP) (µg/L)	Baffle	Baffle Creek, LE/EC, HEV	2 – 2 – 2	ND	ND	ND	ND	-
	Baffle	Baffle Creek, Open coastal, HEV	2 – 2 – 3	ND	ND	ND	ND	-
	Burrum North	HB1, Open coastal, HEV	2 – 2 – 3	ND	ND	ND	ND	-
	Burrum South	HB1, Open coastal, HEV	2 – 2 – 3	ND	ND	ND	ND	-
Secchi depth (m)	Baffle	Baffle Creek, LE/EC, HEV	1.3 - 2 - 2.5	ND	ND	ND	ND	-
	Baffle	Baffle Creek, Open coastal, HEV	>5.0	ND	ND	ND	ND	-
	Burrum North	HB1, Open coastal, HEV	Insufficient data	ND	ND	ND	ND	-
	Burrum South	HB1, Open coastal, HEV	Insufficient data	ND	ND	ND	ND	-
GBR mean annual Trigger Value								
Particulate nitrogen[1] (PN) (µg/L)	GBR	Enclosed coastal	-	ND	ND	ND	ND	-
		Open coastal	20	ND	ND	ND	ND	-
Particulate phosphorus[1] (PP) (µg/L)	GBR	Enclosed coastal	-	ND	ND	ND	ND	-
		Open coastal	2.8	ND	ND	ND	ND	-
Sedimentation[2] (mg/cm²/d)	GBR	Enclosed coastal	3	ND	ND	ND	ND	-
		Open coastal	3	ND	ND	ND	ND	-
Temperature[3] (ºC)	GBR	All	+1	20.2	24.9	26.5	1.06	41
Pesticides (species protected)	GBR	All	99%	ND	ND	ND	ND	-

[1]Seasonal adjustments for PN, and PP are approximately ± 20% of mean annual values

[2]Daily maximum of 15 mg/cm²/d

[3]Above long term average, percentiles are average values across reference sites over the period

*Table 19 Sub-regional indicator values by water year from monitoring between 09/2020 to 11/2022. Exceedance of reference site interim percentiles indicated by orange highlight, *grey highlight indicates possible contamination issues. Reference sites comprised Pancake Creek (Baffle sub-region, lower estuary), Ethel Rocks (Baffle sub-region, open coastal waters), Four Mile Reef (Burrum North, open coastal), and Point Vernon (Burrum South, open coastal).*

