

Catchment loads modelling methods

Reef Water Quality Report Card 2023–2025

Reef 2050 Water Quality Improvement Plan



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Catchment pollutant delivery — catchment loads modelling methods

This report summarises the data and methods used for reporting progress toward the Reef 2050 Water Quality Improvement Plan (Australian and Queensland governments 2018) 2025 water quality targets. The catchment loads modelling program is one line of evidence used to report on progress in the Reef Water Quality Report Card 2023–2025.

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 sediment loads
- pesticides: to protect at least 99% of aquatic species at the end-of-catchments.

Catchment loads modelling

Quantifying the impact of land management practice change on long-term water quality through monitoring alone is not possible at the whole Great Barrier Reef (GBR) scale. Models are, therefore, used in conjunction with the monitoring program to predict long-term changes in water quality.

The purpose of the modelling is to report on the progress towards the Reef 2050 Water Quality Improvement Plan 2025 load reduction targets for fine sediment (FS), dissolved inorganic nitrogen (DIN), particulate phosphorus (PP) and particulate nitrogen (PN). The ability to model progress towards the new pesticide target is in development. In the meantime, pesticide risk is reported through the catchment loads monitoring program.

This document provides a summary of the catchment loads modelling methods. A detailed outline of the modelling methods and outputs are available from McCloskey et al., 2021a and McCloskey et al., 2021b.

Modelling framework

The eWater Source Catchments modelling framework (eWater, 2010) was modified to GBR Source (Ellis 2017) to enable the synthesis of management practice change, paddock monitoring and modelling, plus catchment monitoring data to estimate end-of-catchment pollutant loads. The catchment models generate pollutant loads for current/ baseline conditions for up to 10 land uses, and improved practices for land uses where management practice change is reported (e.g. grazing, and cropping land uses). Modelling is conducted over a fixed climate period. This enables changes in water quality that are only due to the implementation of improved management practices to be modelled.

Model scenarios

To quantify changes in pollutant loads resulting from the adoption of improved agricultural management practices, three model scenarios¹ are run for a fixed 30-year climate period:

- **Pre-development load** (prior to agricultural development)

¹ A scenario describes the major processes in a river system or catchment that are modelled. This includes catchment and sub-catchment definition, rainfall run-off and constituent generation models, data sets and parameters. You can create multiple scenarios to break complex projects into distinct parts or duplicate existing scenarios to conduct what-if experiments without disrupting the original. Any change to the definition of sub-catchments, node-link network, FUs, or the models within FUs, forms a new scenario. Similarly, a different set of inputs or parameters can be used to set up a new scenario, such as a change in land use or a climate change (eWater Source User Guide 4.1).

- **Baseline load** representing the current (2023) agricultural management practice benchmark
- **Change (improved practice) load**, where the proportion of land managed under improved practices is adjusted to reflect adoption for the reporting period.

The proportion of land managed under defined practices is the only variable that changes between these scenarios. This enables the calculation of relative load reductions attributable solely to improved agricultural management practices.

Baseline loads are estimated for the current (2023) management practice benchmark. Load reductions are then calculated by running the model with the new practice adoption layer for the same 30-year modelling period as the baseline. The difference in load is the load reduction for that reporting period.

Catchment modelling approach

Pollutant loads are summarised in the Reef Water Quality Report Card for the 35 basins draining to the Great Barrier Reef lagoon. This catchment-scale water quantity and quality model uses a node link network to represent processes of generation, transport and loss of water and constituents within major waterways in a catchment (see Figure 1). The model generates estimates of run-off and pollutant loads for each functional unit. Functional units (FUs) are areas within a sub-catchment that have similar behaviour in terms of run-off generation and/or nutrient generation e.g. land use within a sub-catchment. Run-off and pollutants are transported from a sub-catchment through the stream network, represented by nodes and links, to the end of the catchment. These components represent the sub-catchment and waterway network.

