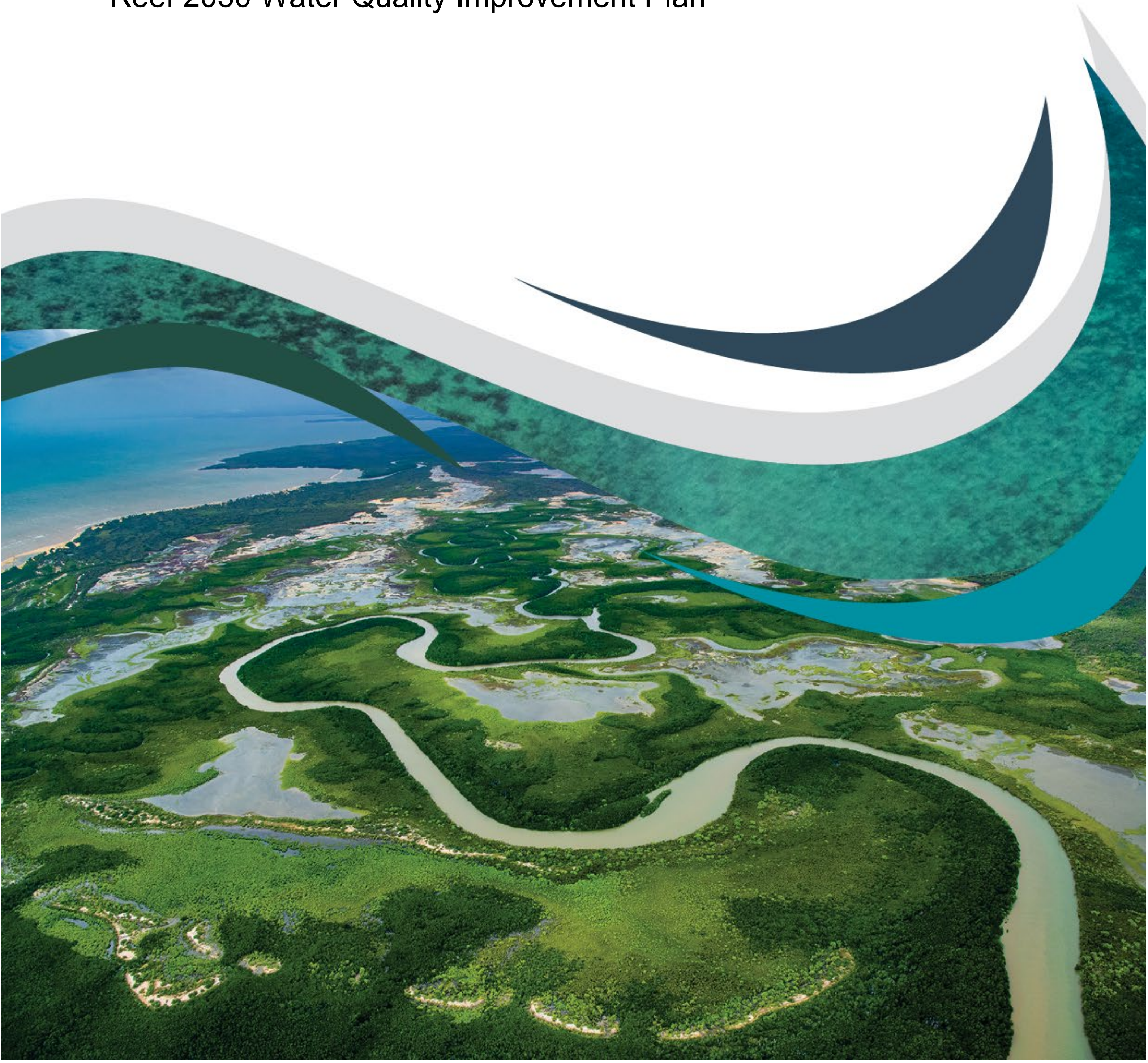
Australian Government

Queensland Government

Catchment monitoring methods

Reef Water Quality Report Card 2021 and 2022

Reef 2050 Water Quality Improvement Plan



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Catchment monitoring methods

