Australian Government

Queensland Government

Catchment loads modelling methods

Reef Water Quality Report Card 2020

Reef 2050 Water Quality Improvement Plan

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CONTENTS

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 (Reef 2050 WQIP) (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 2020.

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 annually on the progress towards the Reef 2050 WQIP 2025 load reduction targets for total suspended sediment (TSS), 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.

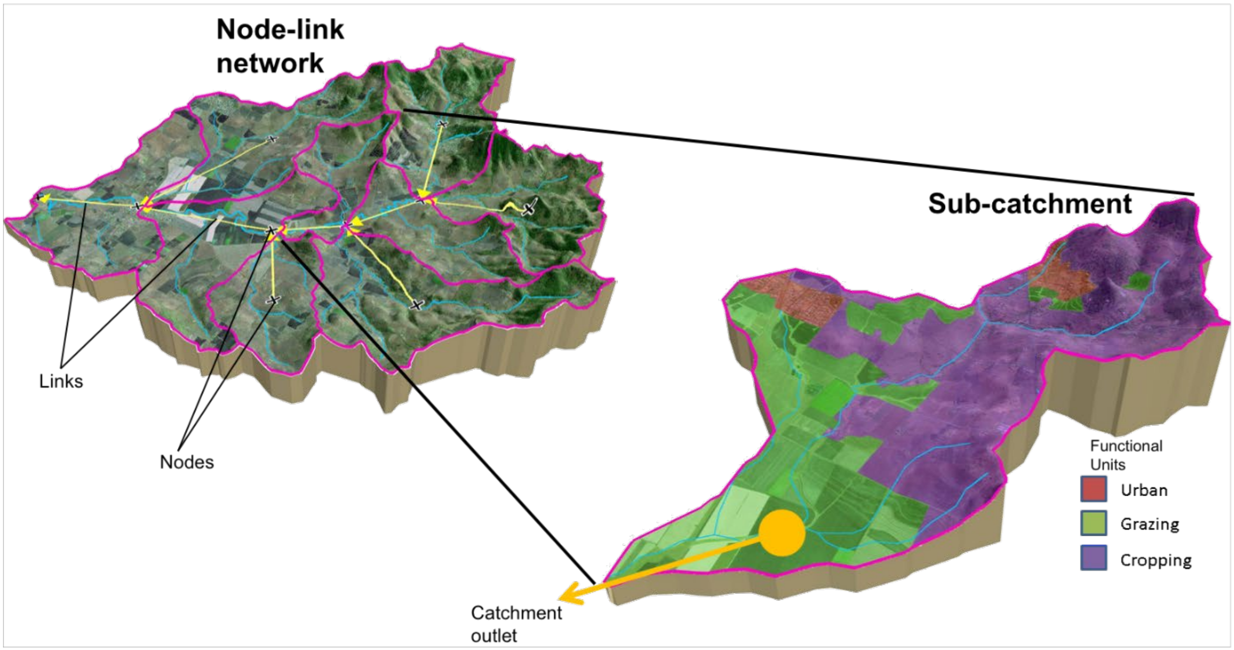
This document provides a summary of the methods of the catchment loads modelling. A detailed outline of the modelling methods and outputs are available from McCloskey et al., 2021a and McCloskey et al., 2021b.

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 and improved practices for each individual land-use. 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.

Baseline loads are estimated for the current (2016) management practice benchmark.

From the baseline, the reduction in loads resulting from improved management practice adoption is calculated by running the model with the new practice adoption layer for the same 28-year modelling period as the baseline. The difference in load is the load reduction for that investment year.

Pollutant loads are summarised in the 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, transportation and transformation 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.



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 report card. The model runs for a fixed climate period (1986 to 2014), to remove the influence of climate on estimated load reductions. The most current land-use mapping is incorporated when models are periodically updated (details of the mapping data can be found at: www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/qlump/qlump-datasets).

The pollutants modelled were:

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

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 WQIP 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. See the Agricultural land management practice adoption methods report for more information about the water quality risk frameworks.

