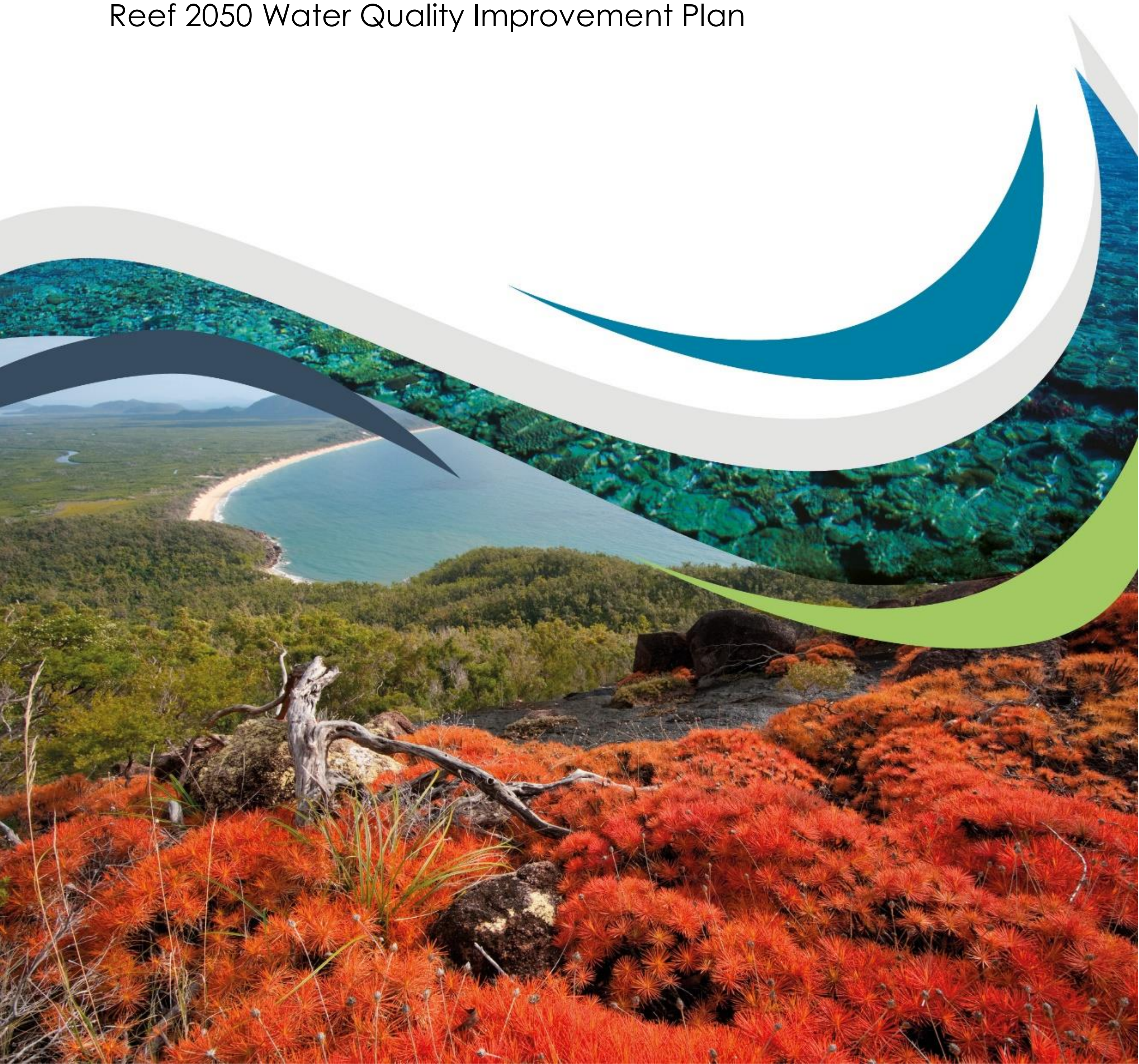
Australian Government

Queensland Government

Marine modelling methods

Reef Water Quality Report Card 2019

Reef 2050 Water Quality Improvement Plan



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Citation

Australian and Queensland governments, 2020, *Marine modelling methods, Reef Water Quality Report Card 2019,* State of Queensland, Brisbane.