This report summarises the methods undertaken by the Catchment monitoring program that reports the catchment monitoring results required for the delivery of the Reef Water Quality Report Card 2021 and 2022. The Catchment Monitoring Program provides data to the Catchment Loads Modelling Program to validate progress towards achieving the Reef 2050 Water Quality Improvement Plan (Australian and Queensland governments 2018) 2025 water quality targets. The Catchment Monitoring Program also delivers Pesticide Risk Condition calculations for comparison of the risk posed by pesticides for each basin, region and the whole of the Great Barrier Reef catchment area, with the Pesticide Risk Baseline and pesticide target.

The water quality targets are:

- 60% reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen loads
- 20% reduction in anthropogenic end-of-catchment particulate nutrient loads
- 25% reduction in anthropogenic end-of-catchment fine sediments loads
- to protect at least 99% of aquatic species from pesticides at the end-of-catchments.

Monitoring sites

Catchment water quality was measured at more than 61 sites across 23 major catchments that discharge to the Great Barrier Reef lagoon (Figure 1) during the 2020-2021 monitoring year, and more than 68 sites across 24 major catchments (Figure 2) during the 2021-2022 monitoring year as part of an ongoing, long-term monitoring program. Water quality monitoring site numbers and locations vary slightly from year to year, due to various logistical, climatic and operational reasons.

During 2020-2021, 55 sites across 23 major catchments were monitored for total suspended solids and nutrients. Pesticides were monitored at 34 sites across 20 major catchments (pesticides were not monitored in the Cape York region). During 2021-2022, 56 sites across 23 major catchments were monitored for total suspended solids and nutrients. Pesticides were monitored at 38 sites across 21 major catchments.

Monitoring sites are classified as either end-of-catchment or sub-catchment sites. The end-of-catchment monitoring sites are located at the lowest point in a river or creek, where the discharge can be accurately measured, typically where gauging stations have been established and are being maintained by the Queensland Department of Natural Resources, Mines and Energy. Sub-catchment sites are located at the lowest point in a sub-catchment (tributary), mainly at existing gauging stations. Water quality samples collected at each monitoring site provide data related to land management activities in the catchment area upstream of the site. Both site types provide field data that are used to calibrate and validate catchment models.

Monitoring currently captures an estimated 92% of the total suspended solid load and 88% of the dissolved inorganic nitrogen load discharged to the Great Barrier Reef lagoon. Pesticides are monitored in all priority locations.