Representation of pre-agricultural land management 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. Off-shore coral coring and sediment tracing work suggests anthropogenic loads have increased anywhere from 2-10 times the current 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.

The assumptions made when modelling pre-development are:

- Hydrology was kept the same for baseline and the pre-agricultural 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.
- Management factors for streambank models were adjusted to reflect a very low risk to water quality (https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef/management-practices).

To reflect the modelled load reduction for each report card as a result of changes in adoption of improved agricultural management practices, three scenarios[1] are run:

- Pre-development load (prior to agricultural development) for the 28-year modelling period .
- The baseline load for the 28-year modelling period (i.e. representing the agricultural management practice benchmark 2016).
- Change load for the 28-year modelling period with the proportion of land managed using improved practices adjusted to reflect the previous year's adoption.

The proportion of land managed using defined management practices is the only variable that changes between modelled scenarios. This 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.

[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).

Modelled load estimates were calibrated and or validated against field data collected through the Catchment Loads Monitoring program at 43 monitoring sites across 20 catchments 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 and 2019. Prior to the release of each report card, modelled load estimates are reviewed both internally and externally.

Management practice change

The Reef 2050 WQIP 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 timeseries 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 (1986 to 2014).
- 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 runs that are used to populate the catchment models represent 'typical' management practices for a given management class and do not reflect the actual array of management practices that occur year-to-year across the Great Barrier Reef catchments.
- Paddock model simulations represent the reported management practice adoption water quality risk frameworks as a set suite of practices.
- Application rates of pesticides and fertilisers that are used to populate the paddock models are derived through consultation with relevant industry groups and regional NRM bodies.
- 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 Department of Agriculture and Fisheries (DAF) Paddock to Reef Agricultural Management Practice Adoption program team annually.

- The water quality benefits from adopting a management practice change are assigned in the year that on-ground works were implemented, so time lags that may occur in the system are not accounted for.

- It is important to note that these 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 Catchments model (www.ewater.org.au) was modified to incorporate hillslope constituent generation from the most appropriate paddock models for cropping, sugarcane 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 P2R Source. 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 Catchments 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 Catchments 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 catchment using the 2016 management practice benchmark. A pre-development land use map was also developed and modelled. The model was then run for a 28-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 2016, 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).

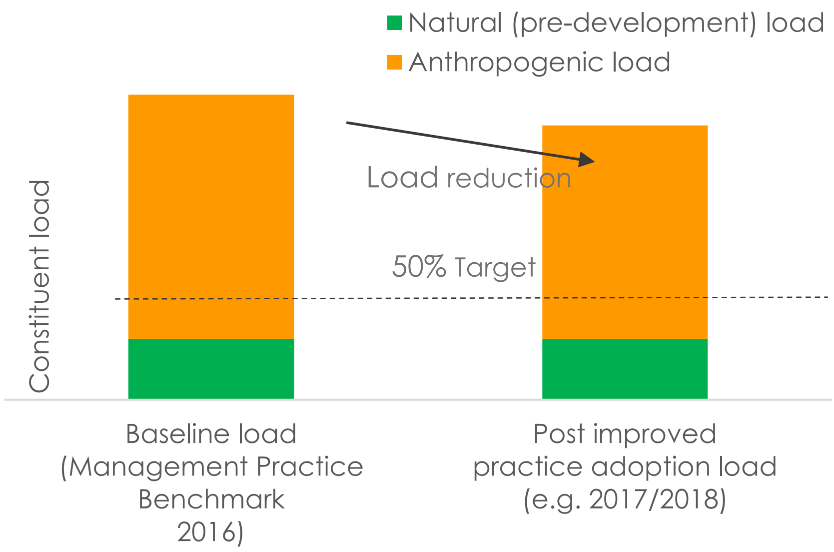


Figure 2: Example of modelled pre-development and anthropogenic pollutant loads, and the load reduction following investment in improved management practices.