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Marine modelling methods

The Marine Modelling Program (Waterhouse et al. 2018) directly supports the 2050 outcome of Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP) (Australia and Queensland governments), which is:

"Good water quality sustains the outstanding universal value of the Great Barrier Reef, builds resilience, improves ecosystem health and benefits communities."

The Marine Modelling Program was established in 2016 to:

- Assess trends in ecosystem health for the Great Barrier Reef in relation to water quality and its linkages to end-of-catchment loads by predicting, assessing and reporting trends in inshore water clarity and concentrations of chlorophyll a.
- Predict physical and biogeochemical properties of Reef waters under a range of scenarios to assess the impact of management practices and contribute to the establishment or review of basin-level water quality targets.
- Support regional and whole-of-Great Barrier Reef water quality risk assessments by predicting the impact of rivers on the Great Barrier Reef waters under a range of conditions.

Given the scale of the Great Barrier Reef, it would be impractical to measure and report water quality through the entire area and at a reasonable frequency using monitoring data alone. Satellite imaging can be used to cover this wide spatial area but is generally considered to have lower accuracy and is seasonally affected by cloud cover. Therefore, the eReefs modelling framework is used in conjunction with the monitored information and satellite observations to extrapolate water quality across the entire Great Barrier Reef. The model is used to generate the marine water quality metric.

This report describes the methods used to generate the marine water quality metric for the period 1 October 2018 to 30 September 2019 (water year 2018-2019).

Marine modelling methods

Marine models which integrate physical processes and ecosystem responses play an integral part in supporting resilience-based management and linking science and observations to policy and decision making.

In this context, the marine component of eReefs delivers and operates numerical models capable of simulating and predicting the physical hydrodynamic state, sediment transport, water quality and basal ecology of the Great Barrier Reef lagoon<https://research.csiro.au/ereefs/models/>. Together, these models provide the ability to simulate the transport and fate of waterborne material, from the ocean or land, and assess its impact on Reef water quality (Skerratt et al., 2019a).

In 2015-2016, as part of National Environmental Science Programme (NESP) Project 3.2.5, eReefs models were used for the first time to report on chlorophyll *a* (productivity linked to nutrient concentrations) and Secchi depth (proxy for water clarity and presence of fine sediments) across the entire Great Barrier Reef (Robillot et al., 2018). These measures underpinned a new water quality metric for the Reef water quality report cards. The metric considered all six regions in calculating the Reef-wide score and is based on open coastal waters.

The new metric is underpinned by the eReefs biogeochemical model and integrates true-colour data from satellite images for improved accuracy in what is commonly referred to as data assimilation (Baird et al., 2016). This integration of multiple streams of data to measure and report on water quality differs from the previous metric which relied exclusively on model predictions of water quality variables like chlorophyll and suspended sediments derived from satellite data. The eReefs model has been assessed extensively against *in situ* observations with detailed assessment findings available in the Technical assessment of the eReefs biogeochemical simulation [gbr4_H2p0_B3p0_Chyd_Dcrt] against observations (Skerratt et al., 2019b). The approach to calculating Reef water quality indices and overall scores was independently peer-reviewed as part of NESP Project 3.2.5.

eReefs coupled hydrodynamic - biogeochemical model

The eReefs coupled hydrodynamic, sediment and biogeochemical modelling system involves the application of a range of physical, chemical and biological process descriptions to quantify the rate of change of physical and biological variables. The process descriptions are generally based either on a fundamental understanding of processes or on actual measurements when a specific process was able to be isolated and studied. The model also requires external inputs, such as observed river flows and pollutant loads. The three components of the model are:

- The hydrodynamic 3-D model as defined by Herzfeld (2006, 2015).
- The sediment transport model, which adds a multilayer sediment bed to the hydrodynamic model grid and simulates sinking, deposition and resuspension of multiple size classes of suspended sediment (Margvelashvili, 2009, Margvelashvili et al., 2016).
- The biogeochemical model, which simulates optical, nutrient, plankton, benthic organisms (seagrass, macroalgae and coral), detritus, chemical and sediment dynamics across the whole Great Barrier Reef region, spanning estuarine systems to offshore reefs (Figure 1. Skerratt et al., 2019a).