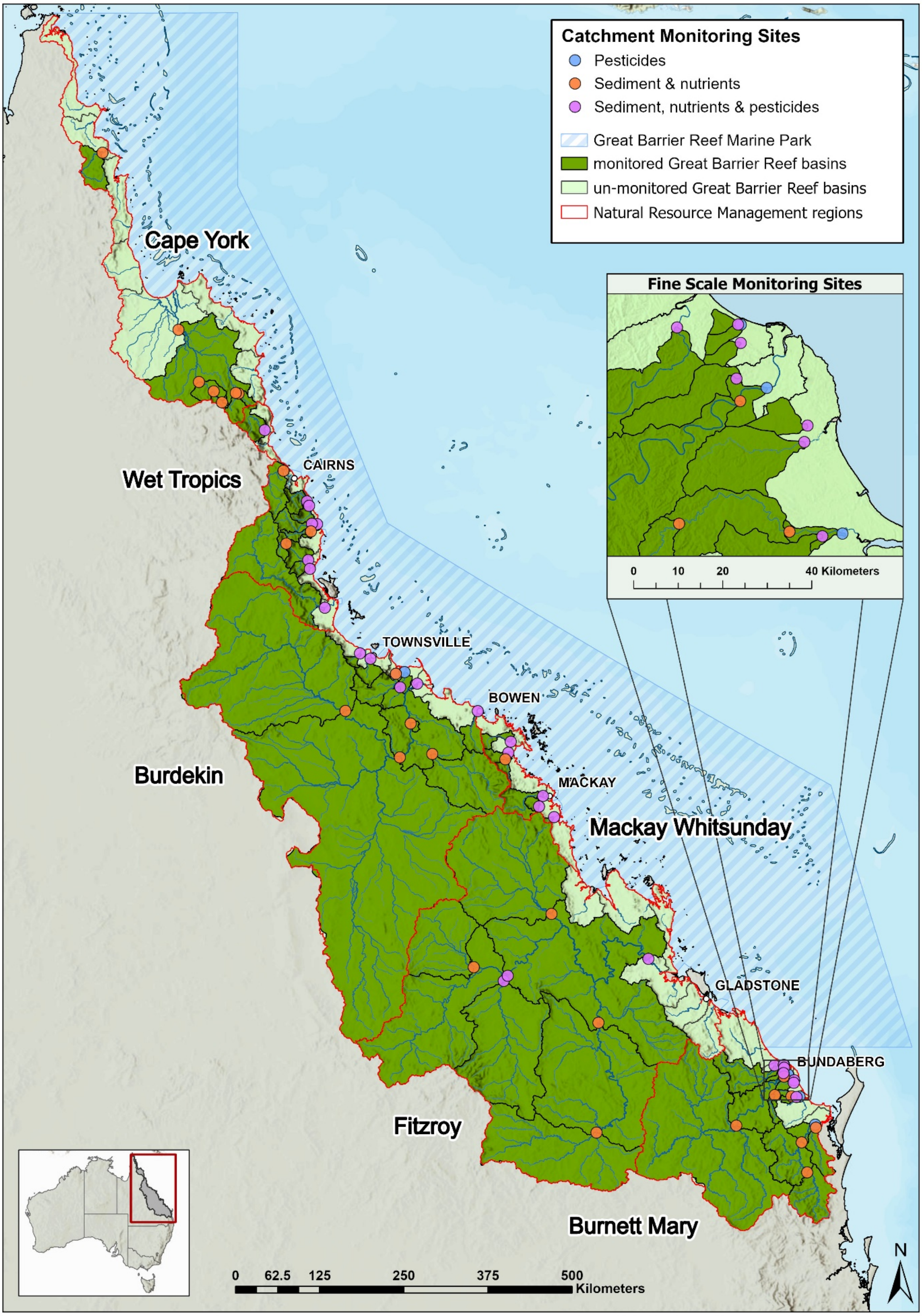

Figure 1: Map showing the location of 2020-2021 monitoring year catchment monitoring program sites in the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program.

