Methods

Great Barrier Reef

Report Card 2016

Reef Water Quality Protection Plan

Australian Government

Queensland Government

Management practice methods

This report summarises the development of revised management practice baselines for the Reef Water Quality Protection Plan 2013 and how progress toward the plan's target for adoption of best practice is assessed.

The target for adoption of best practice is as follows (Australian and Queensland governments, 2013):

- 90 per cent of sugarcane, horticulture, cropping and grazing lands are managed using best management practice systems (soil, nutrient and pesticides) in priority areas by 2018.

Paddock to Reef program – water quality risk frameworks

The Paddock to Reef Integrated Monitoring, Modelling and Reporting Program ('Paddock to Reef program') has developed water quality risk frameworks for each agricultural industry. These frameworks articulate best practice in relation to the Reef Water Quality Protection Plan adoption target. The features of the Paddock to Reef water quality risk frameworks are as follows:

- The suites of practices relevant to each pollutant are described in the frameworks. Not all of the practices in the production system are described, only those practices that pose the greatest potential water quality risk, through movement of sediments, nutrients or pesticides off farm, are described. The majority of these practices also present productivity and/or profitability enhancements.
- Not all practices are equal. The frameworks allocate a percentage weighting to each practice depending upon its relative potential influence on off-farm water quality.
- The 'best practice' level is the level targeted by Reef Water Quality Protection Plan investments.

These practices are described in terms of their relative water quality risk, which range from Low to High.

For the purpose of describing industry status and progress towards the Reef Water Quality Protection Plan 2013 adoption target, best management practice (BMP) is defined as the area managed under Low and Moderate-Low risk levels.

Table 1: Grazing industry – Paddock to Reef program classification of management practices based on relative risk to water quality

Water Quality Risk	Low	Moderate-Low	Moderate-High	High
Resource condition objective	Practices are highly likely to maintain land in good (A) condition and/or improve land in lesser condition	Practices are likely to maintain land in good or fair (A/B) condition and/or improve land in lesser condition	Practices are likely to degrade some land to poor (C) condition or very poor (D) condition	Practices are highly likely to degrade land to poor (C) or very poor (D) condition

For sugarcane, horticulture and grains, the water quality risk framework describes management practices relating to managing nutrients, pesticides and sediments. For grazing systems, the framework describes management practices relating to dominant sources of soil erosion; and pasture (hillslope), streambank and gully erosion.

Table 2: Cropping industries (sugarcane, bananas, grains and horticulture) – Paddock to Reef program classification of management practices based on relative risk to water quality

Water quality risk	Low	Moderate-Low	Moderate-High	High
Description	Lowest water quality risk, commercial feasibility not well understood	Best Management Practice	Minimum Standard	Superseded

Water quality risk frameworks provide the basis for describing:

- industry status in relation to achievement of best practice systems. The Paddock to Reef program has developed new management practice baselines to correspond with the revision of targets, actions and investments under the Reef Water Quality Protection Plan 2013.
- annual progress from these 2013 baselines toward the 90 per cent adoption target.

Establishing farm management baselines for the Reef Water Quality Protection Plan 2013

Paddock to Reef program management practice and management system benchmarks have been developed for each agricultural industry sector, and in each major river basin within each region. There are varying levels of uncertainty or confidence in these benchmarks for many reasons (see Table 3).

Table 3: Summary of data sources and uncertainty around management system baselines developed for the Reef Water Quality Protection Plan 2013

Industry	Primary data sources	Confidence in management system baselines	Sources of uncertainty
Bananas	1:1 growers survey Banana BMP Guide (anonymous, aggregated) Reef Programme grant applications (anonymous)	Medium	High level of heterogeneity within the industry, particularly with respect to farm size. A relatively small number of very large farms that can skew results.
Grains	Grains BMP program (anonymous) Expert agronomist workshops	High	Over 80% of the industry is represented in the baseline sample. However, some Grains BMP questions that do not allow discrimination of practices at a fine level.
Grazing	Grazier 1:1 survey	Medium	The survey has enabled an excellent appreciation of farm management. However, there is an assumption that good management corresponds to good resource condition. Some river basins have insufficient sample size to develop a baseline that is specific to that basin. In these instances the broader regional baseline is used.

Industry	Primary data sources	Confidence in management system baselines	Sources of uncertainty
Horticulture	Growcom Farm Management System (anonymous)	High	A very large proportion of industry is represented in the baseline sample (depending on region). However, some Horticulture farm management systems questions do not allow discrimination of practices at a fine level.
Sugarcane	1:1 grower surveys Smartcane BMP program (anonymous, aggregated) Reef Programme grant applications (anonymous)	Medium	There is uncertainty around management related to timing of fertiliser and herbicide applications. It mostly relates to variance in interpretation by field staff capturing data on farm. Conflicting evidence emerging around degrees of adoption of some practices in some areas.

Grazing

The prevalence of different management practices used in grazing businesses was determined through surveys of commercial-scale graziers between late 2011 and early 2014. Surveys took the form of one-on-one, semi-structured interviews conducted on farm by experienced professional grazing extension officers. Survey questions were designed to align with the practices articulated in the grazing water quality risk framework i.e. the responses recorded align with varying degrees of water quality risk associated with that management. The framework further aligns these practices with the erosion process that is most directly influenced by those practices. While the key management categories remained consistent, the questions and practice descriptions used in wet coastal landscapes were different to those used in rangelands grazing systems.

For reporting and modelling purposes, the specific management practice data was analysed to develop management system risk ratings (from Low to High) that reflect the water quality risk of the mix of individual practices on a farm. Survey responses to individual questions (practice descriptions) were weighted and aggregated to develop a water quality risk score for the practices associated with each erosion process—pasture (hillslope) erosion, streambank erosion and gully erosion. As an example, Table 4 shows the scoring method for responses to a question about objectively determining long-term carrying capacity.

Table 4: Grazing land management survey question 11 - the categories of response and the water quality risk score allocated for each category of response

Survey Question: For long-term planning, what do you base your average carrying capacity on?	Score	Risk level
Historical experience and/or anecdotal advice (not documented)	0	High
Long-term stock and stocking rate records (documented in diaries, paddock records etc.)	4	Moderate
Some objective measure of safe stocking rate calculations, including property map and based on historical data, subjective assessment of resource condition	7	Low-moderate
Documented records, including property map and safe stocking rate calculations based on land type, property infrastructure and objective assessments of land condition	10	Low

The survey question in Table 4 accounts for 10 per cent of the total water quality risk score for practices related to hillslope erosion risk. The ‘best practice’ response is allocated a score of 10, and the least sophisticated management is allocated a score of zero. A total water quality risk score for the practices related to hillslope erosion was derived by combining scores for all relevant questions.

Scores for each erosion process were then assigned a management risk rating (Table 5), based on expert review of specific combinations of management practices.

Table 5: Water quality risk scores used to categorise management risk ratings

Erosion process	Water quality risk rating			
	Low	Low-Moderate	Moderate	High
Hillslope erosion	81–100	59–80	33–58	0–32
Streambank erosion	100	66–99	33–65	0
Gully erosion	85–100	62–84	32–61	0–31

Table 6: Key grazing management categories and weightings used in developing water quality risk scores and ratings

Erosion process	Management category (each informed by a suite of practices)	Paddock to Reef Weighting (%)
Hillslope erosion	1. Average stocking rates imposed on paddocks are consistent with district long-term carrying capacity benchmarks for comparable land types, current land condition, and level of property development	20%
	2. Retention of adequate pasture and ground cover at the end of the dry season is informed by (1) knowledge of ground cover needs and (2) by deliberate assessment of pasture availability in relation to stocking rates in each paddock during the latter half of the growing season or early dry season	40%
	3. Strategies implemented to recover any land in poor or very poor condition (C or D condition)	25%
	4. The condition of selectively-grazed land types is effectively managed	15%
	Hillslope erosion assessment	100%
Streambank erosion	5. Timing and intensity of grazing is managed in frontages of rivers and major streams (including associated riparian areas) and wetland areas (includes control of stock access to streams and provision of off-stream watering points)	100%
Gully erosion	6. Strategies implemented, where practical and affordable, to remediate gullied areas	30%
	7. Linear features (roads, tracks, fences, firebreaks, and water points located and constructed to minimise their risk of initiating erosion	40%
	1 – 4 Hillslope erosion assessment	30%
	Gully erosion assessment	100%

Grazing management system baselines for the Reef Water Quality Protection Plan 2013 were based on management system ratings for individual businesses, aggregated to form baselines for representative river basins within natural resource management (NRM) regions. These individual ratings and baselines were reviewed by regional experts and compared with corresponding data, where available (such as aggregated, anonymous assessments conducted by graziers participating in the Grazing BMP program). Where insufficient samples were available to discriminate management at the level of river basins, the baseline for the entire NRM region was used.

Table 7: Number of individual grazing businesses and area represented in grazing baseline estimates

Region	Rangelands	Wet coastal	Area represented (hectares)	Area as % of region
Cape York (Normanby)	11 + 17*	-	1,263,673 ha	58%
Wet Tropics	8	117	123,129 ha	18%
Burdekin	98	-	3,103,197 ha	24%
Mackay Whitsunday	-	28 + 43*	154,089 ha	38%
Fitzroy	98	-	991,677 ha	8%
Burnett Mary	55	30	368,130 ha	10%

*Additional detailed samples provided courtesy of Cape York Sustainable Futures and Reef Catchments Mackay Whitsunday Isaac NRM.

Sugarcane

Key management practices relevant to water quality risk of sugarcane farming systems were articulated in a water quality risk framework for sugarcane in 2013.

Table 8: Key sugarcane management categories and weightings articulated in the Paddock to Reef program water quality risk framework

Management category	Weighting
Sediment (runoff and soil loss)	
Crop residue cover (green cane trash blanketing)	30%
Controlled traffic farming	25%
Land management during cane fallow	25%
Tillage in plant cane (land preparation)	20%
Nutrients (nitrogen)	
Matching nitrogen supply to crop nitrogen requirements	60%
Timing of fertiliser application with respect to rainfall or irrigation	30%
Application method (surface or subsurface)	10%
Pesticides	
Timing the application of residual herbicides	40%
Targeting application to reduce the volume of herbicide applied	40%
Residual herbicide use in ratoons	20%
Water	
Calculating the amount of water to apply	70%
Managing surface runoff	30%

The prevalence of each of these key management practices in the sugarcane industry was estimated through a benchmarking process conducted throughout 2013–14.

- A suite of questions directly relating to the Paddock to Reef program water quality risk framework was the basis of a survey conducted by regional NRM organisations on behalf of the program. Sampling was targeted as much as possible to ensure that up to 50 per cent of the growers sampled had not previously had high levels of engagement with the initiatives of the Reef Water Quality Protection Plan. In each region, a target was set of a minimum of 100 randomly selected growers across catchments.

- Congruent datasets were obtained through the Smartcane BMP program and recent applications (2012–13 and 2013–14 where available) for the Australian Government's incentive programs.
- In each region, small expert panels were convened to review the adoption levels indicated by the source data and confirm adoption estimates for each practice level, for each management issue. The proportion of growers and the area at each level were checked for sensibility and modified if sufficient supporting evidence was available. Supporting evidence was in the form of discrete data (data from mills, data from local productivity service organisations, specific project data, other Paddock to Reef program data on rates and volumes of nutrient and pesticide use) and the weight of local opinion.