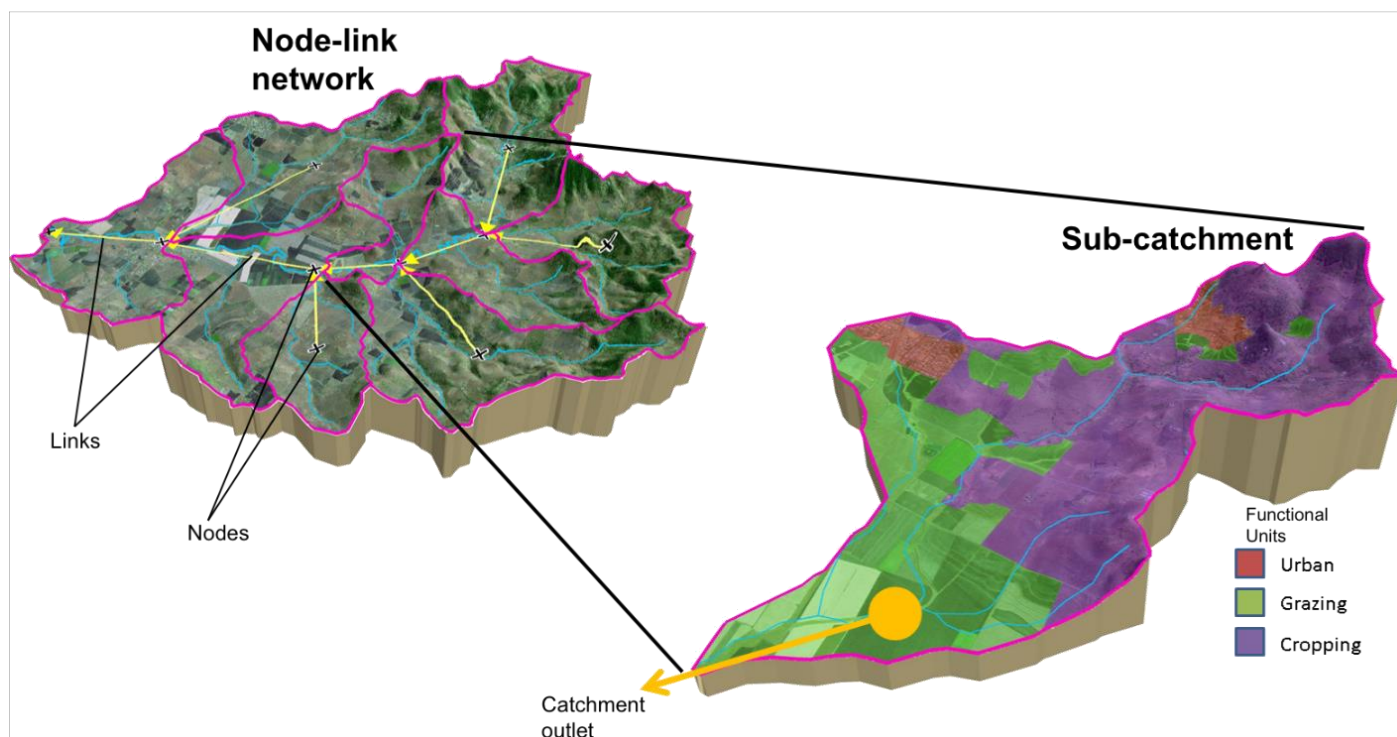


Figure 1: Example of a functional unit (FU) and node-link network generated in Source Catchments (source eWater).

The Source Catchment model runs at a daily time-step which enables the interactions of climate and land management to be reflected in modelled outputs. Aggregated average annual catchment loads are required for the Reef Water Quality Report Card. The model runs for a fixed climate period (1993 to 2023), to remove the

influence of climate on estimated load reductions. The most current land use mapping is incorporated when models are periodically updated.²

The pollutants modelled were:

- fine sediment (FS) and coarse sediment
- dissolved and particulate nutrients.

Water quality risk frameworks

The Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef program) agricultural management practice adoption program has developed water quality risk frameworks for each agricultural industry. These frameworks articulate best management practice in relation to the Reef 2050 Water Quality Improvement Plan land and catchment management targets for agricultural management practice adoption. These practices are described in terms of their relative water quality risk, from low to high.

Representation of a pre-development scenario

It is important to note that the pre-development modelled loads were constructed to reflect a scenario prior to agricultural development. The aim was to enable load changes from management to be quantified. The scenario does not represent a true pre-development landscape. Offshore coral coring and sediment tracing work suggests fine sediment loads have increased anywhere from 1 to 5 times the pre-development load (Bartley *et al.* 2018, Lewis *et al.* 2014 and Hughes *et al.* 2009, McCulloch *et al.* 2003a). The modelled estimates of fine sediment fall within these ranges.

Key assumptions made when modelling pre-development are:

- hydrology was kept the same for baseline and the pre-development land management scenarios with dams and weirs maintained
- ground cover was increased to 95% in grazing areas
- with the exception of grazing, all other land uses reverted to nature conservation area
- the foliage projected cover layer was increased to 95% riparian cover
- gully cross-section areas were reduced to 10% of their baseline values.