Indicator	**Sub-region**	**Reference percentile 20th – 50th – 80th**	**Water year mean value**											
			2020 - 2021				**2021 - 2022**				**2022 - 2023**			
			Med	Mean	SE	N	Med	Mean	SE	N	Med	Mean	SE	N
Chl-a (µg/L)	Baffle (LE/EC)	0.25 – 0.25 – 1.1	1.30	2.02	0.70	6	0.38	0.88	0.39	12	0.85	0.81	0.22	4
	Baffle (OC)	0.25 – 0.5 – 1.66	0.75	1.09	0.25	12	0.50	0.67	0.13	24	0.25	0.62	0.22	8
	Burrum North (OC)	0.25 – 0.25 – 2.14	0.95	1.32	0.29	22	0.9	1.7	0.29	41	0.25	0.52	0.06	14
	Burrum South (OC)	0.25 – 0.5 – 1.16	0.70	0.76	0.19	6	0.60	0.8	0.19	12	0.78	0.8	0.32	4
TSS (mg/L)	Baffle (LE/EC)	2.5 – 8 – 16	3.75	4.58	0.69	12	12.5	25.5	7.36	12	14.5	18	4.85	4
	Baffle (OC)	2.5 – 8.5 - 12	2.75	9.13	0.13	24	10.0	12.9	0.26	24	9.17	9.54	0.36	8
	Burrum North (OC)	2.5 – 9.5 – 14	2.5	4.75	0.78	40	11.0	18.9	3.38	41	13.0	12.7	0.95	14
	Burrum South (OC)	2.9 – 7 – 11.2	3.5	4.2	0.91	10	9.5	10.4	0.93	12	9.7	9.58	1.46	4
Turbidity (NTU)	Baffle (LE/EC)	0.25 – 1.1 – 1.7	0.78	0.78	0.27	2	1.25	1.87	0.58	12	0.73	0.78	0.31	14
	Baffle (OC)	0.25 – 1.4 – 2.5	0.53	0.58	0.13	4	2.0	2.1	0.26	24	0.83	1.10	0.36	8
	Burrum North (OC)	0.25 – 0.7 – 2.6	0.9	0.76	0.13	7	2.8	3.9	0.51	41	0.95	1.27	0.29	14
	Burrum South (OC)	1.1 – 2.7 – 3.8	0.63	0.63	0.20	2	2.70	3.0	0.39	12	3.25	3.45	0.57	4
TN (µg/L)	Baffle (LE/EC)	14 – 60 – 276	95.0	98.3	27.3	6	50	71.7	21.1	12	375*	377.5*	10.3	4
	Baffle (OC)	18 – 70 – 316	105.0	105.8	20.7	12	58.3	61.1	9.9	24	380*	380.4*	21.5	8
	Burrum North (OC)	30 – 100 – 242	110.0	122.4	16.2	21	80.0	92.2	11.6	41	325*	319.1*	26.8	14
	Burrum South (OC)	58 – 110 – 250	125.0	128.3	30.1	6	85.0	80.0	16.2	12	345*	352.5*	54.1	4
Dissolved oxygen (% saturation)	Baffle (LE/EC)	96 – 99 – 101	98.6	98.3	0.9	12	97.5	98.3	15.1	9	101.5	101.8	29.4	3
	Baffle (OC)	95 – 99 – 102	99.0	98.3	0.6	24	96.5	97.7	8.4	20	101.5	101.2	0.4	8
	Burrum North (OC)	98 – 100 – 102	100.1	101.2	0.5	42	98.4	97.8	6.3	35	100.9	101.6	0.8	14
	Burrum South (OC)	89 – 98 – 105	99.0	100.1	1.9	12	93.5	97.8	12.3	10	96.4	97.6	6.5	4
pH	Baffle (LE/EC)	8.0 – 8.1 – 8.2	8.2	8.2	1.0	10	8.2	8.2	1.2	9	8.1	8.0	2.3	3
	Baffle (OC)	8.1 – 8.2 – 8.2	8.2	8.2	0.7	20	8.2	8.2	0.7	20	8.1	8.1	0.0	8
	Burrum North (OC)	8.1 – 8.2 – 8.3	8.2	8.2	0.5	35	8.2	8.2	0.5	35	8.1	8.1	0.0	14
	Burrum South (OC)	8.0 – 8.2 – 8.3	8.1	8.1	1.0	10	8.2	8.2	1.0	10	8.1	8.0	0.0	4

9 Knowledge gaps

Recent Gidajil coral and water quality surveys (2020 - 2022) have served to provide highly relevant, spatially, and temporally replicated data for monitored coral sites. However, these data are preliminary and to better inform water quality guidelines for coral health in the project area, critical knowledge gaps remain.

Coral data knowledge gaps related to historic data sets:

- Data is patchy in time and space, much is unpublished and/or does not meet findability, accessibility, interoperability, and reusability (FAIR) principles;
- A lack of standardised and replicated methodology and surveyed sites limits the ability for longer-term trend detection; and
- Methods and outputs are not comparable to MMP/LTMP data for GBR inshore corals, generation of report card scores, and impact attribution.

More recent coral site monitoring could be complemented via:

- Incorporation of additional indicators of coral health and resilience, e.g. colony size distribution, quantification of bleaching, and disease prevalence, and other stressors such as anchor damage;
- Inclusion of additional sites, in particular key coral sites at Woody Island and further offshore, to better establish change related to spatial differences in water quality; and
- Bi-annual surveys would assist understanding of change associated with flood effects and recovery, i.e. conducted before and after the wet season.

Water quality data knowledge gaps remain at coral sites and catchments of the wider study area relevant to coral health:

- Current coral site water quality surveys do not include analysis of some indicators relevant to coral health, including water clarity (secchi depth), sedimentation, and contaminants (pesticides);
- Some indicators require more detailed/and or differing analytical approaches to be relevant to the environment under study, primarily nutrients (PN, PP, FRP, TP);
- Other relevant data to better inform risks to coral health, include hydrodynamics (to inform dispersion and remobilisation), sediment composition (proportion of fine sediments with grainsize of <63 μm, clay and silt), and sediment quality (associated nutrients and contaminants); and
- Inclusion of additional monitoring sites along a distance gradient offshore (in line with MMP approaches), would serve to better inform changes in water quality from land-based sources, versus remobilisation effects.