Modelling improvements

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

- A desktop and field gully mapping program continues to improve the spatial representation of gully density and geometry in the models. Updated gully maps have been incorporated for selected areas within the Fitzroy region.
- Annual monitoring/modelling validation workshops are held to compare model performance against monitoring data.
- Updated land use mapping incorporated for the Fitzroy, Burdekin and Burnett Mary regions.
- 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

Modelled TSS, 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.

Qualitative confidence ranking

Dissolved inorganic nitrogen	Particulate nitrogen	Particulate phosphorus	Sediment
●●○○○	●●●○○	●●●○○	●●●○○

A multi-criteria analysis was used to qualitatively 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 43 catchment loads monitoring sites and modelled relationships are based on published data from historic and ongoing research. Extensive gully mapping underpins the sediment modelling. 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.

References

Australian and Queensland governments, 2019a, *Catchment Pollutant Delivery - Catchment Loads Monitoring Method Summary*, Paddock to Reef Integrated Monitoring, Modelling and Reporting program, Queensland Government, Brisbane, Australia.

Australian and Queensland governments, 2019b, *Stewardship – Agricultural Management Practice Adoption Methods*, Paddock to Reef Integrated Monitoring, Modelling and Reporting program, Queensland Government, Brisbane, Australia.

Australian Government and Queensland Government, 2018, *Reef 2050 Water Quality Improvement Plan 2017–2022*, Queensland Government, Brisbane, Australia, pp. 56, <www.reefplan.qld.gov.au/__data/assets/pdf_file/0017/46115/reef-2050-water-quality-improvement-plan-2017-22.pdf>.

Queensland Land Use Mapping Program 2019, Queensland Department of Environment and Science, Brisbane, Australia. <www.qld.gov.au/environment/land/management/mapping/statewide-monitoring/qlump/qlump-datasets>.

Bartley, R., Bainbridge, Z.T., Lewis, S.E., Kroon, F.J., Wilkinson, S.N., Brodie, J.E., Silburn, D.M., 2014a. Relating sediment impacts on coral reefs to watershed sources, processes and management: a review. Sci. Total Environ. 468–469C, 1138–1153.

Ellis, R & Searle, R 2013, 'An integrated water quality modelling framework for reporting on Great Barrier Reef catchments', in J Piantadosi, RS Anderssen and J Boland (eds) *MODSIM2013, 20th International Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, December 2013, pp. 3183–89, <www.mssanz.org.au/modsim2013/L21/ellis.pdf>.

Ellis, RJ 2017, *Dynamic SedNet Component Model Reference Guide: Update 2017*, Concepts and algorithms used in Source Catchments customisation plugin for Great Barrier Reef catchment modelling, Queensland Department of Science, Information Technology and Innovation, Bundaberg, Queensland.

eWater 2018, *Source User Guide 4.7*, eWater Cooperative Research Centre, Canberra, Australia.

Holzworth, DP, Huth, NI, deVoil, PG, Zurcher, EJ, Herrmann, NI, McLean, G, Chenu, K, van Oosterom, E, Snow, VO, Murphy, C, Moore, AD, Brown, HE, Whish, JPM, Verrall, S, Fainges, J, Bell, LW, Peake, AS, Poulton, PL, Hochman, Z, Thorburn, PJ, Gaydon, DS, Dalgliesh, NP, Rodriguez, D, Cox, H, Chapman, S, Doherty, A, Teixeira, E, Sharp, J, Cichota, R, Vogeler, I, Li, FY, Wang, E, Hammer, GL, Robertson, MJ, Dimes, J, Whitbread, AM, Hunt, J, van Rees, H, McClelland, T, Carberry, PS, Hargreaves, JNG, MacLeod, N, McDonald, C, Harsdorf, J, Wedgwood, S and Keating, BA 2014, 'APSIM - Evolution towards a new generation of agricultural systems simulation', *Environmental Modelling and Software*, vol. 62 pp. 327–50.

Hughes, A.O., Olley, J.M., Croke, J.C., McKergow, L.A., 2009. Sediment source changes over the last 250 years in a dry-tropical catchment, central Queensland, Australia. Geomorphology 104, 262–275.