Reporting load reductions

For each Reef Water Quality Report Card three scenarios (pre-development, baseline, and change) are run over the 30-year period. The proportion of land managed using defined management practices is the only variable that changes between modelled scenarios.

This approach allows for the relative load reductions attributed to the areas of improved agricultural management practices to be reported. Approximately 10 land uses are modelled in each region including grazing, sugarcane, grain cropping, horticulture and bananas.

Calibration, validation and review

Modelled load estimates were calibrated and/or validated against field data collected through the [Catchment Loads Monitoring program](#). This includes:

- 26 end-of-catchment sites

² Details of the mapping datasets can be found on the Queensland Land Use Mapping Program website at www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/qlump/qlump-datasets

- 22 sub-catchment sites
- 8 fine-scale monitoring sites that discharge to the Great Barrier Reef lagoon.

For further information on the model calibration and validation processes and results, refer to McCloskey et al., 2021a and McCloskey et al., 2021b.

The Catchment Loads Modelling program undergoes an external peer review every three to four years. The program was reviewed in 2012, 2015, 2019, and 2024. Prior to the release of each Reef Water Quality Report Card, modelled load estimates are reviewed both internally and externally.

Management practice change

The Reef 2050 Water Quality Improvement Plan [water quality risk frameworks](#) describe and categorise farming practices according to recognised water quality improvements at the paddock scale. Improvements in water quality as a result of adopting improved management practices were determined by linking paddock model time series outputs to catchment models.

Management practice change has been modelled for the sugarcane, grains, horticulture, banana and grazing areas of the Great Barrier Reef catchments. For details on how management practice changes are represented in the modelling, refer to McCloskey et al. 2017A and Waters *et al* 2014.

Improved management of gullies and streambanks are modelled to reflect activities such as gully restoration, excluding stock via fencing off gullies and streambanks, and installing off-stream watering points. Spatial data on investments in improved practices are provided by industry and the six natural resource management (NRM) bodies within each region to enable good spatial representation of where works occurred.

Modelling assumptions

- Loads reported for each report card reflect the relative change in modelled average annual loads for the specified model run period (1993 to 2023).
- Land use areas in the model are static over the model run period and are based on the latest available Queensland Land Use Mapping Program (QLUMP) data.
- Paddock model outputs used in the catchment models, represent 'typical' management practices in each management class and do not reflect the actual array of management practices being applied on a particular area of land. The data to support individual representation of every agricultural enterprise does not exist and is unlikely to ever do so.
- Paddock model simulations represent the reported management practice adoption water quality risk frameworks as a set suite of practices.
- Management practices such as soil management, fertiliser regimes, mill mud application rates, irrigation, and water recycling were defined through consultation with relevant local industry groups and technical experts in each region.
- Paddock models use broad scale, simplified layers of soils and climate zones, which are fit for the purpose of modelling end-of-system loads. They will not provide an accurate representation of landscape attributes and climatic variation at a farm scale.
- Management practice adoption areas represented in the model are applied at the spatial scale of the data supplied by the delivery organisations and collated by the Queensland Department of Primary Industries (DPI) Paddock to Reef Agricultural Management Practice Adoption program team annually.
- The water quality benefits from adopting a management practice change are modelled across the entire model period, so time lags that may occur in the system are not accounted for.
- It is important to note that the modelled load reductions are based on improved land management adoption data supplied by organisations that receive Australian and Queensland government funding

to increase the adoption of best management practices. Results are, therefore, indicative of the likely long-term water quality response due to adoption of improved land management practices for a given scenario, rather than a measured reduction in load.

Linking paddock and catchment models

The eWater Source model (www.ewater.org.au) was modified to incorporate hillslope constituent generation from the most appropriate paddock models for cropping, banana and sugarcane areas, and the Revised Universal Soil Loss Equation (RUSLE) for grazing. Gully and streambank erosion and floodplain, channel and reservoir deposition processes added to the model were based on the SedNet/ ANNEX approach (Wilkinson et al. 2014). The modified framework is referred to as GBR Dynamic SedNet. A detailed description can be found in Ellis and Searle (2013) and Ellis (2017). The spatial and temporal representation of gully, streambank and in-stream erosion processes were incorporated to better represent the erosion processes observed in the summer-dominant rainfall areas of northern Australia.

Two approaches were used to represent improved land management practices in the Source model depending on the land use of interest. In the first approach, for sugarcane, bananas and cropping, the constituent time series (e.g. load per day per unit area) for the given land use was supplied from a paddock model. Unique combinations of climate, soil type and defined management practices within each land use were identified and represented spatially in the paddock model simulations used to inform the catchment models. For cropping (grain cereal crops) and bananas, the HowLeaky model was used (Rattray et al. 2004). For sugarcane modelling, the Agricultural Production Systems sIMulator (APSIM) (Holzworth et al. 2014) was used. For load reduction representation, the defined management practice for a particular land use segment was altered between scenarios.