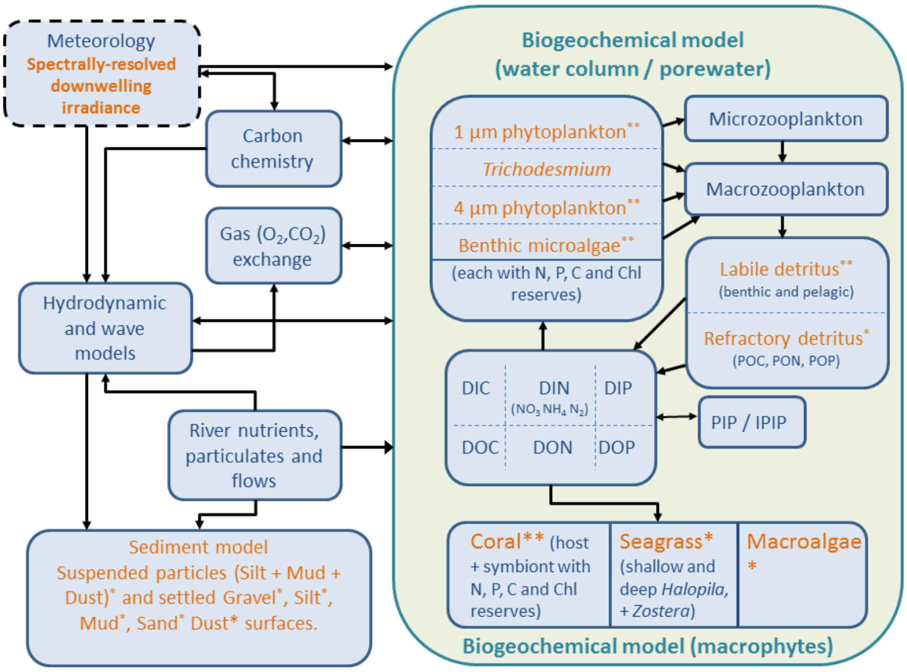

Figure 1: Conceptual framework of the eReefs coupled hydrodynamic-biogeochemical model. Orange variables are optically active (i.e. either scatter or absorb light), influencing the vertical attenuation of light and the bottom light field. The model is forced by rivers along the Reef with nutrient and sediment loads (Baird et al., 2016) using the Source Catchments model. Source: Skerratt et al., 2019a.

Briefly, the biogeochemical model considers four groups of microalgae (small and large phytoplankton, *Trichodesmium* and microphytobenthos), two zooplankton groups, four macrophytes types (seagrass types corresponding to *Zoster sp.*, two *Halophila sp.* types, and macroalgae) and coral communities. Photosynthetic growth is determined by concentrations of dissolved nutrients (nitrogen and phosphorus) and photosynthetically active radiation. Overall, the model contains 23 optically active constituents (Baird et al., 2016). The biogeochemistry model was updated in 2018 to specifically consider ultrafine sediment particles and their impact on matters such as water clarity.

The model is currently forced with freshwater inputs from rivers along the Great Barrier Reef. River flows for 17 rivers are obtained from the Queensland Department of Natural Resources, Mines and Energy gauging network. Nutrient concentrations flowing in from the ocean are obtained from the CSIRO Atlas of Regional Seas (CARS) 2009 climatology (Ridgway et al., 2002).

River pollutant loads are obtained from the Source Catchments modelling outputs (Ellis and Searle, 2013) up to 30 April 2019. To provide daily time series prediction of pollutant loads past 30 April,2019, pollutant generation models are used that estimate daily loads through varying monthly concentrations. These monthly concentration outputs allow the model predictions to be extended by providing daily rainfall run-off model inputs (i.e. the run-off of the day), without the need to update many thousands of farm scale sub-models.

The eReefs model can be run without using observations from the marine environment, which is referred to as a non-assimilating simulation. However, data assimilation provides the single best estimate of the biogeochemical state of the Reef by combining modelling and observations (Jones et al., 2016), and also improves the skill of the model to make predictions (Skerratt et al., 2019a, b). Data assimilation systems can be thought of as using a model to interpolate between observations.