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APPENDIX

National, state and reef water quality policy context

This section provides an overview of:

- The national and Queensland water quality policy and legislation to which this coral project is contributing
- Great Barrier Reef water quality management commitments
- Ramsar obligations in relation to the management of Great Sandy Strait
- Great Sandy Marine Park planning and management

National water quality context

The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG 2018) are an online suite of technical guidelines under the National Water Quality Management Strategy (NWQMS). The ANZG supersede the previous ANZECC (2000) water quality guidelines (except where ANZG indicate that ANZECC information remains applicable).

In addition to national toxicants guidelines (e.g. pesticides, metals), the ANZG are progressing the development of some ecoregional guidelines for non-toxicant indicators. However, the key ANZG message is to promote the derivation of site-specific guidelines for physico-chemical (PC) stressors where possible, rather than automatically 'default' to a national set of guideline values for all indicators:

> *Australia and New Zealand have a wide range of ecosystem types and environments, which create enormous differences in water quality characteristics between regions. Additional environmental factors, such as local natural water quality, can significantly alter the effects of PC stressors at a site, and these factors can vary considerably between sites.*
> *This is why water and sediment quality assessments that use more localised guideline values and advice targeted to the relevant local scale will always be more accurate than those using national or regional DGVs. As a general rule of thumb: the greater the spatial resolution, the more accurate the assessment. For this reason, there is a preferred hierarchy of types of guideline values for PC stressors, as shown below.'*

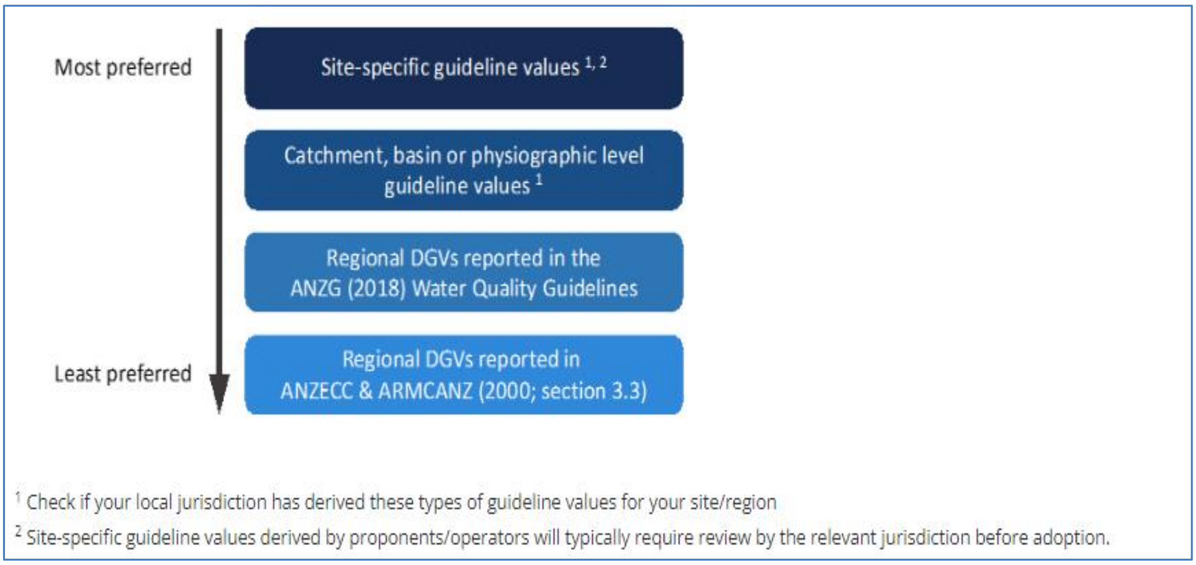


Figure 1 ANZG hierarchy for physical and chemical stressors. (Source: ANZG 2018, Your Location)

It is within this national framework that the department has progressed the development of more regionally and locally-specific water quality materials under Queensland legislation, as discussed below.