Best management practice systems for sediment, nutrient, or pesticide management are assessed through aggregating the adoption levels of each practice according to their framework weighting.

Bananas

The Paddock to Reef program water quality risk framework for bananas is based on the Australian Banana Grower's Council (ABGC) *Banana BMP Environmental Guideline* (http://bmp.abgc.org.au/). The specific practices of the banana farming system that are most relevant to water quality risk were collated into a focused framework that also aligns with the management practice monitoring system used by Terrain NRM (the regional NRM organisation in the Wet Tropics). Prioritising and weighting these practices for relative water quality risk was done in consultation with Queensland Government scientists, officers from the ABGC, Terrain NRM and extension officers from the Queensland Department of Agriculture and Fisheries.

The pollutants of most concern with respect to the banana industry are sediments and nutrients. There is little to no use of the residual herbicides (with relatively high ecological toxicities) that are common in other cropping sectors. Herbicides commonly used with bananas have relatively low ecological toxicity and are not priorities for the Reef Water Quality Protection Plan 2013. Offsite movement of these herbicides, when it occurs, is largely a function of runoff and soil loss, which is a focus area in the framework.

Table 9: Key banana management categories and weightings articulated in the Paddock to Reef program water quality risk framework

Management category	Weighting
Sediment (runoff and soil loss)	
Crop removal	10%
Fallow management	20%
Tillage – plant crop	15%
Ground cover (inter-rows and headlands)	35%
Controlling runoff (contouring)	10%
Controlling runoff (drains)	5%
Sediment traps	5%
Nutrients	
Soil testing	10%
Matching nutrient supply to crop demand	60%
Fertiliser application frequency	15%
Fertiliser application method	15%
Water	
Calculating the amount of water to apply	70%
Managing surface runoff	30%

The prevalence of each of these key management practices in the Wet Tropics was estimated through a benchmarking process conducted during 2013–14. No data was available to support baseline development in the banana production areas of southern Cape York. Anonymous data sources for the Wet Tropics included:

- a grower survey conducted in 2012 by Terrain NRM and the ABGC, representing 125 growers and approximately 75 per cent of the cropped area of bananas
- management practice data collected by Terrain NRM from 2012–13 applications for the Australian Government's Reef Rescue program
- aggregated anonymous data from the *Banana BMP Environmental Guideline*, available for discussion while reviewing adoption benchmarks with experienced extension officers.

Horticulture

The Paddock to Reef program water quality risk framework for the horticulture industry is based on the water quality management module of Growcom's Hort360 best management practice program (http://www.growcom.com.au/land-water/hort360/). The 50 management issues covered in the farm management system module were reviewed in collaboration with Growcom to focus on a smaller subset of the 17 management issues with greatest influence on offsite water quality.

Table 10: Key horticulture management categories and weightings articulated in the Paddock to Reef program water quality risk framework

Management category	Weighting
Sediment (runoff and soil loss)	
Use of vegetated buffers	5%
Fallow management	35%
Managing in-field runoff	20%
Managing inter-rows	25%
Managing roads and headlands	10%
Sediment trapping	5%
Nutrients	
Soil testing to inform nutrient budgeting	10%
Leaf testing to inform nutrient budgeting	10%
Objective nutrient budgeting	30%
Fertiliser application method	25%
Determining crop nutrient requirements	25%
Pesticides	
Determining pesticide requirements	30%
Managing risk of runoff and drift	30%
Integrated Pest Management (IPM)	40%
Water	
Irrigation scheduling	30%
Matching irrigation interval and volume with crop requirements	50%
Water recapture and use	20%

Anonymous data from growers completing Growcom's farm management system modules during 2012–14 was analysed according to the water quality risk framework weightings. This specific management practice data was analysed to develop management system risk ratings (from Low to High) that reflect the water quality risk of the mix of individual practices on a farm. Data was available for the Burnett Mary, Fitzroy, and Burdekin NRM regions. Farm management system data was not available for the Wet Tropics and the Mackay Whitsunday NRM regions (where there is no current Reef Water Quality Protection Plan investment in horticulture).

Table 11: Number of individual horticulture businesses and area represented in horticulture baseline estimates

Region	Businesses	Area (hectares)
Burnett Mary	303	21,900
Fitzroy	45	2,025
Burdekin	122	22,056

Grains

The Paddock to Reef program water quality risk framework for the grain farming industry is based on a range of key management areas selected from four modules of the Grains BMP program (www.grainsbmp.com.au). Eighteen management issues were assigned weightings according to their potential for influencing offsite water quality. These weightings were developed through a review process by Queensland Government scientists and experienced Central Queensland agronomists and agricultural consultants.

Table 12: Grains BMP program modules and management questions used in developing the Reef Water Quality Protection Plan 2013 management baseline

BMP Module	Management category	Weighting
Sediment (runoff and soil loss)		
Property design layout	Use of contour and diversion banks in sloping cropping areas	15%
Property design layout	Sediment trapping devices	5%
Property design layout	Waterways and drainage lines	5%
Making best use of rainfall	Stubble volume and persistence	15%
Making best use of rainfall	Retain stubble during the fallow	20%
Making best use of rainfall	Cropping frequency	10%
Making best use of rainfall	Need for tillage	20%
Making best use of rainfall	Wheel traffic	10%
Pesticides		
Pesticide application	Pest identification	5%
Pesticide application	Resistance management	10%
Pesticide application	Product selection	5%
Pesticide application	Risk of residual pesticide movement	40%
Property design layout	Pesticide and sediment movement	40%
Nutrients		
Crop nutrition	Records of crop yield and quality	10%
Crop nutrition	Frequency of soil testing for nitrogen	30%

BMP Module	Management category	Weighting
Crop nutrition	Influence of stored soil moisture on yield and fertiliser decisions	30%
Crop nutrition	Impact of seasonal outlook on making fertiliser decisions	20%
Crop nutrition	Application timing to minimise potential losses and maximise uptake	10%

Anonymous data from BMP program participants was analysed according to these weightings in order to develop management system risk ratings (from Low to High) that reflect the water quality risk of the mix of individual practices on a farm. Where insufficient samples were available to discriminate management at the level of river basins, the baseline for the entire NRM region was used for Paddock to Reef reporting.

The number of businesses represented in management system baselines for each category was:

- sediment (runoff and soil loss): 301
- pesticides: 327
- nutrients: 262.

Table 13: Area of grain farms represented in baselines by region and river basin

Region	River basin	Area (hectares)
Burnett Mary	Barambah	961
	Burnett	2,275
Burdekin	Suttor	76,054
Fitzroy	Boyne	285
	Comet	74,869
	Dawson	62,463
	Fitzroy	12,140
	Isaac	16,076
	Mackenzie	31,022
	Nogoa	75,248

Describing annual progress toward achieving the Reef Water Quality Protection Plan 2013 adoption target

Management practice baselines have been developed for each of the critical practices, for each agricultural industry, each region and each river basin. At the farm scale, these management practices combine to form a management system. Progress in the adoption over time of improved and/or best management practice is monitored. Where management change has occurred, the 2013 baseline is amended to reflect that change.

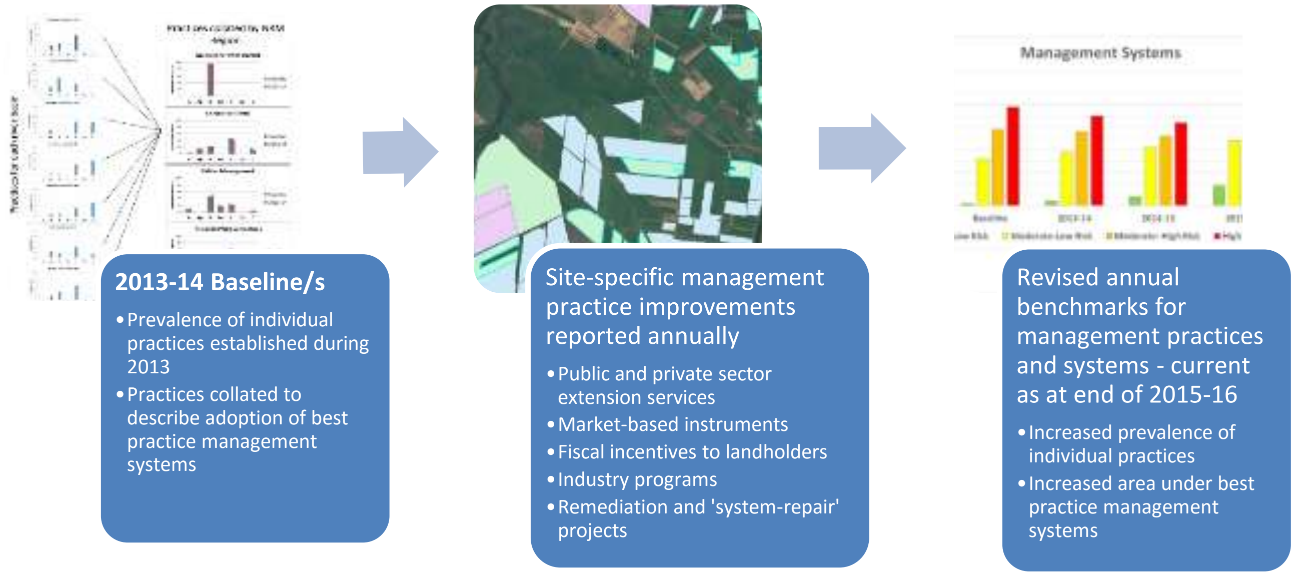


Figure 1: The process for monitoring baselines and management practice improvements and benchmarks

The limitations with this approach are as follows:

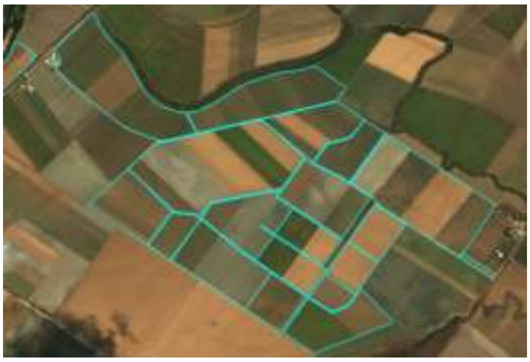
- Management change is identified where and when it is reported to have occurred. This relies on delivery organisations sensibly and appropriately reporting on their activities and the impacts of those activities. The Paddock to Reef program describes and reports on the impacts of change for which there is reasonable and sensible evidence.
- Management improvements that occur without the intervention of third party delivery organisations are not detected as there are no industry-wide mechanisms for capturing or reporting management practice change. There is likely to be a degree of *understatement* of improvements for this reason.
- Any regression of practices (i.e. adopting practices with greater water quality risk) is difficult to detect as these are unlikely to be reported. However, the approach can appropriately reflect regression if necessary. For this reason, it is possible that some impacts may be *overstated*.

Evidence of management practice change

Organisations receiving funding through the Reef Water Quality Protection Plan 2013 for the purpose of increasing the adoption of best management practice are required to report the impacts of their work as per the relevant industry water quality risk framework. They report on how individual sites or farm enterprises are managed—using the practice descriptions in the water quality risk frameworks—both before an intervention and after (as a result of) that intervention. The ‘interventions’ reported on for the 2016 Great Barrier Reef Report Card (Table 14) include financial incentives (cash grants and reverse tenders), capacity-building extension, on-farm trials, private sector consulting, remediation of severe erosion features, and industry training.

The process for evaluating reported impacts is summarised in Figure 2.