In the second approach, the RUSLE model was written into the Source model to model hillslope soil erosion in grazing lands. The cover term (C-factor) in the model is generated from remotely sensed ground cover satellite imagery seasonally (four scenes per year). The paddock-scale model GRASP (McKeon et al. 1990) was used to provide scaling algorithms for each scenario to account for changes in management in each identified land type; for example, shifting areas from moderate risk to moderate-low risk. These scaling algorithms were applied at the pixel scale to each ground cover satellite image for the modelling period. This is applied according to a spatial representation of areas of defined management practices as provided annually by regional NRM bodies. Calculations were performed pixel by pixel, with results accumulated to a single land use representation in each sub-catchment. All loads generated for each land use represented within a sub-catchment were then aggregated at the sub-catchment scale and routed through the stream network.

Total load

The **total baseline load** is the load modelled within each Great Barrier Reef basin using the 2023 management practice benchmark. A pre-development scenario was also built (described above). The model was then run for a 30-year period to establish an average annual load for this period: **the pre-development load**. The **anthropogenic load** was calculated as the total baseline load less the pre-development load.

Load reductions

To reflect investment in improved management practices since 2023, the model was then re-run in each year for the same climate period using the proportions of lowest risk to high risk management practice areas in that year. The relative change in pollutant loads from the anthropogenic baseline after investment reflects the load reduction due to changes in management practices (see Figure 2).

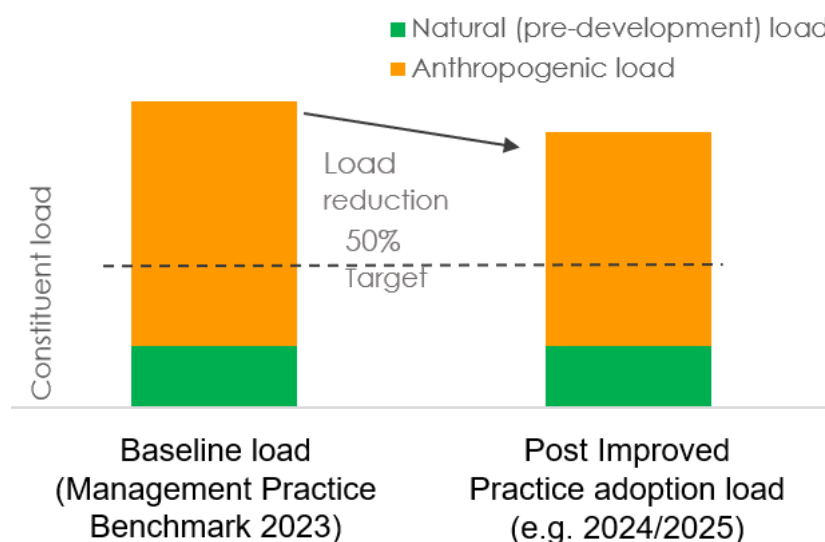


Figure 2: Example of modelled pre-development and anthropogenic pollutant loads, and the load reduction following investment in improved management practices.

Modelling improvements

In response to the independent external reviews of the program in 2015, 2019 and 2024, and recommendations from the Queensland Audit Office and the Great Barrier Reef Water Science Taskforce (GBRWST, 2016), improvements include:

- hydrology recalibration using an approach consistent with Queensland Hydrology (the Queensland Government unit responsible for water planning modelling; Egan, 2024) which has significantly improved the model performance
- model run period shifted to 1993–2023 (cf. 1986–2014) to better represent average annual loads under current conditions
- improved model calibration and validation using an increasing pool of monitoring data (most catchment water quality data is available from 2010 onwards)
- land use updated across the GBR catchment area to 2021
- significant improvements were made to the streambank model, including better representation of bankfull flow, using LiDAR to parameterise stream cross sections and new regressions for parameter application
- improved modelling of floodplain deposition through improved representation of flow distribution between the stream channel and floodplain
- updates to soil input datasets including surface and subsurface nitrogen (N) and phosphorus (P) concentrations, surface and subsurface clay silt fraction, soil erodibility, among others
- improved hillslope erosion modelling through updated ground cover data
- updates to riparian vegetation extent, floodplain area and bank erodibility
- updated gully density and cross-sectional information based on the Queensland Government gully mapping program
- updated sewage treatment plant data
- a conservative approach to instream deposition and remobilisation was applied by setting those processes to equilibrium in Cape York and Wet Tropics, consistent with other NRM regions
- adjustment to storage trapping to better represent the 20 µm fraction of fine sediments