Queensland water quality legislative context

This coral project is undertaken in support of the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (Water Policy), subordinate legislation to the *Environmental Protection Act 1994* (EP Act). The purpose of the Water Policy is to achieve the object of the EP Act in relation to waters and wetlands, that is, protecting Queensland's water environment while allowing for development that is ecologically sustainable. For detailed information on the Water Policy, refer to the Water Policy page on the department's website. The Water Policy management framework follows the philosophy in ANZG (2018) as outlined above, including where possible, derivation of materials based on local or regionally relevant water quality information.

The Water Policy provides a framework for developing locally relevant environmental values (EVs), management goals and water quality objectives (WQOs) for Queensland waters (these terms are defined below). Pending government approval, these are listed in schedule 1 of the Water Policy, with schedule 1 documents and mapping available from the Water Policy page on the department's website (listed by region). Schedule 1 materials inform planning and decision making for development under the EP Act (e.g. point source environmentally relevant activities); local government planning and decision making for urban land development under the State Planning Policy (Water Quality State Interest - Planning Act); best practice management approaches to address diffuse emissions from rural lands; development of report cards on aquatic ecosystem health; and catchment scale management planning and decisions by non-legislative Regional NRM bodies.

EVs, WQOs and accompanying mapping were included under schedule 1 of the Water Policy for fresh, estuarine, and coastal/marine waters of the Mary and Burrum River basins, K'gari, Hervey Bay, and GSS in 2010. This includes level of protection mapping (encompassing waters identified for high ecological value (HEV level of protection).

Waters of the Burnett and Baffle basins have not been scheduled in the Water Policy, however, as a GBR catchment, a Water Quality Improvement Plan (WQIP) has been prepared by the regional NRM body, Burnett Mary Regional Group, for the Burnett Mary Region (including Burnett-Baffle, Mary and Burrum basins), and includes basin specific water quality targets and priorities.

The ultimate intent is for the results of this coral project to form a suitable input to any future schedule 1 documents and mapping under the Water Policy. As the formal EVs/WQOs process requires government approvals and takes considerable time, s8 of the Water Policy also includes a framework for deciding water quality indicators and technical water quality guidelines based on a suite of technical guideline documents. This coral project is therefore intended to meet the requirements of s8 of the Water Policy.

Main terms/concepts under Water Policy

Environmental values (EVs) for water are the qualities that make it suitable for supporting aquatic ecosystems and human water uses (the latter including aquaculture and human consumption of aquatic foods; agricultural uses (e.g. stock watering); recreational uses (e.g. swimming, wading, boating, fishing and aesthetic); drinking water (raw water supply); industrial uses; and cultural and spiritual values. These qualities need to be protected from the effects of habitat alteration, waste releases, contaminated run-off and changed flows to ensure healthy aquatic ecosystems and waterways that are safe for community use.

All Queensland waters (tidal and non-tidal waters, including wetlands, lakes and groundwaters), have EVs. Aquatic ecosystem health is an EV for all Queensland waters and is the focus of this report.

Management goals establish a clearer intent on what components of an EV can be identified for protection and the measures or statements used to assess whether the EV is being maintained The ANZG (2018) notes that management goals '*form the basis for setting appropriate water/sediment quality objectives, and determining management strategies for achieving them'* and, that among others, they should reflect '*key attributes… that must be protected (e.g. key ecosystem assemblages and processes, species of importance'* and *desired levels of protection (for aquatic ecosystems*)'.

For the aquatic ecosystem EV, management goals might be identified for particular ecosystem components (e.g. (fish, seagrass, corals, etc), and where information is available, local water quality requirements established to support these goals.

Water quality indicator for an environmental value for water is *a physical, chemical, biological or other property that can be measured or decided in a quantitative way* (Water Policy, s8) Indicators can therefore include physical (e.g. turbidity, suspended sediment and temperature), chemical (e.g. phosphorus, nitrogen, biochemical oxygen demand and toxicants), biological (e.g. macroinvertebrates and fish), pathogens, and other measures of waterway condition (e.g. erosion and riparian vegetation extent and condition).

Water quality guidelines (WQGs) are the quantitative measures (i.e. numbers) or narrative statements established to protect the EVs of waters. WQGs inform the development of water quality objectives (WQOs) under schedule 1 of the Water Policy. WQOs are derived from site-specific scientific studies, the Queensland Water Quality Guidelines, ANZG, and other documents published by recognised entities. WQGs and WQOs can be expressed in various ways, including concentrations, loads (e.g. tonnes/year), and biological measures.