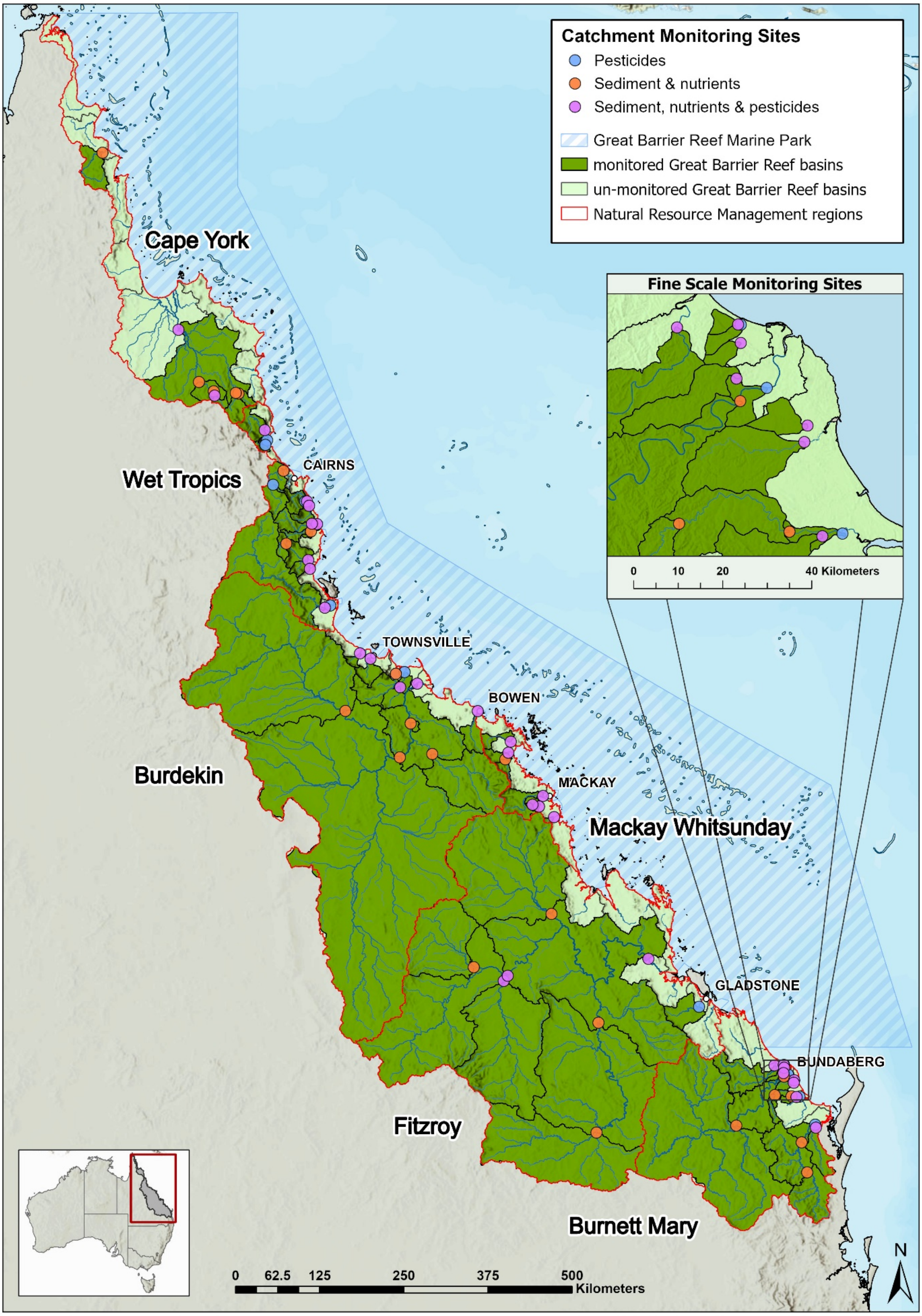

Figure 2. Map showing the location of 2021-2022 monitoring year catchment monitoring program sites in the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program.

Rainfall data

Rainfall totals and rainfall decile data comes from the Bureau of Meteorology National Climate Centre. These data are synthesised using geographic information system tools to display total annual rainfall and annual rainfall deciles for Queensland from 1 July to 30 June each year. The total annual rainfall and annual rainfall deciles provide contextual information regarding the state of the climate during the monitoring year and is described in detail in the annual Great Barrier Reef Catchment Loads Monitoring Program - Condition Report.

Water quality sampling

Water samples are collected, stored, transported and quality assured and quality controlled in accordance with the Environmental Protection (Water) Policy Monitoring and Sampling Manual 2018 (www.ehp.qld.gov.au/water/monitoring/sampling-manual). Water quality samples are collected using two methods: manual grab sampling and automatic grab sampling using refrigerated pump samplers. Intensive sampling (daily or every few hours) is conducted during high flow events and monthly sampling is conducted during low or base-flow (ambient) conditions. For pesticides, intensive sampling (daily or every few hours) is similarly conducted during high flow events and weekly to monthly sampling is conducted during low or base-flow (ambient) conditions over the wet season. For the purpose of sampling pesticides, the standardised wet season (i.e. for assessing the main pesticide exposure period) commences with the first run-off event and continues for 182 days (six months).