Delivery organisations provide annual evidence of impact to the Paddock to Reef program, in the form of GIS data and detailed management practice data (as coded responses to questions based on the water quality risk frameworks).



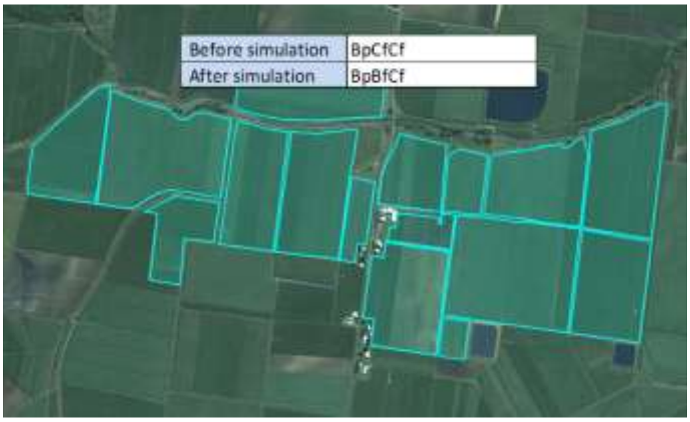
A sugarcane farm is reported at the lowest risk management state for nitrogen fertiliser use in 2013–14.

The same sugarcane farm is reported at the highest risk management state for nitrogen fertiliser in 2015–16.

Identifying spatial and temporal conflicts is essential to ensure that impacts are sensible and not captured more than once.

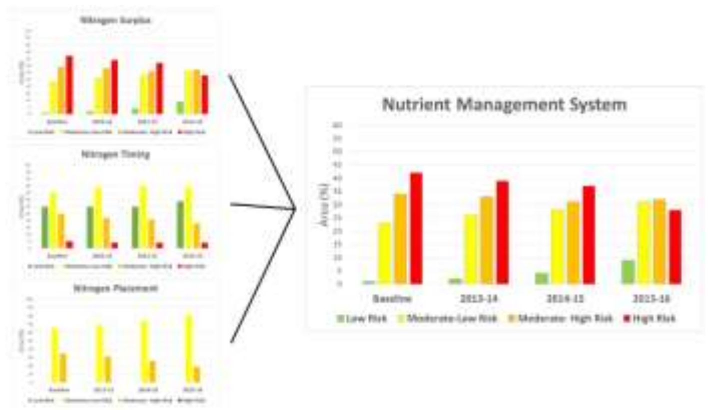
The data is reviewed on a site-by-site basis to provide assurance that reporting towards adoption targets and modelled pollutant load reductions is sensible. This review includes:

- identifying data handling errors
- checking that the nature of the intervention aligns with the reported impact
- checking that the degree of impact (farm management change) is sensible and realistic, including checking that the reported impacts correspond with other independent lines of evidence available to the Paddock to Reef program
- checking that individual sites and impacts on those sites have not previously been reported to the Paddock to Reef program and included in estimates of progress towards Reef Water Quality Protection Plan targets.



For every site (usually a paddock or farm) the management regime and how it is has changed is aligned to modelling simulations which best represent that management (as 'before' and 'after' simulations). The example (left) codifies the trash management, machinery traffic and tillage regime, nutrient rates and timing, and weed management on a cane farm.

Data provided annually to Paddock to Reef catchment modelling constitutes layers that describe change in this way for many hundreds of individual sites.



The management practice and management system baselines for each river basin and NRM region are adjusted annually to reflect the areas validated in the above steps.

Great Barrier Reef Report Cards contain data aggregated up to represent estimates of area under management systems, at the scale of NRM regions.

Figure 2: The process for evaluating impacts reported by organisations through the Reef Water Quality Protection Plan 2013

It is possible that the degree of adoption of best management practice during 2015–16 is a conservative estimate.

Many investments were aiming to facilitate the adoption of best management practice on farms during 2015–16 (Table 14). Most were able to describe the extent of their engagement (i.e. the people they interacted with) and offer some evidence of impact in terms of improved knowledge and skills of participants. However, not all of these were able to provide evidence of the spatial extent and the degree of change that could be attributed to the program. In some instances, this was due to privacy concerns, little or inadequate impact evaluation, or because the impacts are not yet apparent. Several programs and projects reported impacts for the first time in 2015–16.

The year 2015–16 also marked the end of a major investment program—the Australian Government's Reef Programme)—and, as such, the total on-ground effort of that program was relatively low in some areas. Other major investments under the Reef Trust commenced and were in establishment phases during 2015–16, so more on-ground impacts are likely to be reported next year and beyond.

Table 14: Program investments reviewed for Great Barrier Reef Report Card 2016

Region	Sector	Program	Total reported spatial extent of engagement reviewed (hectares, or km of stream)	Spatial extent utilised in determining progress toward Reef Plan targets for adoption and pollutant load reduction (hectares, or km of stream)
Burnett Mary	Sugarcane	Australian Government Reef Programme	7,587	7,587
		Smartcane BMP	16,111	-
	Grazing	Grazing BMP	91,232	-
		Australian Government Reef Programme	11,096	11,096
			70 km	70 km
		DNRM Sustainable Agriculture Project	4,920	4,920
		Australian Government Systems Repair Project	258	258
			12 km	12 km
	Grains	DNRM Sustainable Agriculture Project	944	-
Fitzroy	Grazing	Grazing BMP	1,136,026	-
		Queensland Government extension	104,112	30,267
		Australian Government Reef Programme	90,736	90,736
			921 km	921 km
		QNRM Programme	5,465	5,465
			31 km	31 km
		Australian Governments National Land Care Programme	96,375	-
	Grains	Australian Government Reef Programme	11,693	11,693
		QNRM Programme	18,132	18,132
		Grains BMP	139,815	-
	Horticulture	Australian Government Reef Programme	98	-

Region	Sector	Program	Total reported spatial extent of engagement reviewed (hectares, or km of stream)	Spatial extent utilised in determining progress toward Reef Plan targets for adoption and pollutant load reduction (hectares, or km of stream)
	Cotton	Australian Government Reef Programme	3,956	-
Mackay Whitsunday	Sugarcane	Smartcane BMP	81,001	-
		Queensland Government extension	-	-
		Australian Government Reef Programme	21,833	21,833
	Grazing	Australian Government Reef Programme	2,112	2,112
			8 km	8 km
		Australian Government Systems Repair Project	6	6
			35 km	35 km
Burdekin	Sugarcane	Smartcane BMP	37,551	-
		QLD Government extension	89	89
		RP20C Burdekin Nitrogen Project	12,721	12,721
		Australian Government Reverse Tender	8,064	8,064
	Grazing	Australian Government Reef Programme	31,777	31,777
		Grazing BMP	2,530,411	-
		Queensland Government extension	1,853,729	248,033
	Grains	Grains BMP	6,000	-
Wet Tropics	Bananas	Australian Government Reef Programme	3,338	3,338
	Sugarcane	Australian Government Reef Programme	42,517	42,517
		Smartcane BMP	98,835	-

Region	Sector	Program	Total reported spatial extent of engagement reviewed (hectares, or km of stream)	Spatial extent utilised in determining progress toward Reef Plan targets for adoption and pollutant load reduction (hectares, or km of stream)
		Queensland Government extension	6,152	6,152
		Australian Government Reverse Tender	2,507	2,507
Cape York	Grazing	Australian Government Reef Programme	5,987	5,987

Describing progress

Management practices that are at the Moderate-Low risk and Low risk levels are taken to be 'best management practices'. These are summed in describing the proportion of area managed under best practice, and practices are combined according to their weightings to describe 'best management practice systems'. Figure 3 shows an example where the area managed at best practice in the 2013 baseline increased from 12 per cent (4 plus 8) to 30 per cent (5 plus 25) by the end of 2015–16.

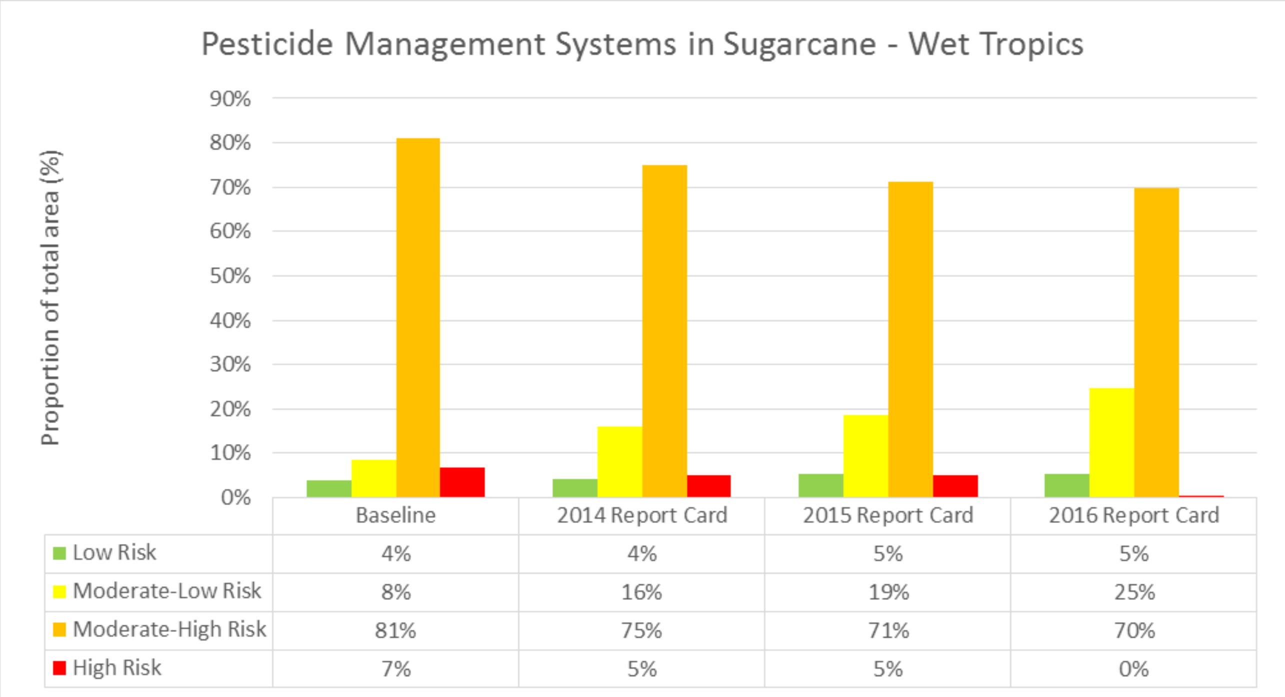


Figure 3: Example showing an increase in the area managed under best practice

Colour coding based on five categories (Table 15) is also used to report progress toward the 90 per cent adoption target.

Table 15: The colour-coded scoring system for the Great Barrier Reef Report Card

Grade	Status	Criteria for June 2016	Colour
A	Very good	90–100%	Dark green
B	Good	68–89%	Light green
C	Moderate	46–67%	Yellow
D	Poor	23–45%	Orange
E	Very poor	0–22%	Red

Qualitative confidence rankings

Sugarcane

Grazing

Horticulture

Grains

A multi-criteria analysis has been used to qualitatively score the confidence in each indicator used in the Great Barrier Reef Report Card from low to high. The approach combined expert opinion and direct measures of error for program components where available.

Reference

Australian and Queensland governments 2013, Reef Water Quality Protection Plan 2013, Reef Water Quality Protection Plan Secretariat, Brisbane.