For the Great Barrier Reef, only remote sensing provides the density of observations required to undertake a large-scale data assimilation (see www.bom.gov.au/marinewaterquality). For shallow inshore waters, using remote sensing to estimate in-water properties is challenging due to the interactions between chlorophyll *a*, sediment, coloured dissolved organic matter and benthic communities, which all absorb and scatter light in the blue and green wavebands. Instead of using remote sensing to estimate in-water properties, the water quality metric is based on the optical calculations of the biogeochemical model, which simulates the normalised remote-sensing reflectance. The data assimilation system uses the mismatch between observed and modelled remote-sensing reflectance to constrain the biogeochemical model (Jones et al., 2016).

A 100 member Ensemble Kalman Filter (EnKF) assimilation system is used informed by observed ocean colour from the NASA MODIS Aqua, VIIRS and ESA Sentinel-3A satellites (Jones et al., 2016). When the ocean colour data is ingested, the model shifts a number of optically-active *in situ* quantities, and in particular phytoplankton numbers, in all ensemble members in a manner that is consistent with the statistical properties of the biogeochemical model. The estimate of the biogeochemical state by the assimilation system is the mean of the 100 ensemble members. While the model assimilates ocean colour data from satellite, it is assessed against the *in situ* observations of chlorophyll *a* concentration, from which the skill of the system can be quantified.

Modelling improvements

The modelling system was initially developed under the eReefs Project and NESP 3.2.5 Project, and improved for Report Card 2017 and 2018. Significant improvements in Report Card 2019 include:

- Incorporating catchment load estimates using the new SOURCE Catchments code with 2019 vegetation cover.
- Improved pre-processing of river loads before input into the model by 'capping' to prevent large river concentrations due to large loads relative to small flows. Loads that cannot be included at the time predicted by SOURCE Catchments are released at the next flow event: this allows concentrations to be below the cap. This mostly affected the O’Connell River due to large ungauged sections of the catchment.
- SOURCE Catchments total suspended sediments were allocated to FineSed (90%) and Dust (10%), replacing constant concentration for Dust of 20 g/m3 used in previous simulations. This reduced the total riverine suspended solids slightly and increased the fraction of ultrafine sediments during large flows.
- From 1 January 2018, Sentinel-3A atmospherically-corrected remote-sensing reflectance was used for the data assimilation.
- Optical properties of suspended inorganic particles were updated based on analysis in Soja-Wozniak et al. (2019). These new values, obtained at Lucinda Jetty Coastal Laboratory, were more representative of the Great Barrier Reef-wide suspended inorganic particles but less representative of coastal embayments.

The revised model has been assessed over eight years and compared to the previous model configuration to confirm it maintained all the properties and skill required to predict water quality.

How the metric is calculated and information reported

The Reef water quality report card marine water quality metric is calculated as follows:

1. Chlorophyll *a* concentration and Secchi depth data are extracted from the assimilated eReefs biogeochemical model at a 4km spatial resolution and daily temporal resolution (midday snapshot) for the entire Reef.
2. The data is partitioned temporally into water years (from 1 October to 30 September of the reporting year) and spatially into zones representing combinations of regions and cross-shelf water bodies (i.e. open coastal, mid-shelf and offshore waters; defined in GBRMPA, 2010). The enclosed coastal water body is excluded due to limitations associated with the 4 km model resolution near the coastline.
3. The site-level data (4 km x 4 km) for each of the three measures are standardised to indices on a continuous scale of zero (very poor) to 100 (very good). This is done by assessing individual values relative to the appropriate water quality guideline value according to a 'modified amplitude indexation routine' (fsMAMP: base 2 logarithm of the ratio of observed value to threshold).
4. Scores for each parameter are aggregated (averaged) temporally over the water year into annual scores and spatially in the open coastal reporting zone. The resulting scores for chlorophyll-a and Secchi depth are then averaged to generate a single score for each region.
5. A Reef score is calculated as the weighted (relative areas) average of regional scores.
6. All reported scores are mapped onto a five-point (A–E) colour-coded grading scale (see Table 1).

Table 1: Marine water quality metric score to grade scale

Grade	Status	Criteria	Colour
E	Very poor	0–20%	Red
D	Poor	21–40%	Orange
C	Moderate	41–60%	Yellow
B	Good	61–80%	Light green
A	Very good	81–100%	Dark green

Qualitative confidence ranking

Data confidence

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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. Marine modelling received a three-dot confidence ranking.

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