Where possible, total suspended solids, nutrients and pesticide samples were collected concurrently. Manual grab samples collected during low flow conditions, where sites are tidally influenced, were taken on the outgoing, low tide. Automatic grab samplers installed in tidal sites were activated during rainfall run-off events based on discharge measured with Horizontal Acoustic Doppler Current Profilers and conductivity and turbidity readings recorded *in situ*.

River discharge data

The volume of water flowing in the rivers is calculated using one of four methods, depending on the location and data availability:

- measured discharge from existing gauging station and extracted from Hydstra - the surface water database of the Department of Regional Development, Manufacturing and Water (Water Monitoring Information Portal);
- 'time and flow factored'[1] measured discharge from existing Department of Regional Development, Manufacturing and Water gauging station(s);
- modelled flows generated in the Source Catchments modelling platform using the Sacramento rainfall runoff model, where the Parameter Estimation Tool (PEST) was coupled with Source for the calibration process; or
- discharge measured by Horizontal Acoustic Doppler Current Profiler, with missing records and periods of low flow and/or strong tide influence infilled with daily modelled flow data.

The selected method for each site is reported annually in the Great Barrier Reef Catchment Loads Monitoring Program - Condition Report.

1 Time and flow factors adjust the flow by adding a time delay due to travel time from the upstream gauging station to the water quality sampling site, and to account for the change in discharge between the upstream gauging station and the end of catchment site due to differences in catchment area.

Water quality sample analysis

The Science Division Chemistry Centre (Dutton Park, Queensland) analyses water samples for total suspended solids and nutrients (Table 1). The Queensland Health Forensic and Scientific Services Organics Laboratory (Coopers Plains, Queensland) analyses water samples for pesticides (Table 2). Both laboratories are accredited by the National Association of Testing Authorities for the analyses conducted.

Table 1: Summary information for each reported analyte in the catchment monitoring program

Reported pollutants	Abbreviation	Measured analytes
Sediment (Total suspended solids)	TSS	Total suspended solids
Total nitrogen	TN	Total nitrogen as N
Particulate nitrogen	PN	Total nitrogen (suspended) as N
Dissolved organic nitrogen	DON	Organic nitrogen (dissolved) as N
Ammonium nitrogen as N	NH_4-N	Ammonium nitrogen as N
Oxidised nitrogen as N	NO_x-N	Oxidised nitrogen as N
Dissolved inorganic nitrogen	DIN	Ammonium nitrogen as N + Oxidised nitrogen as N
Total phosphorus	TP	Total phosphorus as P
Particulate phosphorus	PP	Total phosphorus (suspended) as P
Dissolved organic phosphorus	DOP	Organic phosphorus (dissolved) as P
Dissolved inorganic phosphorus	DIP	Phosphate phosphorus as P

Pesticide monitoring and reporting differs from nutrients and suspended solids due to the large range of pesticides used in agriculture and the variation in their use from one year to the next. For this reason, water samples are analysed for a general suite of pesticides. However, not all pesticides that are detected are reported each year. Other detected and non-detected pesticides are available in the Pesticide Reporting Portal. A sub-set of pesticides, referred to as the *reference pesticides*, were used to measure and compare the Pesticide Risk Condition of catchments, basins and the whole GBR catchment area against the Pesticide Risk Baseline and Reef 2050 pesticide target[2]. The reference pesticides (Table 2) were selected based on the frequency of detection in catchments, the availability of ecotoxicity data for individual pesticides as an indicator of risk, and the scope to model application and run-off of chemicals using Source Catchment models. The reference pesticides include herbicides and insecticides used in a range of agricultural land uses, including sugarcane, grazing, cropping and horticulture.