Ground cover methods

This report summarises the data and methods used for reporting progress towards the target for regional ground cover in the Great Barrier Reef Report Card 2016.

The target for ground cover is as follows (Australian and Queensland governments, 2013):

- Minimum 70 per cent late-dry-season ground cover on grazing lands by 2018.

Further detail about data processing and differences from previous report cards can be found in the ground cover technical report (DSITI, 2017).

Background

Why measure ground cover?

Ground cover is defined as the vegetation (living and dead), biological crusts and stone that are in contact with the soil surface. Ground cover is a key component of many soil processes, including infiltration, run-off and surface erosion. In the Great Barrier Reef regions, low ground cover can lead to soil erosion which contributes to increased sediment loads reaching the Reef lagoon and loss of productivity for grazing enterprises.

It is particularly important to maintain ground cover during dry periods or periods of unreliable rainfall to minimise loss of water, soil and nutrients when rainfall eventually occurs. This practice will also maximise the pasture response to rainfall. Implementing appropriate and sustainable land management practices, particularly careful management of grazing pressure, can help to maintain or improve ground cover, reducing erosion and improving the stability and resilience of the grazing system.

Factors that influence ground cover

Ground cover levels are the result of complex interactions between landscape function (soil type, topography and vegetation dynamics), climate and land management. Some areas maintain naturally higher levels of ground cover due to factors such as high soil fertility and consistently high annual rainfall. The impacts of grazing land management practices on ground-cover levels in these areas can be minimal due to the resilience of the land to respond to pressures. In areas where rainfall is less reliable and soils are less fertile, ground-cover levels can vary greatly and the influence of grazing land management practices on ground-cover levels and on the species composition of the ground cover can be more pronounced.

A number of initiatives aimed at improving grazing land management in Great Barrier Reef regions are in place or are planned. They include programs which are improving management of ground-cover levels appropriate to the regional conditions, such as:

- the industry-led Grazing Best Management Practice program
- infrastructure projects such as fencing key areas and better distribution of watering points for stock
- trials of different grazing strategies
- a range of extension and education activities including development of online, interactive and reporting tools for accessing and viewing ground cover information.

Reporting ground-cover levels for the Reef Water Quality Protection Plan 2013

Progress towards the ground cover target is assessed by the Queensland Ground Cover Monitoring Program and is based on ground-cover monitoring data derived from Landsat satellite imagery that is calibrated by field data. While a range of factors influence ground-cover levels, reporting is presently focused only on information that describes regional ground-cover levels in the current and historical context. Rainfall data is provided here for context only as it is the primary driver of ground cover levels at a regional scale.

A range of products have been or are being developed by the Queensland Ground Cover Monitoring Program which account for the influence of climate, land management and soil type. These products are more appropriate for monitoring local-scale variability and differences in ground cover levels, but are of limited use for the regional-scale reporting required here. Access to some of these products is via the interactive online tool VegMachine and the online reporting tool, FORAGE. Products that prove useful for describing ground cover levels at the regional scale will help to revise future ecologically-relevant and regionally-focused targets, and will be incorporated into future reporting. For example, a metric is in development which improves how the patchiness, or clumping, of ground cover is quantified and represented spatially using new imagery from the Sentinel-2A and 2B satellites.

Methods

The following is a brief overview of the data and methods used for reporting regional ground cover in the Great Barrier Reef Report Card 2016. For further detail about data processing, refer to the ground cover technical report (DSITI, 2017).

Ground cover data

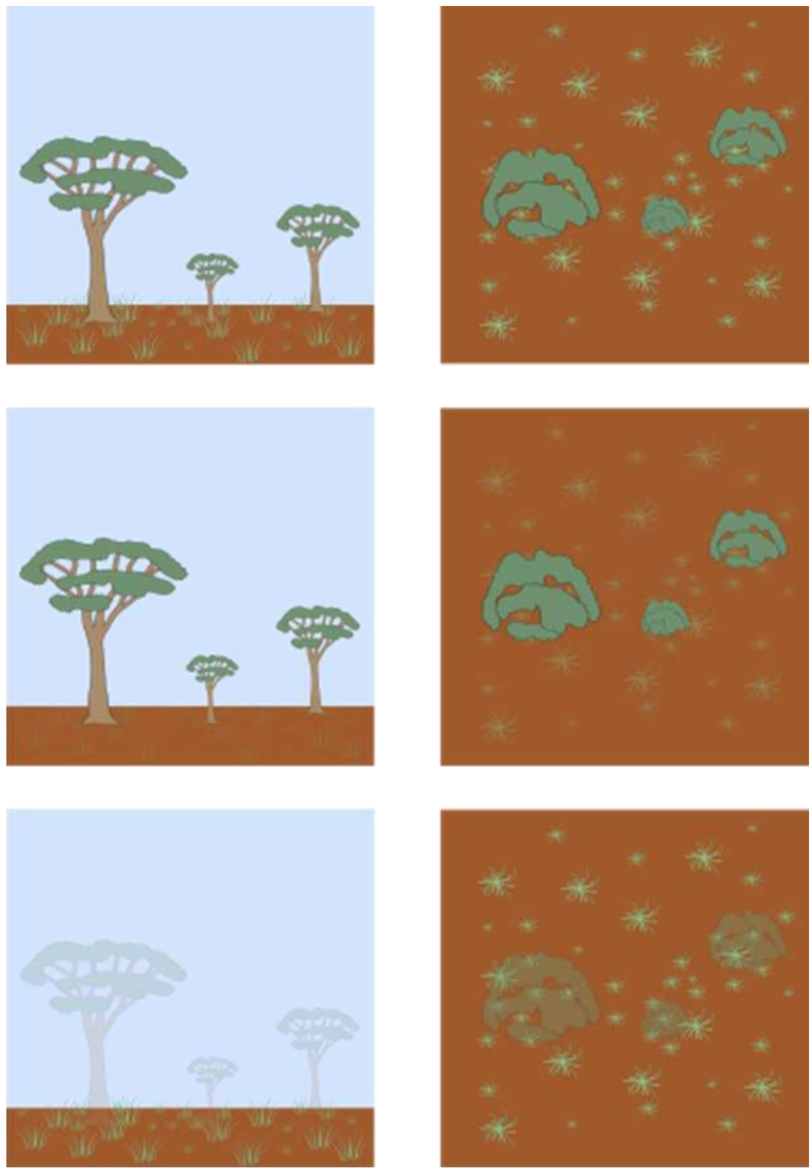
Reporting is based on the measurement of late dry season ground cover using Landsat satellite imagery which has been processed to produce fractional ground cover estimates, using field data for calibration.

Landsat satellite imagery and fractional ground cover

Measurement of ground cover for reporting is based on data derived following the fractional cover method described by Scarth et al. (2010) and Guerschman et al. (2015). The method measures the proportion of green cover, non-green cover and bare ground using reflectance information from late-dry-season satellite imagery from Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+) and Landsat 8 Operational Land Imager (OLI). The spatial resolution of Landsat imagery is approximately 30 metres. The revisit frequency of a Landsat satellite is 16 days and the archive of Landsat data used here dates from 1987 to 2016.

The fractional-cover data is calibrated using over 1500 field observations from a range of ground, tree and shrub cover levels, and a range of environments. It is important to note that the fractional-cover data measures all cover as viewed from above by the satellite, including the trees and shrubs as well as the ground cover and bare ground. To estimate the level of ground cover, the fractional cover data is corrected to effectively remove the influence of trees and shrubs, providing estimates of the level of green ground cover, non-green ground cover and bare ground at ground level (see Figure 1 in Trevithick et al., 2014). The *fractional ground cover* method enables reporting in areas of higher tree cover—up to 60 per cent persistent green (i.e. woody vegetation) cover—allowing most (>90 per cent) of the grazing lands of the Great Barrier Reef catchment areas to be reported on.

As a final step, the green and the non-green ground cover fractions are summed to produce a total ground cover estimate, as erosion and run-off are influenced by all ground cover. This estimate of total ground cover is what is used for reporting here and is hereafter referred to simply as '*ground cover*'. Slight variations may occur in the results produced each year due to new updates and reprocessing of data.



a.

b.

c.

Figure 1: Schematic representation of the correction of the fractional cover data to estimate the fractional ground cover (Trevithick et al., 2014), used for reporting herein. (a) Fractional cover measures all vegetation cover including trees, shrubs and ground cover, as well as bare ground. The ground cover and bare ground are partially obscured by the trees and shrubs. (b) Next, a time-series approach is used to estimate the percentage of 'persistent' cover in the tree and shrub layers. (c) Finally, a correction factor is applied, based on field data, to effectively remove the 'persistent' cover in the tree and shrub layers, thus providing an estimate of the green cover, non-green cover and bare ground, all at the ground level – the fractional ground cover.

Late-dry-season ground cover

Late-dry-season ground cover is estimated using a seasonal composite of fractional ground-cover data. The seasonal composite is derived from each 16-day Landsat satellite image acquired throughout the season. It is produced by selecting the most representative per pixel estimate (i.e. 30 metre x 30 metre area) of fractional ground cover for the season; then, these areas are composited to generate a comprehensive regional dataset (Flood, 2013). This approach has the advantage of removing errors and outliers in the data, providing the most spatially comprehensive coverage as there is generally very little missing data due to cloud, cloud shadow or satellite sensor issues. For reporting here, spring (September–November) seasonal composites (for the period 1987 to 2016) are used, as this best approximates the late dry season.

Reporting regions and grazing lands

Reporting is based on the six natural resource management (NRM) regions which the Great Barrier Reef region comprises:

- Cape York region
- Wet Tropics region
- Burdekin region
- Mackay Whitsunday region
- Fitzroy region
- Burnett Mary region.

Grazing lands in the reporting regions were spatially-defined based on the most recent land-use data provided by the Queensland Land Use Mapping Program (DSITIA, 2012). The most recent version of the mapping is current to 2009 for all reported regions except for Cape York and the Wet Tropics which are current to 2013 and 2015, respectively.

A *reporting region* is defined as that part of an NRM region which is grazing land and has less than 60 per cent persistent green (i.e. woody vegetation) cover.

Reporting ground cover

This report provides a regional overview of late-dry-season ground-cover levels in the Great Barrier Reef region based on analysis of seasonal (spring) total ground cover data. The statistics are calculated for each pixel (i.e. 30 metre x 30 metre area) and then summarised (i.e. averaged) for each of the regions.

Statistics reported for each region include:

- 2016 mean late-dry-season ground cover
- 29-year mean late-dry-season ground cover (1987 to 2016)
- the percentage of the region's reporting area with late-dry-season ground cover less than 70 per cent in 2016
- the percentage of the region's reporting area with mean late-dry-season ground cover less than 70 per cent for the 29-year period, 1987 to 2016.

Graphs show the distribution of ground cover for each region across the range of ground cover levels. Maps of ground-cover percentages have been provided for the entire Great Barrier Reef region, and for each reporting region, as a visual representation of the statistics listed above. A map comparing ground cover decile rankings for 2016 with long-term mean levels has also been produced.

It is important to note that averaging ground cover across whole regions can mask localised areas of lower cover, particularly in large catchments with a strong rainfall gradient (e.g. the Burdekin and Fitzroy). The mean ground cover reported here is, therefore, indicative of general levels of ground cover within the reporting region. For additional level of reporting, the reporting regions are further divided into catchments (and sub-catchments for larger catchments) in the ground cover technical report (DSITI, 2017).