Figure 2 is a diagrammatic representation of this legislative framework. Management goals, indicators and WQOs are examples only and not for adoption. This study aims to localise these goals and supporting water quality guidelines for corals, and is intended to inform Water Policy provisions under s 8 of the policy and ultimately development of aquatic ecosystem WQOs under schedule 1.

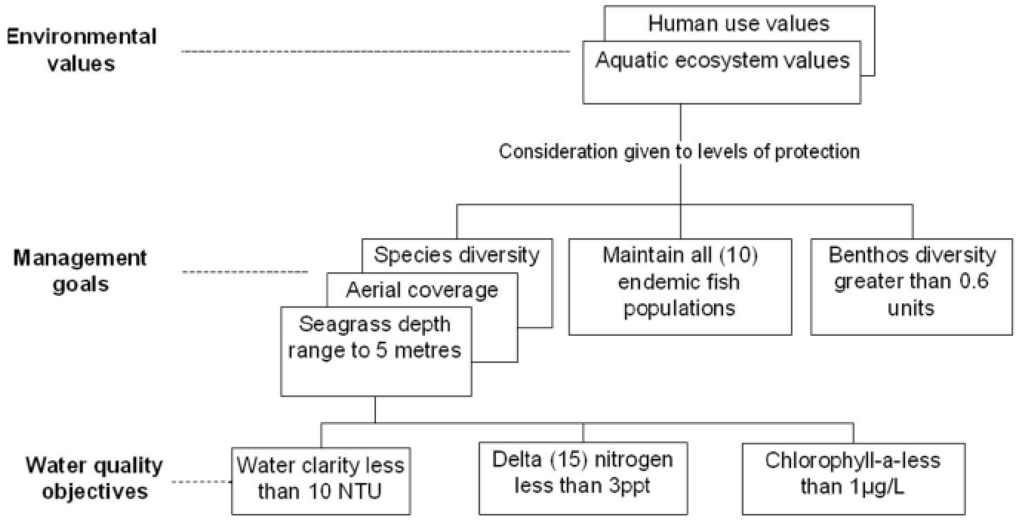


Figure 2 Water quality management concepts (note: example only. Values are not intended for application)

Reef 2050 water quality improvement plan

The Reef 2050 Water Quality Improvement Plan 2017–2022 (Reef 2050 WQIP) is a joint commitment of the Australian and Queensland governments that seeks to improve the quality of water flowing from the catchments adjacent to the Great Barrier Reef. The plan identifies how catchment water quality outcomes under the broader Reef 2050 Long-Term Sustainability Plan will be delivered. The long-term (2050) outcome under the Reef 2050 WQIP is that '*Good water quality sustains the outstanding universal value of the Great Barrier Reef, builds resilience, improves ecosystem health and benefits communities*'. The Reef 2050 WQIP includes the following commitment, identified as contributing to the delivery of Reef 2050 action 1.2: *Review and update water quality objectives and water quality guidelines at regionally relevant scales under the Environmental Protection Policy (Water) 2009* [remade to become the EPP (Water and Wetland Biodiversity) in 2019].

The Reef 2050 WQIP contains end of basin annual anthropogenic load reduction targets for various pollutants across mainland basins draining to the Great Barrier Reef. Pursuant to section 11(64) of the Water Policy, dissolved inorganic nitrogen (DIN) and fine sediment reduction targets have been reflected in the document titled 'Great Barrier Reef River Basins End-of-Basin Load Water Quality Objectives' (September 2019). These are set to achieve relevant marine water quality guideline values set in the Water Quality Guidelines for the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority - GBRMPA, 2010).

The Reef 2050 WQIP also contains targets for pesticides such that end of catchment concentrations of pesticides protect 99% of aquatic species. This corresponds to a high ecological value level of protection. Further information is available from the reef plan website. The ANZG are undertaking a rolling update program for toxicant water quality guidelines (including for a range of pesticides), which will inform this target.