2 Note: The pesticide target encompasses all pesticides in GBR water bodies. All possible measures are taken to include as many pesticides in the metric to measure progress towards the target; however, measuring and modelling progress is reliant on other data (e.g. ecotoxicity and application data) not just concentration information, which is not available for all pesticides detected in catchments. For this reason, not all pesticides are included in the metric to measure progress towards the target. The number and types of pesticides included in the metric will expand over time as new data are collected.

Table 2: Pesticides included in Pesticide Risk Metric (not all of the listed pesticides were necessarily detected in collected water samples)

Reference pesticide	Pesticide type	Mode of action
Chlorpyrifos	Insecticide	Acetylcholine esterase (AChE) inhibitor
Fipronil	Insecticide	Gamma-aminobutyric acid (GABA) gated chloride channel blocker
Imidacloprid	Insecticide	Nicotinic receptor agonist
Haloxyfop	Herbicide	Acetyl-coenzyme A carboxylase (ACCase) inhibitor
Imazapic	Herbicide	Acetolactate synthase (ALS) inhibitor
Metsulfuron-methyl	Herbicide	
Pendimethalin	Herbicide	Microtubule synthesis inhibitor
Metolachlor	Herbicide	Very long chain fatty acid (VLCFA) inhibitor
Ametryn	Herbicide	Photosystem II inhibitor
Atrazine	Herbicide	
Terbuthylazine	Herbicide	
Tebuthiuron	Herbicide	
Simazine	Herbicide	
Diuron	Herbicide	
Terbutryn	Herbicide	
Hexazinone	Herbicide	
Metribuzin	Herbicide	
2,4-D	Herbicide	Auxin mimic (Phenoxy-carboxylic acid auxins)
MCPA	Herbicide	
Fluroxypyr	Herbicide	Auxin mimic (Pyridine-carboxylic acid auxins)
Triclopyr	Herbicide	
Isoxaflutole	Herbicide	4-hydroxyphenylpyruvate dioxygenase (4-HPPD) inhibitor

Calculating nutrient and sediment loads

The suitability of the generated water quality monitoring data for use in load calculations was assessed using a sample representivity rating. The annual rating of sampling representivity was assessed against two criteria:

1. the number of samples collected in the top five per cent of annual monitored flow
2. the ratio between the highest flow rate at which a water sample was collected and the maximum flow rate recorded.

The representivity was determined for each monitoring year by assigning a score using the system presented in Table 3.

Table 3: Scores assigned to total suspended solids and nutrients data to determine their representivity

Number of samples in top 5% of flow	Score	Ratio of highest flow sampled to maximum flow recorded	Score
0 – 9	1	0.00 – 0.19	1
10 – 19	2	0.20 – 0.39	2
20 – 29	3	0.40 – 0.59	3
30 – 39	4	0.60 – 0.79	4
>40	5	>0.80	5

The rating of sample representivity for each analyte was the sum of the scores for the two criteria. Sample representivity for each analyte was rated as 'excellent' when the total score was greater than or equal to eight, 'good' when the total score was six or seven, 'moderate' for total scores of four or five, or 'indicative' when the score was less than four. Furthermore, hydrographs were visually assessed to verify the representivity rating.

For nutrients and sediment, the concentration and flow data are used to determine the total load of each pollutant that is transported past the monitoring site in each catchment and sub-catchment. Annual and daily loads are calculated for total suspended solids and the nutrient analytes listed in Table 1, using the ReLo[3] loads calculation software developed by the Queensland Department of Environment, Science and Innovation. The loads estimation models incorporated in the software are consistent with Water Quality Analyser 2.1.2.6 (eWater 2012). The total suspended solids and nutrient loads were calculated using concentrations reported in milligrams per litre (mg L^{-1}).

One of two methods was used to calculate loads: the average load (linear interpolation of concentration) or the Beale ratio. Average load (linear interpolation of concentration) is the most accurate and reliable method, provided events are adequately sampled, with a representivity rating of excellent. For complex events or events with a representivity rating of good, moderate or indicative, the Beale ratio is one of the recommended methods (Joo et al. 2012).