Rainfall data

Rainfall data is provided for current and historical context as rainfall is the primary driver of ground-cover levels at the regional scale. In general, high rainfall in the preceding seasons results in higher ground cover levels and low rainfall in preceding seasons results in lower ground cover levels. Rainfall data was obtained from Scientific Information for Land Owners (SILO) as a five-kilometre grid. For each reporting region, the mean annual rainfall was then calculated from October to September for each year from 1986, to align the mean annual rainfall with the late-dry-season reporting period.

Scoring system

A standardised scoring system is used for each of the key indicators in the Reef Report Card. The scoring system is used to assess and communicate the status of the indicator against the Reef Water Quality Protection Plan (2013) target.

Ground cover target

Minimum 70 per cent late dry season ground cover on grazing lands by 2018.

Table 1: The colour-coded ground cover scoring system

Grade	Status	Criteria – mean ground cover for late dry season 2016	Colour
E	Very poor	0–30%	Red
D	Poor	30–39%	Orange
C	Moderate	40–49%	Yellow
B	Good	50–69%	Light green
A	Very good	70–100%	Dark green

Qualitative confidence ranking

A multi-criteria analysis is used to qualitatively score the confidence in each indicator used in the Reef report card from low to high. The approach combined the use of expert opinion and direct measures of error for program components where available. Ground cover has received a four-bar confidence ranking.

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Wetland condition methods

Introduction

The Paddock to Reef program

The catchments of the Great Barrier Reef (the Reef) have been extensively modified over the past 160 years for agricultural production, industry and urban settlement, leading to a decline in the quality of water entering the Reef lagoon and modification of coastal ecosystems such as wetlands and floodplains (Brodie and Mitchell, 2005; Kroon and Brodie, 2009; Brodie et al., 2013; GBRMPA, 2014; Waterhouse et al., 2016; Waterhouse et al., 2017).

In response, the Great Barrier Reef Water Quality Protection Plan 2003 (Reef Plan) was initiated to address the threat to the Reef. The plan was updated in 2009, 2013 and again in 2017 in a joint Queensland and Australian government initiative (Australian and Queensland governments, 2009; Australian and Queensland governments, 2013). In it, a set of water quality and management practice targets is outlined for catchments discharging to the Reef, with the long-term goal to ensure that the quality of water entering the Reef has no detrimental impact on the health and resilience of the Reef. Progress towards targets is assessed through the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (the Paddock to Reef program).

The 2013 Reef Plan includes the following revised catchment target for wetlands:

- There is no net loss in extent, and an improvement in the ecological processes and environmental values, of natural wetlands.

The Reef report card is produced to assess progress towards the water quality and catchment targets defined in the Reef Plan 2013, following regional investments in improved land management practices. These practices aim to improve water quality and protect and enhance key areas of the region. Key areas include freshwater wetlands, which have both a water quality protection function and value in their own right as an integral component of reef catchment ecosystems. Strategic actions for improving wetland condition are outlined in the *Wetlands in the Great Barrier Reef Management Strategy 2016–21* (DEHP, 2016).

Changes in wetland *extent* have been reported since 2011. With the establishment of the Great Barrier Reef catchment wetland monitoring program (the wetland program), reporting on change in wetland environmental values and, ultimately, ecological processes of natural freshwater wetlands, is now included as part of the Paddock to Reef program and the Reef report card.

This baseline report covers the component of the 2013 Reef Plan wetland target addressing wetland values and ecological processes.

Wetlands in the Reef catchment

The natural freshwater wetlands of the Reef catchment are an integral component of a dynamic interconnected ecosystem that includes and sustains the Reef. The natural environmental values of wetlands and the ecosystem processes that underlie them serve many beneficial purposes within this greater ecosystem, including mitigating the downstream impacts of land-based human activities (Arthington et al., 1997; Waterhouse et al., 2016). However, the capacity of wetlands to thrive as part of the catchment landscape and to perform these valuable services to the Reef is finite (Verhoeven et al., 2006). Disturbance to wetland ecosystem components and processes has flow-on effects on downstream components and processes of the Reef ecosystem (Bunn and Arthington, 2002; Brodie and Mitchell, 2005;

GBRMPA, 2012; Sheaves et al., 2014; GBRMPA, 2014). In many areas, wetlands and other coastal ecosystems have been modified or lost over the last 160 years (Australian and Queensland governments, 2015; Waterhouse et al., 2016). Their restoration and rehabilitation in strategic locations is expected to improve water quality and ecosystem function.

The 2015 DSITI report, *A landscape hazard assessment for wetlands in the Great Barrier Reef catchment*, identifies potential anthropogenic pressures on wetlands and qualitatively associates them with broadscale land uses and infrastructure types. The land-use driven pressures on wetlands are classified as:

- input pressures (including nutrients, sediments and pesticides)
- harvesting/exploitation
- water regime change
- biological introductions/perpetuation
- habitat disturbance or alteration.

The land use/pressure characterisation process and hazard assessment indicated that the most ubiquitous land-use-driven pressures influencing wetlands and their natural environmental values are changes to hydrology; inputs of nutrients; inputs of sediments; direct addition and/or removal of water to and from the wetland; and plant and animal pests. The land uses having the strongest associations with individual pressures, and driving multiple pressures on wetlands, were urban development, irrigated cropping and horticulture, intensively managed grazing, mining and extensive grazing.

In 2013, 77 per cent of the pre-European extent of non-riverine freshwater wetlands in the Reef catchments—vegetated swamps (palustrine) and lakes (lacustrine)—remained (Reef WQ Report Card 2014). The 2013 Scientific Consensus Statement (Schaffelke et al., 2013) on land-use impacts on Reef water quality and ecosystem condition notes that:

> Poor land use and management practices affect many of the remaining coastal freshwater wetlands, with inputs of excess sediment and nutrient and certain irrigation techniques affecting wetland structure and function, for example by facilitating weed growth, loss of connectivity, reduced oxygen levels and flow rate (Department of Premier and Cabinet, 2013).

Wetland values in the paddock-to-reef context

In the Reef Plan whole-of-catchment context, wetlands are 'key areas' that have a water quality function as well as intrinsic environmental values to be protected and enhanced. Hence the following wetland target:

- There is no net loss of the extent, and an improvement in the ecological processes and environmental values, of natural wetlands.

In Queensland, section 81A of the Environmental Protection Regulation 2008 (part of the *Environmental Protection Act 1994*), defines wetland *environmental values* as the qualities of a wetland that support and maintain:

- the health and biodiversity of the wetland's ecosystems
- the wetland's natural state and biological integrity
- the presence of distinct or unique features, plants or animals and their habitats, including threatened wildlife, near threatened wildlife and rare wildlife under the *Nature Conservation Act 1992*
- the wetland's natural hydrological cycle
- the natural interaction of the wetland with other ecosystems, including other wetlands.

For the purposes of the Paddock to Reef program, four of these values were initially used as wetland environmental values (WEVs) for reporting.[1] A pilot study using these WEVs to assess wetlands led to small changes resulting in a coherent set of WEVs that aligned with examples of rapid assessment instruments for gauging the condition of wetlands (see Tilden et al., 2015). The WEVs currently used are:

- WEV 1 The biological health and diversity of the wetland's ecosystems (biotic integrity)
- WEV 2 The wetland's natural physical state and integrity (physical integrity)
- WEV 3 The wetland's natural hydrological cycle (hydrology)
- WEV 4 The natural interaction of the wetland with other ecosystems, including other wetlands (connectivity).

The Great Barrier Reef Marine Park Authority's Outlook report (GBRMPA, 2012) defines a set of *ecological processes* of natural and modified coastal ecosystems linked to the health and resilience of the Reef. They are:

- physical processes of transport and mobilisation, namely: recharge/discharge, sedimentation/erosion, deposition and mobilisation processes
- biogeochemical processes of energy and nutrient dynamics, namely: production, nutrient cycling, carbon cycling, decomposition, oxidation-reduction, regulation processes, chemical / heavy metal modification
- biological processes (processes that maintain animal/plant populations), namely: survival/reproduction, dispersal/migration/regeneration, pollination, recruitment.

These ecological processes of natural wetlands support the environmental values listed in the environmental protection regulation above. Within the context of ecological processes supporting environmental values, the causal relationships are complex and interconnected. For example, land-use-driven changes to the processes of wetland recharge and discharge, such as occur in parts of the lower Burdekin where wetlands are used to store irrigation water, will affect not only a wetland's natural hydrological cycles but also the health and diversity of its ecosystems and the interaction of the wetland with other ecosystems (Perna et al, 2012). Conversely, ecological process changes, for example in the reproduction of wetland species, will affect not only the health and biodiversity of a wetland's ecosystem but also, potentially, its interaction with other ecosystems that rely on wetland productivity as a source of nutrients, and will sometimes also affect wetland hydrology.

Addressing the target for wetland ecosystems

The Great Barrier Reef catchment wetland monitoring program aims to report on changes in wetland environmental values and, ultimately, ecological processes of natural freshwater wetlands.

The program uses a Driver–Pressure–State–Impact–Response (DPSIR) conceptual framework, illustrated in Figure 1, which can be applied at three levels of assessment:

- landscape-scale studies
- rapid wetland-specific assessments
- detailed validating studies and research projects.

The program directly assesses pressure and state using rapid wetland-specific assessment methods, and will assess impact over time.

[1] The 'presence of distinct or unique features, plants or animals and their habitats, including threatened wildlife, near threatened wildlife and rare wildlife under the *Nature Conservation Act 1992*' was dropped because the emphasis of the wetland monitoring program is on anthropogenic impacts. Distinct or unique features may be present or absent in wetlands regardless of anthropogenic impacts.

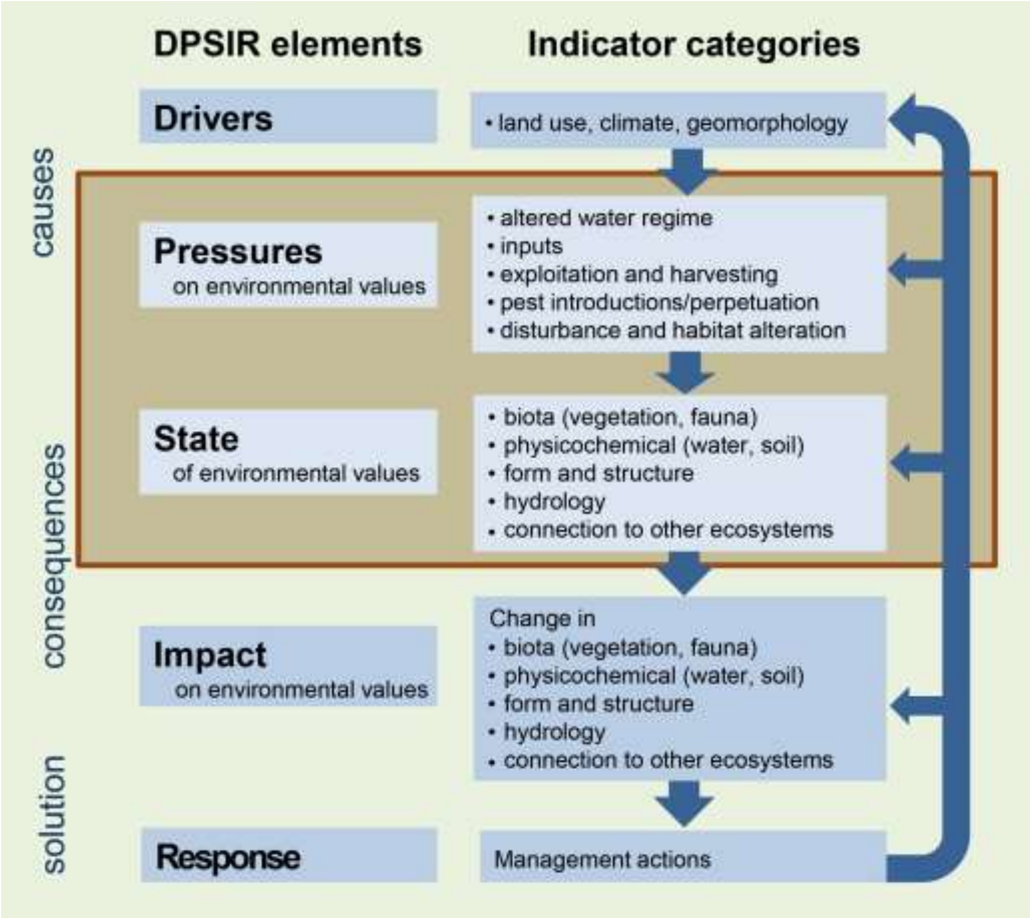


Figure 1: Conceptual framework for wetland monitoring program. The assessment tool (WFAT–M) directly assesses pressure and state (outlined) and can assess impact over time.