McKeon, G, Day, K, Howden, S, Mott, J, Orr, D, Scattini, W and Weston, E 1990, 'Northern Australian savannas: management for pastoral production', *Journal of Biogeography*, vol. 17 no. 4–5, pp. 355–72.

Lewis, S.E., Olley, J., Furuichi, T., Sharma, A., Burton, J., 2014. Complex sediment deposition history on a wide continental shelf: implications for the calculation of accumulation rates on the Great Barrier Reef. Earth Planet. Sci. Lett. 393, 146– 158.

McCulloch, M., Fallon, S., Wyndham, T., Hendy, E., Lough, J., Barnes, D., 2003a. Coral record of increased sediment flux to the inner Great Barrier Reef since European Settlement. Nature 421, 727–730.

McCloskey, G.L., Baheerathan, R., Dougall, C., Ellis, R, Bennett, F.R., Waters, D., Darr, S., Fentie, B., Hateley, L.R., and Askildsen, M. (2021a). Modelled estimates of fine sediment and particulate nutrients delivered from the Great Barrier Reef catchments. Marine Pollution Bulletin Special Edition. Vol 165 April 2021. 112163.

McCloskey, G.L., Baheerathan, R., Dougall, C., Ellis, R, Bennett, F.R., Waters, D., Darr, S., Fentie, B., Hateley, L.R., and Askildsen, M. (2021b). Modelled estimates of dissolved inorganic nitrogen exported to the Great Barrier Reef lagoon. Marine Pollution Bulletin Special Edition. Vol 171 October 2021, 112655.

Rattray, DJ, Freebairn, DM, McClymont, D, Silburn, DM, Owens, JS & Robinson, JB 2004, 'HOWLEAKY? The journey to demystifying "simple technology"', in Raine, SR, Biggs, AJW, Menzies, NW, Freebairn, DM and Tolmie PE (eds), *Conserving soil and water for society: sharing solutions, The 13th International Soil Conservation Organization Conference*, International Soil Conservation Organization, Brisbane, Australia.

Waters, DK, Carroll, C, Ellis, R, Hateley, L, McCloskey, GL, Packett, R, Dougall, C and Fentie, B 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Whole of GBR, Technical Report, Volume 1*, Queensland Department of Natural Resources and Mines, Toowoomba, Queensland.

Wilkinson, SN, Dougall, C, Kinsey-Henderson, AE, Searle, RD, Ellis, RJ and Bartley, R 2014, 'Development of a time-stepping sediment budget model for assessing land use impacts in large river basins', *Science of the Total Environment*, vol. 468–9, pp. 1210–24.

Further reading

Carroll, C, Waters, D, Vardy, S, Silburn, DM, Attard, S, Thorburn, P, Davis, AM, Halpin, N, Schmidt, M, Wilson, B & Clark, A 2012, 'A Paddock to Reef Monitoring and Modelling framework for the Great Barrier Reef: Paddock and Catchment component', *Marine Pollution Bulletin, Special Issue: Catchments to Reef Continuum: Case Studies from the Great Barrier Reef*, vol. 65, no. 4–9, pp. 136–149.

McCloskey, G, Waters, D, Baheerathan, R, Darr, S, Dougall, C, Ellis, R, Fentie, B and Hateley, L 2017B, 'Modelling pollutant load changes due to improved management practices in the Great Barrier Reef catchments: updated methodology and results', *Technical Report for Reef Report Card 2014*, Queensland Department of Natural Resources and Mines, Brisbane, Australia.

McCloskey, GL, Waters, D, Baheerathan, R, Darr, S, Dougall, C, Ellis, R, Fentie, B and Hateley, L 2017A, 'Modelling pollutant load changes due to improved management practices in the Great Barrier Reef catchments: updated methodology and results', *Technical Report for Reef Report Cards 2015*, Queensland Department of Natural Resources and Mines, Brisbane, Queensland.

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.