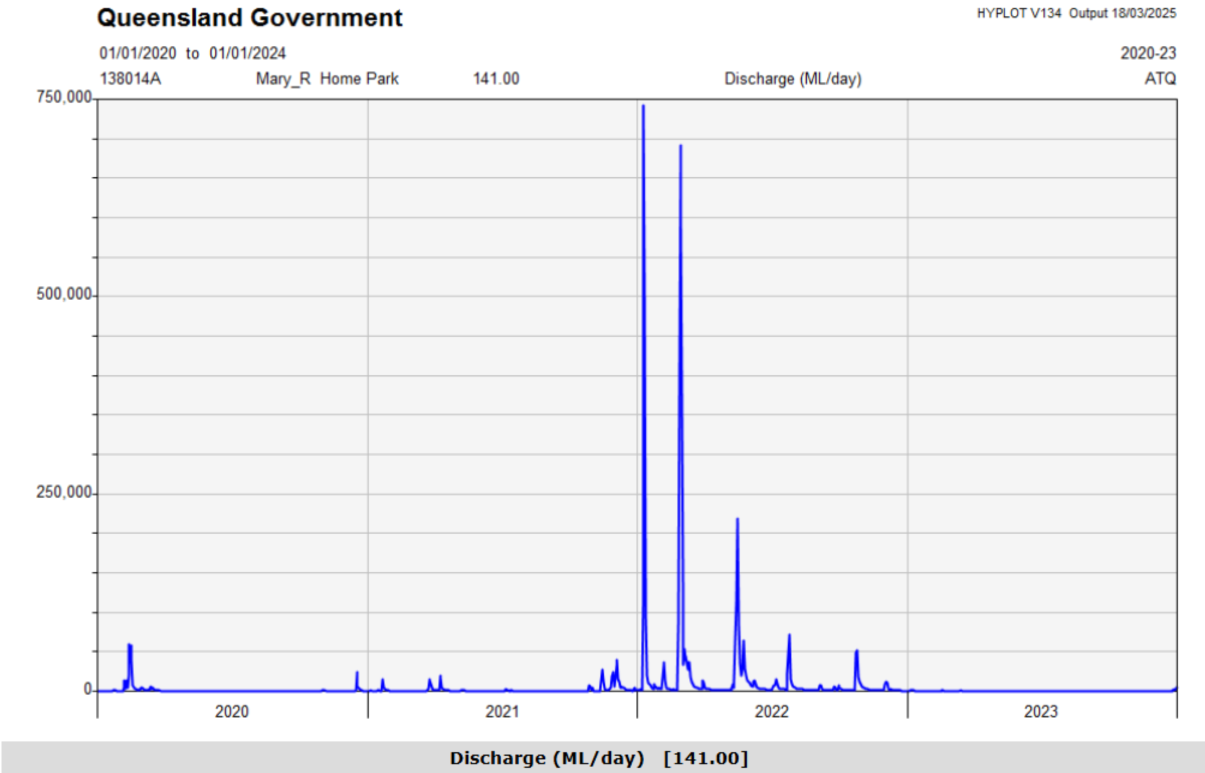
Great Barrier Reef water quality guidelines