In 2014, a pilot study was carried out, both to inform the development of a program for monitoring wetland values in the Reef catchments and to test the Wetland Field Assessment Tool for Monitoring (WFAT–M)[2], developed for the monitoring program (see Tilden et al., 2015).

During the dry months of 2015 and 2016, a refined version of the WFAT–M tool was used to gather baseline data for anthropogenic *pressure* on wetland environmental values (WEVs) and the *state* of wetland environmental values across the whole Reef catchment from Cape York to the Burnett Mary region. The outcome of this baseline study of wetland environmental values in the Reef catchments is reported in the 2016 Reef report card, under 'wetland condition results'.

Methods

Monitoring design

Based on the outcome of the 2014 pilot study, the Reef wetland monitoring program was designed with the following characteristics:

- **Sample size**—The proposed sample size is 100 wetlands, to be assessed in five panels of 20 in an augmented, serially-alternating panel design (Table 1). This panel design allows testing to occur for change between two times after three rounds of wetland assessments. By this stage, two panels of wetlands, for a total of 40 wetlands, will have been assessed twice. Subject to confirmation or

[2] An adaptation of the Wetland Field Assessment Toolkit (WFAT), under development by the Queensland Wetlands Program

adjustment after the first round of baseline data collection, a sample of 40 wetlands was estimated to be the minimum needed for *change* in wetland values to be detected at a level of precision allowing meaningful Reef-wide reporting within the timeframe of the current Reef Plan (2013) and beyond. The chosen level of precision was a difference between mean WFAT–M scores of ±1 between two assessment times (power = 0.8, α = 0.05).

- **Sample structure**—A sub-population of wetlands comprising all Reef natural freshwater *floodplain wetlands in dense aggregations* was chosen for reporting on the Reef Plan target. Floodplain wetlands were chosen to narrow the population of all freshwater wetlands in the Reef catchment to a sub-population more connected with Reef water quality and ecology that would also be of interest to wetland managers. Choosing dense aggregations of wetlands produced a less scattered sample that was more efficient to assess. It also focused on areas where the condition of wetlands was more likely to affect Reef water quality, due to the greater volume of ecological processing by wetlands. Figure 2 shows the aggregations of wetlands that define the sub-population. Approximately 65 per cent of floodplain wetlands and 40 per cent of all Reef freshwater wetlands are encompassed by these areas of dense aggregations.
- **Sampling method**—The Generalised Random Tessellation Stratified (GRTS) method (Stevens and Olsen, 2004) was used to draw a large master sample of all Reef natural freshwater wetlands. This master sample gives maximum flexibility to the design of future research (Larsen et al., 2008). From this master sample, an oversample of floodplain wetlands in dense aggregations was chosen according to GRTS rules for preserving randomness and spatial balance. These wetlands will represent the sub-population for reporting on the Reef Plan target.
- **Allocation of sampling effort in time**—A panel design was chosen for the monitoring program to maximise trend detection while also allowing for the measurement of wetland status across the sub-population (Table 1). A decision was made to focus on Reef-wide reporting for the current phase of the project (including catchments from the Mary River in the south to the Normanby River in the north); however, the program was designed to allow for rapid scaling up to report by region should additional resources become available.[3]

Table 1: Panel design for monitoring the sample of 100 wetlands in the Reef catchment

Panel	Assessment round									
	1 (2015–16)	**2** (2017)	**3** (2018)	**4** (2019)	**5** (2020)	**6** (2021)	**7** (2022)	**8** (2023)	**9** (2024)	**10** (2025)
1	20	20	20	20	20	20	20	20	20	20
2	20		20						20	
3		20		20						20
4					20		20			
5						20		20		
Year total	40	40	40	40	40	40	40	40	40	40
Total sample	40	60	60	60	80	100	100	100	100	100

[3] More information about the rationale behind these design decisions is given in Tilden et al. (2015).

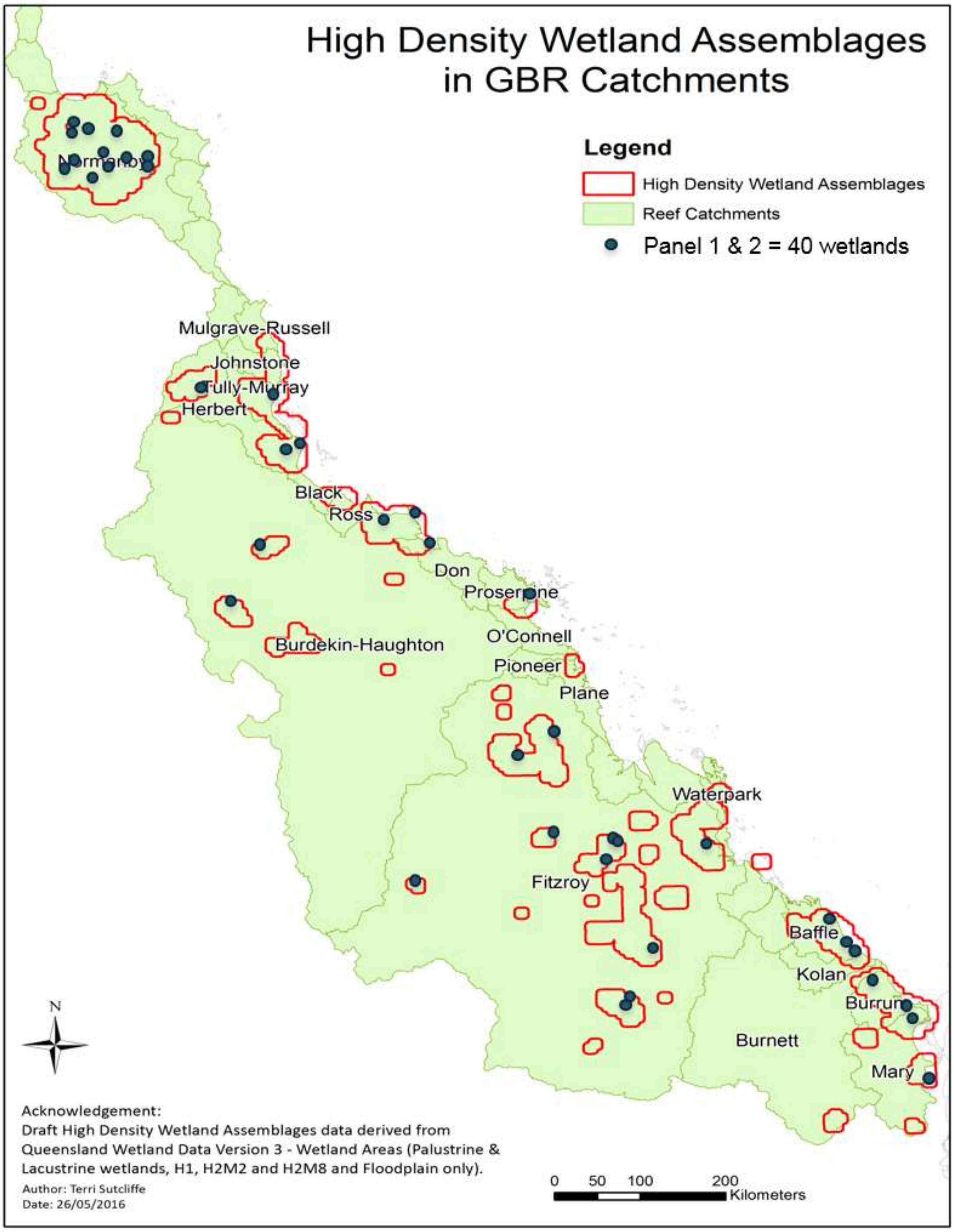


Figure 2: Extent of the sub-population of floodplain wetlands chosen for reporting on the target. Areas with dense aggregations of floodplain wetlands defined using the 'point density' tool in ArcGIS Spatial Analyst are outlined in red. Within those areas the GRTS spatially balanced random sample for panels 1 and 2 (40 wetlands) is shown.

Scoring wetlands using the wetland field assessment tool for monitoring (WFAT–M)

Figure 3 shows the Driver–Pressure–State–Impact–Response framework applied at the rapid-assessment scale of the Wetland Field Assessment Tool for Monitoring (WFAT–M).