- incorporation of the reference water quality data from areas with a lower level of catchment modification (e.g., conservation areas) to improve the pre-development load estimates (see further explanation below)
- refinement of acceptable parameter bounds and parameter justification, including identification of default parameter values
- comprehensive model quality assurance and quality control, including rigorous cross-regional checks, as well as the development of default models and a specialised dashboard for rapid model evaluation (both inputs and outputs)
- annual monitoring/modelling validation workshops are held to compare model performance against monitoring data
- research into parameter sensitivity/uncertainty in modelled inputs and outputs is continuing to guide future data collection and provide estimates of load uncertainty.

How the information is reported

Progress towards the targets is estimated by determining how much the modelled pollutant load has reduced from the average annual modelled anthropogenic baseline (total load less the pre-development load). This is calculated as a percentage reduction in average annual modelled load.

The average annual percentage reduction in load is calculated as:

$$\text{Reduction in load (\%)} = \frac{(\text{anthropogenic baseline load} - \text{anthropogenic change}) \times 100}{\text{anthropogenic baseline load}}$$

where, anthropogenic baseline load = total load less pre-development load

The results are presented in the Reef Water Quality Report Card 2023–2025 as the percentage progress towards load reduction targets. This is calculated as the reduction in load (percent), as calculated above, divided by the target load reduction (percent).

The progress to date in load reductions is calculated as:

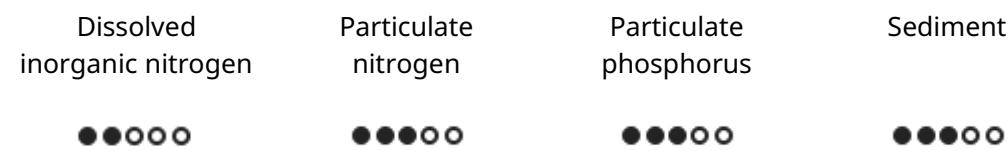
$$\text{Progress to date (\%)} = \frac{\text{reduction in load (\%)} \times 100}{\text{load reduction target (\%)}}$$

Reported progress towards the targets is based on the following definitions:

Reported change	Definition
Improving	Progress of 1% or greater towards the load reduction target over the reporting period.
No change	Less than 1% progress towards the load reduction target over the reporting period.
Declining	Negative progress of 1% or more over the reporting period.
Target met	100% of the load reduction target achieved

Modelled FS, DIN, PN and PP at the end of the catchment are reported for the total Great Barrier Reef catchment, six regions and 35 sub-catchments.

Semiquantitative confidence rankings



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

Sediment and particulate nutrients scored higher for confidence as the modelling for these parameters is based on well-established methods, particularly for hillslope erosion processes. Models are validated with data from more than 56 catchment loads monitoring sites and modelled relationships are based on published data from historic and ongoing research. The models undergo numerous quality assurance checks and research is currently underway to measure and report uncertainty within the models.

Dissolved inorganic nitrogen scored lower for confidence as the way in which nitrogen changes form as it moves from paddock to the Great Barrier Reef is more complex to represent within the modelling framework.

Glossary

ANNEX: Annual Network Nutrient Export model is a static model that predicts the average annual loads of phosphorus and nitrogen in each link in a river network.

APSIM: Agricultural Production Systems sIMulator.

Agricultural land management practice adoption program: A component of the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program which develops rigorous estimates of management practice adoption and annual management practice change for the major agricultural industries of the Great Barrier Reef catchments: sugarcane, grazing, horticulture, grains and bananas.

Sediment: Sediments in water include clay, silt, sand and coarser particulate material, and are referred to as 'total suspended solids' (this is how they are measured in the water column) or 'total suspended sediment'. Sediments are characterised by different particle sizes. Not all sediment or particle size fractions present the same risk to the Great Barrier Reef, with **fine** (<20µm) **sediment** moving furthest into the marine environment, leading to increased turbidity and reduced light and, therefore, posing the greatest risk.

GRASP: Soil water pasture growth model.

HowLeaky: Agricultural system water balance and crop growth model based on PERFECT.

USLE: Universal Soil Loss Equation.

C-factor: Cover management factor (**C**) in the USLE that represents effects of vegetation and other land covers.

SedNet: Sediment River Network Model used to determine catchment sediment yields and sediment sources.

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