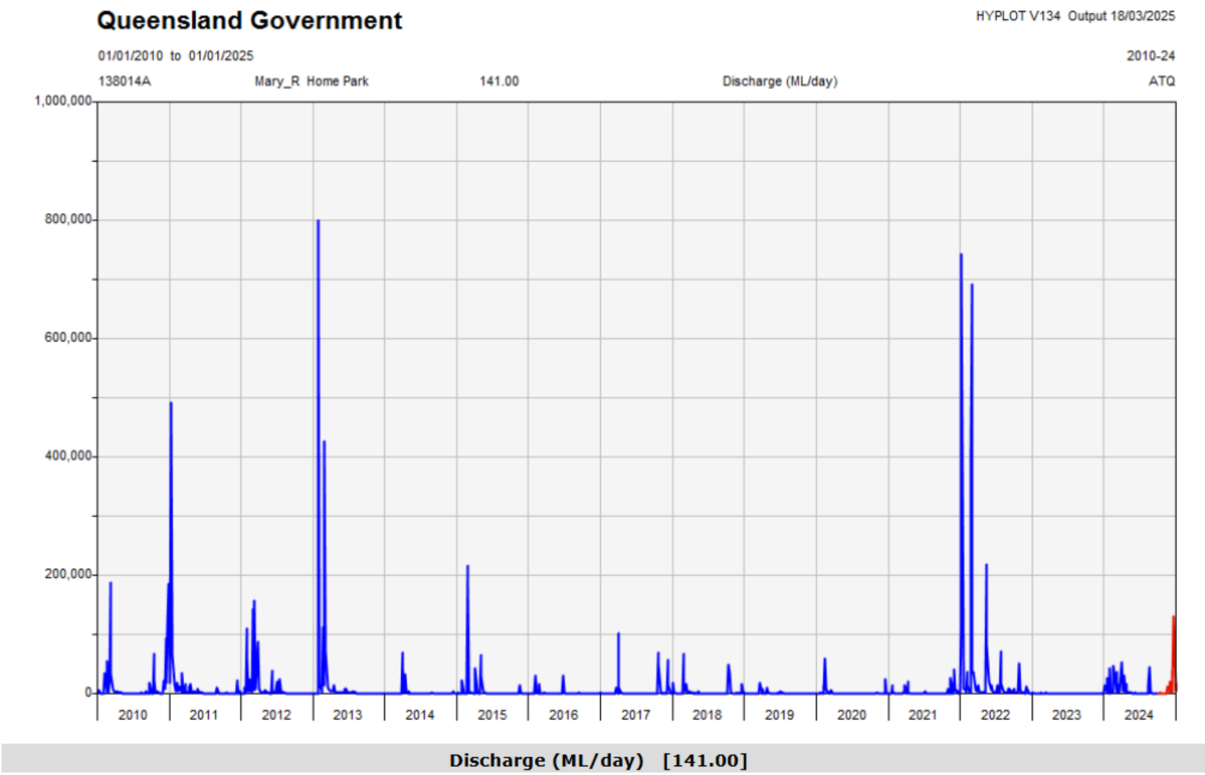
Details on the technical/scientific basis for key GBRMP guideline values relevant to corals (e.g. TSS, chl-a), and how they have been carried through into reef management planning are outlined in other sections of this report. Since the development of Water Quality Guidelines for the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority - GBRMPA, 2010)., GBRMPA and DESI have worked closely together to develop local EVs and WQOs for Queensland state coastal and marine waters overlapping with GBR waters across multiple GBR regions. This information has been incorporated into Water Policy schedule 1 materials (documents and mapping) available from the department's Water Policy webpage. Further information confirming this linkage between GBRMPA and the Water Policy are provided on the GBRMPA water quality webpage, the Water Quality Australia GBR web page, and in the GBRMPA water quality position statement.

Stream discharge

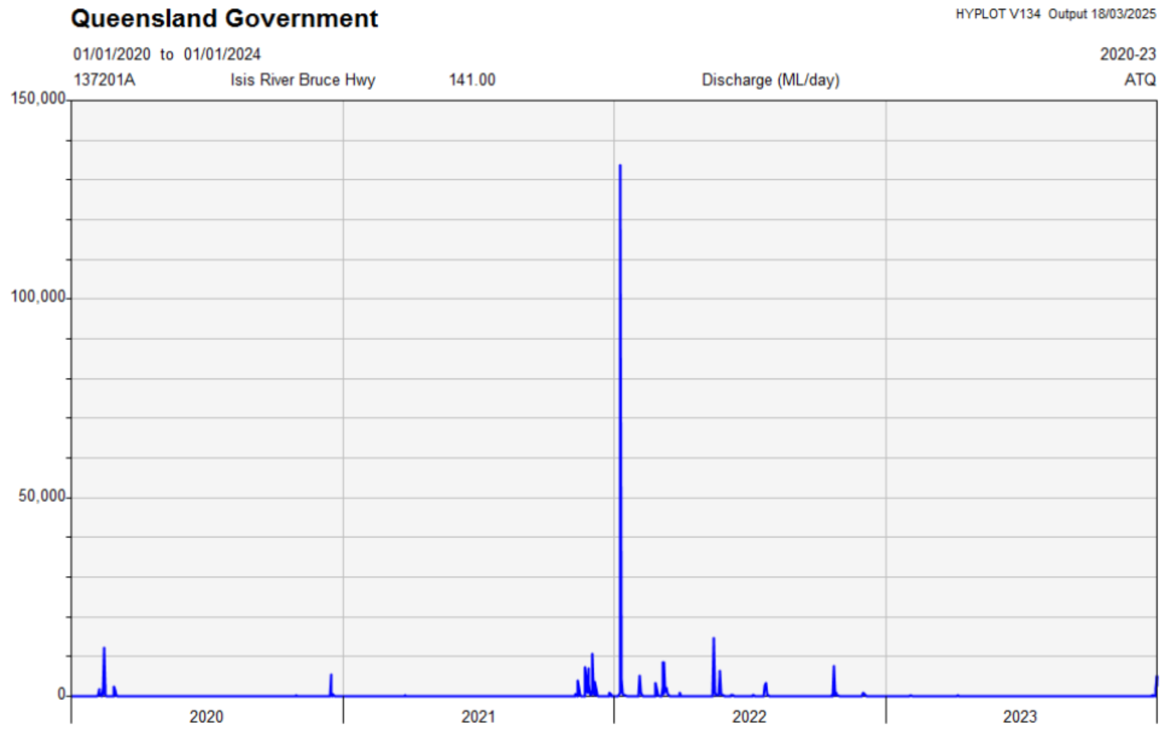
Stream discharge (Megalitres/Day) at key rivers between 01/01/2020 – 31/12/2023 and 01/01/2010 – 31/12/2023