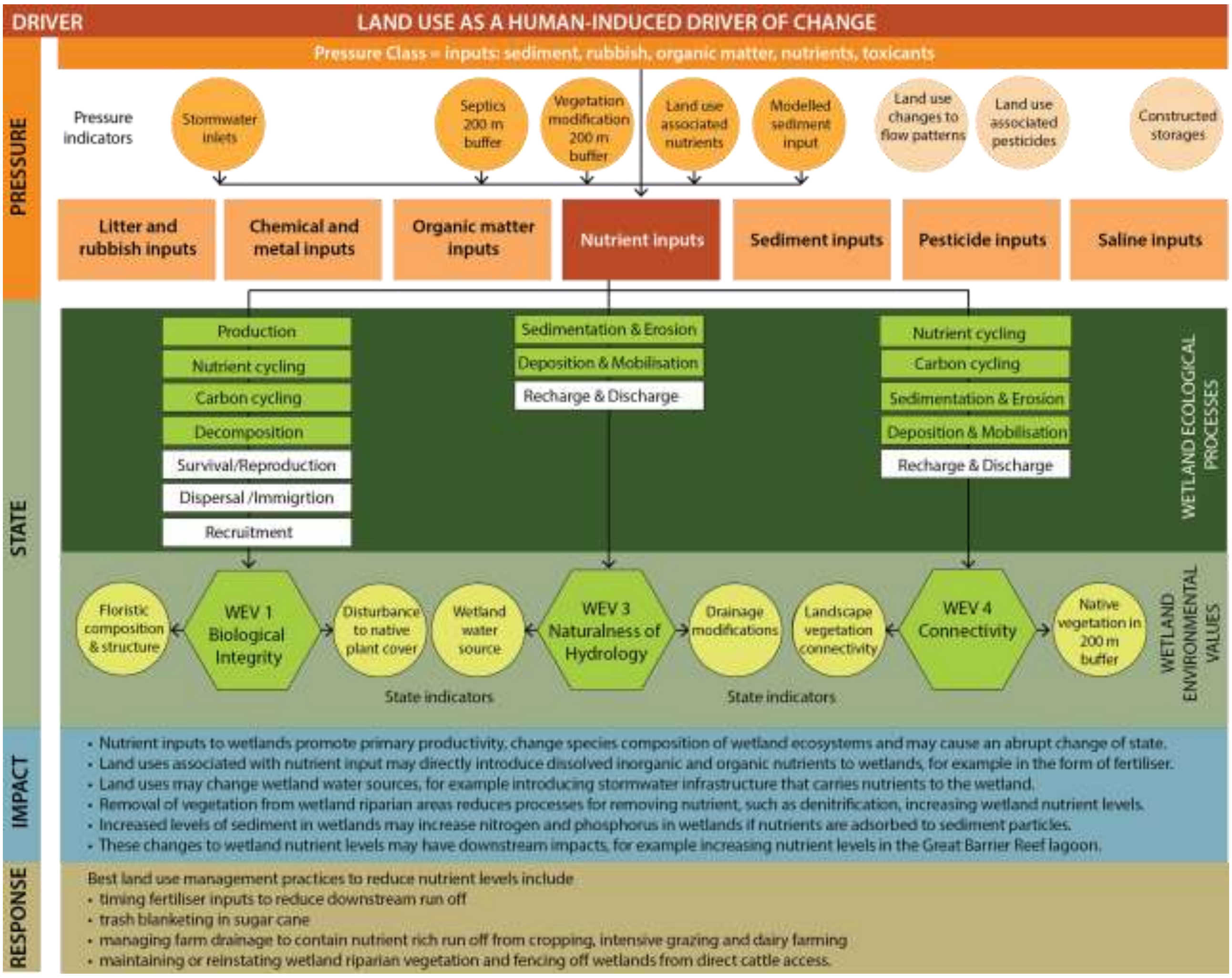


Figure 3: A Driver–Pressure–State–Impact–Response conceptual model showing an example of anthropogenic input pressures to wetlands, focusing on nutrients. The relationships between anthropogenic *pressures* and the *state of wetland values* are mediated by wetland ecological processes. Individual pressures affect many of the ecological processes that determine the state of wetland values. The WFAT–M measures pressure and state but does not illuminate the complex causal relationships involving ecological processes. Understanding these processes will be a fertile subject for future studies of how wetlands function under pressure from human land use in the Reef catchments.

The WFAT–M tool was developed to measure anthropogenic disturbance to the environmental values of individual wetlands on a gradient from 'natural' to 'highly disturbed'. It is designed to measure and track status, changes and trends in (a) anthropogenic pressure on wetland environmental values (WEVs) and (b) the state of WEVs (the latter could also be characterised as wetland *condition*). The pressures on WEVs, and the state of WEVs are gauged with indicators related to wetland components and processes (Table 2).

The wetland scoring scales at three levels are described in Table 3.

- Each wetland is scored on two separate indices,[4] **pressure** and **state**; the first represents land-use **pressure** on natural WEVs while the other represents the **state** of those values (i.e. wetland condition).
- For each index, four sub-indices are evaluated, based on the four WEVs described earlier, with multiple indicators assessed per WEV.
- Individual indicators are assessed on ordinal scales with scores generally ranging from one to five.

[4] Index is defined as a compound measure that aggregates multiple indicators.

Overall pressure and state values per wetland are calculated by aggregating indicator scores and are then converted to scores on a 13–point scale. For reporting purposes, the numerical scores are collapsed into a 5-point A–E scale. Aggregated values on a 5–point numerical scale are also calculated for each of the four WEV sub-indices and these are also reported as A to E (Table 3).

For both pressure and state, individual wetland scores are aggregated to produce means and other statistics for reporting at the Reef-wide scale. Norman (2010) summarises work supporting the use of parametric statistics on aggregated ordinal data.

Table 2: Indicators used to gauge the pressures on wetland environmental values (WEVs) and the state of WEVs (wetland condition) [5]

PRESSURE INDICATORS		
WEV 1 Biological health and diversity of the wetland's ecosystems		Indicator type
P1	Land use associated with the introduction or perpetuation of pest species	Desktop (field verified)
P2	Modification of vegetation in the 200 m buffer (excluding mapped wetland)	Desktop
P3	Land use associated with pesticide residue inputs	Desktop
P4	Land use associated with nutrient inputs	Desktop
P5	Number of septic systems within 200 m of the wetland per ha of mapped wetland	Desktop (field verified)
P7	Plant pest cover in the mapped wetland	Field
P8	Plant pest cover in the 200 m buffer	Field
P9	Fishing (or other fauna taking) within the mapped wetland	Field
WEV 2 The wetland's natural physical state and integrity		
P10	Sediment supply (modelled, GBR)	Desktop
P12	Number of stormwater or other point inflows per hectare of wetland	Field
P13	Recreational use	Field
WEV 3 The wetland's natural hydrological cycle		
P15	Floodplain hydrology	Desktop
P16	Land use associated with changes to natural water flow patterns	Desktop
P17	Area under constructed water storages	Desktop
P18	QWP hydrological modifier code for the mapped wetland	Desktop (field verified)
WEV 4 The natural interaction of the wetland with other ecosystems, including other wetlands		
P20	Native vegetation cleared within 5 km of the wetland	Desktop
P21	Loss of wetland regional ecosystems within 5 km of the wetland	Desktop

[5] About 60 per cent of WFAT–M indicators were adapted from the Wetland Field Assessment Tool, currently under development by the Queensland Wetlands Program. These indicators were in turn adapted from Scheltinga et al. (unpublished). The remainder were adapted from other rapid-assessment instruments or devised specifically for the WFAT–M, on the basis of published literature and/or botanical and hydrological expert opinion.

STATE INDICATORS		
WEV 1 Biological health and diversity of the wetland's ecosystems		
S1	Floristic composition and vegetation structure	Field (sampling site)
S2	Disturbance to native plant cover by people, plant or animal pests, or livestock	Field (sampling site)
S3	Exotic plant cover	Field (sampling site)
WEV 2 The wetland's natural physical state and integrity		
S5	Integrity and stability of the upper water body margin	Field (traverse)
S6	Naturalness of landform	Field (sampling site)
S7	Direct disturbance by humans, livestock or pigs physically impacting soil	Field (sampling site)
S8	Pugging by livestock and feral pests in the mapped wetland	Field (traverse)
WEV 3 The wetland's natural hydrological cycle		
S9	Drainage modifications and artificial structures altering natural surface water flow patterns	Field (traverse)
S10	Wetland water regime – wetland water source	Field (traverse)
S11	Wetland water regime – abstraction (water taken out for use)	Field (traverse)
WEV 4 The natural interaction of the wetland with other ecosystems, including other wetlands		
S13	Connectivity of the wetland within a landscape context	Desktop (traverse)
S14	Native vegetation in the wetland's 200 m buffer zone (excluding the mapped wetland)	Desktop (field verified)

Table 3: Scoring and reporting scales for individual wetlands

Indicator scores	1			2			3			4			5
Reported indicator scores	A			B			C			D			E
Aggregated sub-index values (per WEV)	≤1.8			>1.8 to ≤2.6			>2.6 to ≤3.4			>3.4 to ≤4.2			>4.2
Numerical scores	1			2			3			4			5
Report card scores	A			B			C			D			E
Aggregated overall pressure and state values	≤1.267	>1.267 to ≤1.534	>1.534 to ≤1.8	>1.8 to ≤2.067	>2.067 to ≤2.334	>2.334 to ≤2.6	>2.6 to ≤2.867	>2.867 to ≤3.134	>3.134 to ≤3.4	>3.4 to ≤3.667	>3.667 to ≤3.934	>3.934 to ≤4.2	>4.2
Numerical scores	1	2	3	4	5	6	7	8	9	10	11	12	13
Report card scores	A	A	B	B	B	C	C	C	D	D	D	E	E

WFAT–M assessment and data collection

The WFAT–M was developed for rapid wetland-specific assessments of the pressure on and state of environmental values, combined with long-term monitoring for evidence of change. To achieve this, the tool combines indicators of disturbance to wetland environmental values, both desktop (spatial imagery) indicators and field-based indicators. The WFAT–M methods are documented in three sections:

- a desktop workbook, for reproducing a standard set of maps and other information to be used in the field
- a desktop assessment methods guide and data sheets, for conducting the desktop component of the assessment and recording results
- a field methods guide and data sheets, for conducting the field assessment and recording results.

The desktop assessment, using spatial data, maps and aerial imagery, gives whole-of-wetland scores for its pressure and state indicators. The field assessment has two components: (a) pressure and state indicators scored for the whole-of-wetland while conducting a traverse (according to rules set out in methods guide) and (b) state indicators scored at sampling sites within the wetland.

For each wetland, sampling sites are chosen according to rules set out in the methods guide. A typical wetland would have 5–8 sampling sites, including sites at the inlet and outlet of the wetland, sites at hydrological modifiers, sites in the most undisturbed part of the wetland, and sites in the 200-metre buffer, close to the wetland. Larger wetlands require more sampling sites to be assessed.

Rules for recording the location of sites ensure that the same sampling sites are assessed at each repeat visit to the wetland. This is to maximise the detection of trends.

Data reports

Wetland data is processed with purpose-written R code. Data entry and handling is automated to a high degree to minimise error while still allowing eyes-on checks to maintain a high standard of data quality assurance.

For each wetland, standard data reports are produced, with aggregated scores for overall pressure and overall state as well as aggregated pressure and state scores for each WEV and individual indicator scores. The scales for individual indicators and for WEVs range from one to five, while the overall scores range from one to 13 as illustrated in Table 3. Using the data provided in these reports, descriptive statistics are calculated for reporting against the Reef Plan wetland target.

Figure 4 summarises an individual wetland assessment workflow and activities using the WFAT–M.