Calculating the Pesticide Risk Metric

The Pesticide Risk Metric estimates the percentage of species protected from mixtures of pesticides detected during a standardised wet season. This period is typically when the vast majority of rain occurs and therefore the greatest probability that pesticides will be transported, either as soluble or bound forms, to waterways and their associated aquatic ecosystems. The wet season was defined as the six-month period (182 days) following the first flush in each monitored waterway.

The Pesticide Risk Metric was calculated from the monitored concentration data for the 22 reference pesticides (Table 2), and forms the basis of pesticide reporting in the Great Barrier Reef Catchment Loads Monitoring Program Condition Report and the Pesticide Risk Condition for the Reef Water Quality Report Card 2020. Pesticide Risk Condition can be used to assess distance from the Pesticide Risk Baseline[4]. Details of all the methods involved in the calculation of the Pesticide Risk Metric, Pesticide Risk Baseline and Pesticide Risk Condition are provided in Warne et al. (2020a), Warne et al. (2020b) and Neelamraju et al. (2021). A brief overview of the principal components of the Pesticide Risk Metric are provided below.

The 22 reference pesticides have multiple different modes of action (Table 2). The toxicity of pesticides with different modes of action was calculated using the independent action model of joint action (Plackett and Hewlett 1952) within the multiple-substance-potentially affected fraction (ms-PAF) method

3 ReLo is a software program developed by the Queensland Department of Environment and Science. The loads estimation models incorporated in this software are consistent with Water Quality Analyser 2.1.2.6 (eWater 2012). ReLo allows the batch processing of load calculations, a function that is not currently available within Water Quality Analyser (eWater 2012).

(Traas et al. 2002). The pesticide mixture toxicity was calculated for all samples collected over the wet season. Where there was more than one sample per day, a daily mean pesticide mixture toxicity value was calculated.

In order to express the concentration data for all 22 reference pesticides as a single number that represents the wet season pesticide risk to aquatic ecosystems, the mixture toxicity data (i.e. Pesticide Risk Metric values) for all water samples collected over the wet season were then summarised as a single value. This required estimating the daily average per cent of species affected for days that were not monitored during the wet season using a multiple imputation technique (Rubin 1996; Donders et al. 2006; Patrician 2002). This involved fitting a statistical distribution to the observed data for the wet season for the site. This distribution was then used to impute values to fill in the missing days in the 182-day period. The application of the Multiple Imputation method assumes that the distribution of sampling over the wet season encompasses the variability of pesticide concentrations over the wet season. This was usually ensured by having a good balance between ambient samples and event samples. Where that balance of ambient and event samples could not be achieved, then a decision was made about whether the calculated Pesticide Risk Metric was a reliable estimate of the wet season risk[5]. The resultant 182 days of data were then divided by 182 to obtain the Pesticide Risk Metric and ranked into five risk categories (Table 4). These categories were consistent with the ecological condition categories used in the Australian and New Zealand Water Quality Guidelines (ANZWQG) for Fresh and Marine Waters.

The Pesticide Risk Metric method was used to obtain pesticide risk values for four groups of pesticides - total pesticides (all 22 pesticides included in the Pesticide Risk Metric), insecticides, photosystem inhibiting (PSII) herbicides and other (non-PSII) herbicides.

Table 4: Risk categories used to assess pesticide risk

Pesticide Risk Metric value		Risk category	Ecological condition (ANZWQG)
% species affected	% species protected		
≤1%	≥99%	Very low	High Ecological Value
>1 to 5%	95 to <99%	Low	Slightly to Moderately Disturbed
>5 to 10%	90 to <95%	Moderate	Highly Disturbed
>10 to 20%	80 to <90%	High	
>20%	<80%	Very high	

Once the Current Basin Condition values were obtained for PSII Herbicides, Other Herbicides and Insecticides, they were converted from per cent species protected to per cent species affected (i.e., 100% - % species protected). The Current Basin Condition (per cent species affected) values for PSII Herbicides, Other Herbicides and Insecticides were summed. The relative contribution for PSII Herbicides was calculated for each basin using Equation 1.