Mary River at Home Park

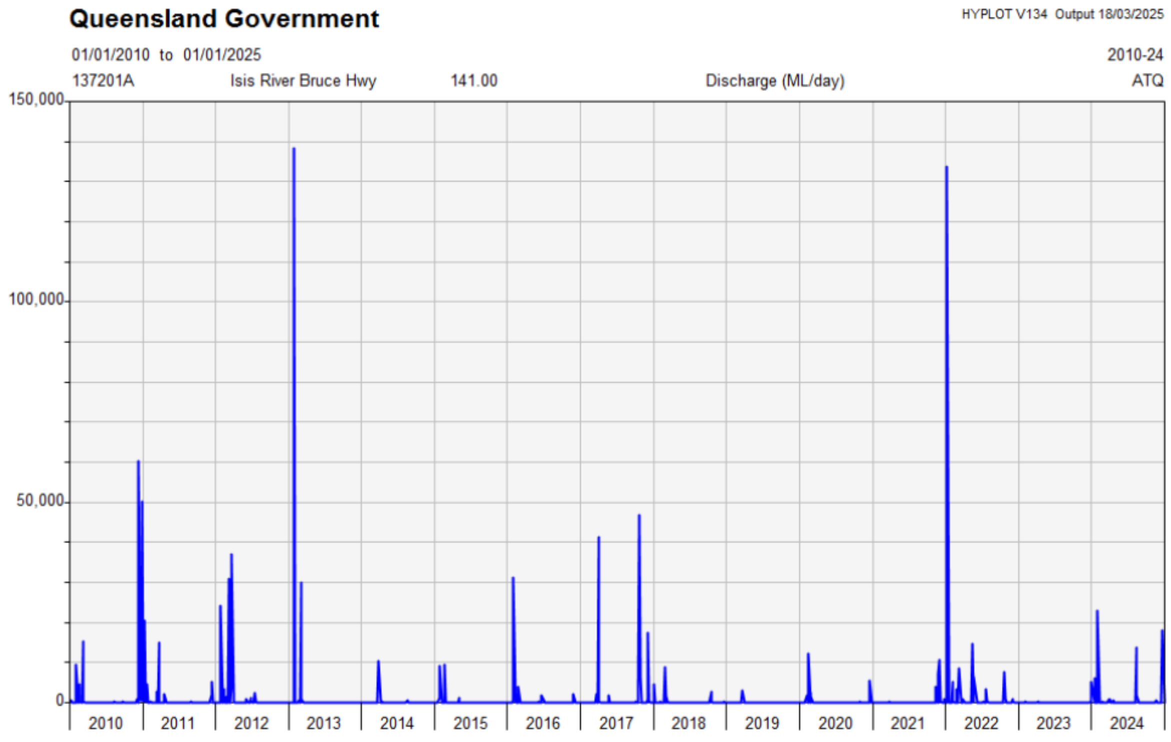




Isis River at Bruce Highway



Discharge (ML/day) [141.00]



Discharge (ML/day) [141.00]

Elliott River at Dr Mays Crossing