Equation 1:

$$\text{Relative contribution (PSII)} = 100 \times \left(\frac{\%\ \text{affected}_{\text{PSII}}}{\sum \%\ \text{affected all groups}}\right) \quad (1)$$

where $\%\ \text{affected}_{\text{PSII}}$ is the estimated per cent of species affected by PSII Herbicides for a basin and Σ % affected all groups is the estimated sum of the per cent species affected by PSII Herbicides, Other Herbicides and Insecticides for the same basin.

5 In the 2021-2020 monitoring year, a decision was made that the Current Pesticide Risk for the Don River basin would not be calculated for Reef Water Quality Report Card because the sampling across the wet season was biased toward event monitoring, and therefore not reflective of the risk across the wet season.

The relative contribution of Other Herbicides (OH) and Insecticides (I) of each basin were calculated using equations 2 and 3, respectively.

Equation 2:

$$\text{Relative contribution (OH)} = 100 \text{ x } \left(\frac{\%\ \text{affected}_{OH}}{\sum \%\ \text{affected all groups}}\right) \quad (2)$$

Equation 3:

$$\text{Relative contribution (I)} = 100 \text{ x } \left(\frac{\%\ \text{affected}_{I}}{\sum \%\ \text{affected all groups}}\right) \quad (3)$$

where % affected$_{OH}$ and % affected$_{I}$ are the estimated per cent of species affected by Other Herbicides and Insecticides, respectively for a basin.

Reporting on pesticides for the report card

Pesticide monitoring data from the Great Barrier Reef Catchment Loads Monitoring Program were used to calculate the Pesticide Risk Metric (expressed as a per cent of species protected) at each monitoring site. These data were weighted according to the size of the sub-catchment compared to the catchment they belong to. The weighted values were then used to modify the per cent of species protected values from the Pesticide Risk Baseline (Warne et al. 2020b) to estimate the Pesticide Risk Condition of each catchment. The same approach was applied to the regions and the entire Great Barrier Reef Catchment Area. This method does not enable reporting of progress to the pesticide target, as the Pesticide Risk Condition values are affected by annual variations in climatic conditions. The relative contribution of PSII herbicides, other herbicides and insecticides to the Pesticide Risk Metric values was also determined for each catchment. Details of all these calculations are provided in Neelamraju et al. (2021).

Semiquantitative confidence rankings for reporting on pesticides

Data confidence ●●●○○

A multi-criteria analysis was used to score the confidence in each indicator used in the report card from low to high (Australian and Queensland governments 2020). The approach combined expert opinion and direct measures of error for program components where available.

The methods used to calculate Pesticide Risk Condition, and distance from the Pesticide Risk Baseline, received a three-dot confidence ranking. The rationale for this confidence ranking is provided below.

Rationale for the confidence ranking

Maturity of methods

A score of three was awarded because the methods have now been thoroughly reviewed. This resulted in a final score of 1.5 when the 0.5 weighting factor was applied. The score of 1.5 applied to catchments, basins, regions and the GBRCA scales.

Validation

An overall score of two was awarded because the data used in the calculations have either been validated or are direct measurements from monitoring (analytical results), but the per cent of species protected have not validated in the field.

Representativeness

An overall score of two was awarded based on a representivity assessment for the predictions at the whole of the Great Barrier Reef scale. This value was awarded because the high-confidence monitoring data at the catchment scale was used to adjust values at the basin, region and whole of GBR levels.

Directness

An overall score of two was awarded because there are a series of four quantified relationships between land use, hydrological and climatic variables with pesticide mixture toxicity. A higher score was not awarded as the per cent of species protected at the end of catchments is not directly measured.

Measurement error

A score of two was awarded because some components do not have error quantified.

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