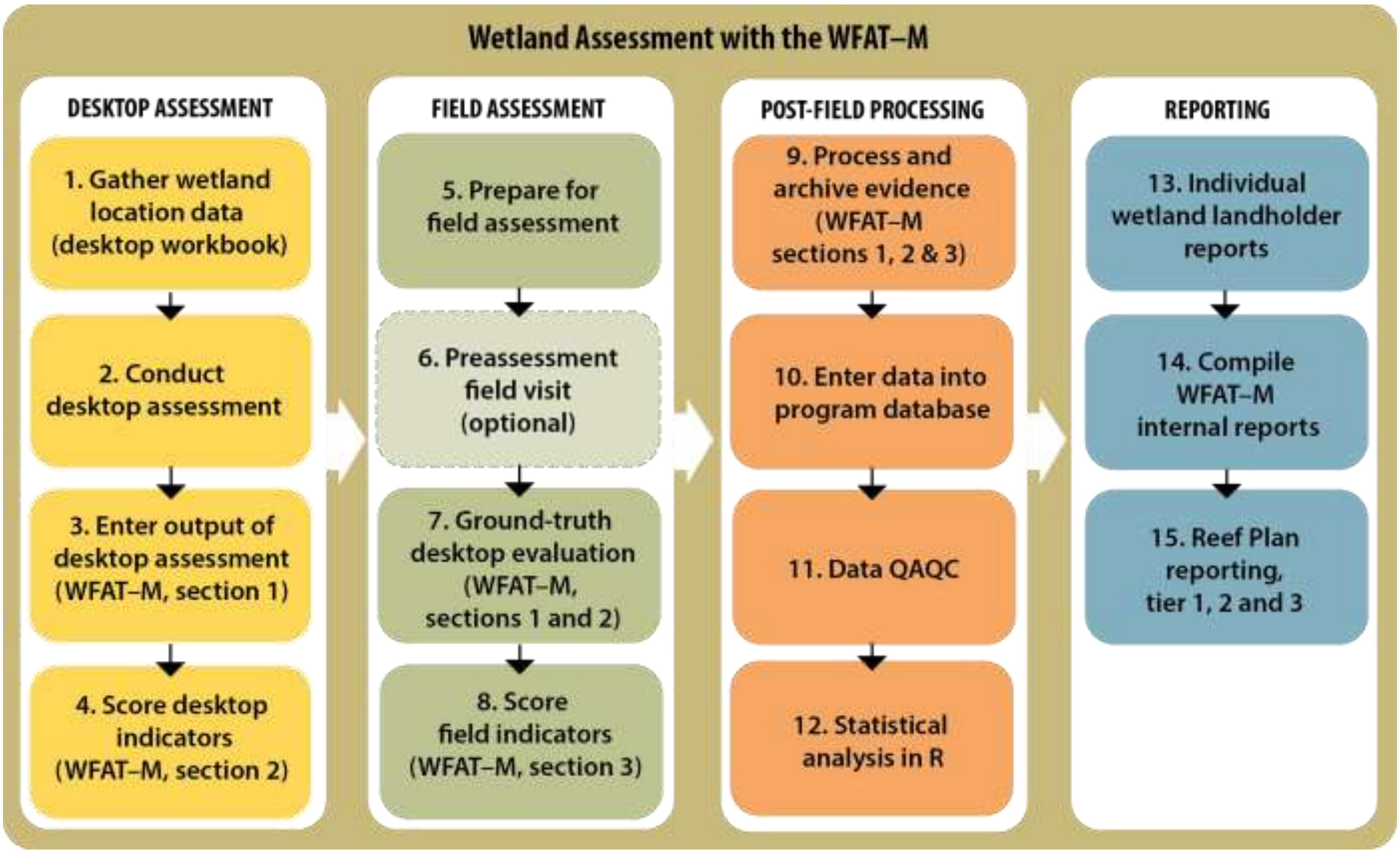


Figure 4: Wetland assessment and reporting workflow using the WFAT–M

Baseline assessments

The land managers of 66 randomly selected wetlands from the defined sub-population were approached for permission to conduct ongoing monitoring assessments.

Forty-one wetlands,[6] comprising panels one and two of the monitoring design, were assessed with the WFAT–M during the dry months of 2015 and 2016. For each wetland, two reports were produced: (a) a report of the anthropogenic *pressure* on the wetland's environmental values and (b) a report of the *state* of the wetland's environmental values. Statistics based on these assessments are reported as a baseline for Reef catchment freshwater floodplain wetlands in dense aggregations, which constitute the sub-population of interest.

The statistical tests and procedures applied to the data were those recommended in the *Great Barrier Reef catchments monitoring program: Proposed analysis methods* (Tilden and Vandergragt, 2017).

Calculating summary statistics

Descriptive statistics, parametric and non-parametric, were calculated. Mean and variance of WFAT–M scores for overall wetland pressure and state characterise the baseline level of anthropogenic disturbance to the Reef natural freshwater floodplain wetlands, along with the mean and variance per wetland environmental value (WEV) for pressure and state.

Non-parametric measures of central tendency and dispersion are also reported in the wetland condition results section of the Reef report card 2016.

Where appropriate, these statistics are compared with values from the 2014 pilot study to see whether predictions are upheld (such as lower mean WFAT–M pressure and state in the randomly drawn 2015–16 baseline sample).

Testing for regional effect due to adaptation of GRTS procedure

When using an oversample to replace non-responsive wetlands[7] in a GRTS spatially balanced random sample, the standard procedure is to replace the non-responding wetland with the next wetland in the GRTS draw. We drew wetlands, with equal probability, from across the whole Reef catchment, without stratifying by region. Because the draw is catchment-wide, the next wetland in the GRTS list was often from a different region to a non-responding wetland. This proved to be logistically unwieldy. Due to the contractual arrangements of the project, the process of contacting land managers for permission to access wetlands was organised on a natural resource management (NRM) region basis; therefore, the replacement of non-responding wetlands also had to be organised regionally.

To allow this, we adapted the GRTS procedure by sorting the generated list of randomly selected wetlands by NRM region and replacing non-responders with wetlands from the same region until we had achieved the same proportions, by region, in our assessed sample as were in the initial draw. This process would have maintained a spatially balanced random sample of wetlands across the whole Reef catchment, provided any non-responsive wetlands were missing at random *with respect to region*.

We tested the proposition that reordering the GRTS list had significantly altered the probabilities that wetlands from particular regions would be included in the sample. A chi-square analysis was performed to

[6] An additional wetland from the GRTS list was included in panel 1 to avoid having an entire region (Mackay Whitsunday) represented by just one wetland. This was done more for operational than scientific reasons, as one out of 40 wetlands is an accurate proportional representation of the number of floodplain wetlands in the Mackay Whitsunday region. The assessment results for this extra wetland were included in the baseline analysis but the wetland was excluded from the test for the effect of region on non-response. This is because including that extra wetland, doubled the number of wetlands from Mackay–Whitsunday, distorting the likelihood of rejection for that region and creating an artefactual "region" effect in the non-response data.

[7] Non-responsive wetlands are wetlands that cannot be assessed for some reason, such as land manager refusal or inaccessibility.

determine whether there was a region effect. It was assumed that there was a background level of non-response in the population, estimated by the proportion of refusal across the Reef-wide 'approached' sample (i.e. wetlands from the GRTS list whose managers had been approached for permission to assess). The expected numbers for each region were calculated using the inverse of this proportion i.e. the acceptance rate. The observed numbers for the chi-square analysis were the numbers of wetlands assessed in each region (i.e. those wetlands whose managers agreed to assessment). The steps in this analysis are displayed in Table 4. No significant difference among regions was found in the rate of acceptance (chi square = 4.36, critical chi sq = 11.07 for $\alpha = .05$, df = 5).

Table 4: Test for NRM region effect on the wetlands sample due to adaptation of GRTS procedure

Region	No. approached (A)	No. assessed (Observed N)	Acceptance rate	Expected N (A x 0.61)
Burdekin	11	5	0.45	6.71
Burnett Mary	14	7	0.50	8.54
Cape York	12	12	1.00	7.32
Fitzroy	21	11	0.52	12.81
Mackay Whitsunday	3	1	0.33	1.83
Wet Tropics	7	4	0.57	4.27
Total	**66**	**40**	**0.61**	

Testing for non-response bias due to land-use intensity

Early experience of seeking permission to assess wetlands in the 2015–16 baseline sample suggested that there could be a non-response bias related to the intensity of land use. When wetlands were surrounded by conservation lands,[8] access was usually granted to assessors, while wetlands in areas of intensive land use such as cane production or mining were more likely non-responsive because access was refused. Moderate levels of land-use intensity (e.g. grazing in native forests) appeared to be associated with non-response levels about midway between those of conservation lands and intensive land use.

To test the hypothesis that there was no non-response bias due to land-use intensity, the sample (N=40) was classified into three land-use categories based on primary Australian Land Use Management (ALUM) classes – low intensity (conservation and natural environments), moderate intensity (production from relatively natural environments) and high intensity (intensive uses, production from dryland or irrigated agriculture and plantations, and water with a tertiary classification of 'production').

A chi-square test for a linear trend was performed on the proportions of assessed wetlands relative to approached wetlands in the three land-use intensity groups. The results of this and subsequent analyses are presented in the Reef report card 2016 (wetland condition results).

[8] Defined by land use within the 200 m buffer zone of the wetland.

Testing the relationship between WFAT–M scores and land-use hazard to wetlands

In the 2014 pilot study, a validity check was performed on the WFAT–M using data from a desktop landscape hazard assessment (DSITI, 2015) in which catchments across the Reef were assessed for their level of land-use hazard to wetlands. Aquatic Conservation Assessment (ACA) sub-catchments (see, for example, Clayton et al., 2006) were used in these hazard assessments with each of these sub-catchments getting an overall land-use hazard score on an ordinal scale of one to six.

To validate the WFAT–M, land-use hazard assessment scores were attributed to each wetland based on land use in the 200-metre buffer zone of the wetland. Spearman's rho correlations were calculated for the relationships of these land-use hazard scores to WFAT–M overall pressure and WFAT–M overall state of the wetlands in the pilot sample.

For these wetlands, the landscape hazard scores for their surrounding ACA sub-catchments were found to be correlated with both pressure on wetland values ($\rho = 0.64$, $p < 0.01$) and state of wetland values ($\rho = 0.64$, $p < 0.01$) as measured by the WFAT–M.

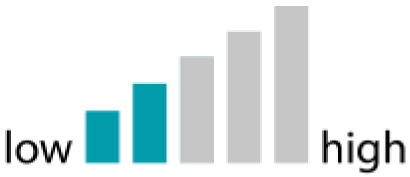
A similar analysis was performed on the data gathered for 41 wetlands during the 2015–16 baseline assessments and the landscape hazard scores for these wetlands were again significantly correlated with both overall pressure on wetland environmental values and state of wetland environmental values, although the correlations were lower ($\rho = 0.37$, $p < 0.05$ for pressure and $\rho = 0.46$, $p < 0.01$ for state).

Qualitative confidence rankings

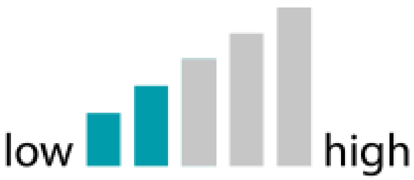
A multi-criteria analysis was used to qualitatively score the confidence in each indicator used in the Reef report card, from low to high (Australian and Queensland Governments, 2016). The approach combined expert opinion and direct measures of error for program components where available.

Wetland condition received a two-bar confidence ranking.

Overall pressure on wetland environmental values



Overall state of wetland environmental values (wetland condition)



For the confidence criterion of 'representativeness', the wetland condition methods have scored 2 out of 3, despite only about one per cent of wetlands in the sub-population of interest having been assessed. This is because the assessed sample is a statistically sound, spatially balanced, random sample of all wetlands in the sub-population. It can therefore be said to represent 100 percent of the population of Reef freshwater floodplain wetlands in dense aggregations.

Once a sample of this size has been empirically demonstrated to be capable of detecting change between times at the desired level of precision (a difference between mean WFAT–M scores of ±1, power = 0.8, α = 0.05), the score for this criterion can increase.

On the other hand, for the confidence criterion of 'directness' the wetland condition methods scored 1 out of 3. Although the data measured have a quantifiable relationship to the reported indicators, it remains for the individual indicators to be calibrated in relation to each other, the sub-indices and the overall score. Also, a small number of indicators do not perform well in discriminating across the range of available classes.

Scores on the remaining criteria and grounds for assigning them are as follows.

Maturity of methods

Score 2 out of 3

- The monitoring design and sampling plan have been peer reviewed and published.
- The WFAT–M is not published. After one more review and update, it should be publishable in about 18 months.

Validation

Score 2 out of 3

The assessment uses a mix of remotely sensed and field survey data.

The field survey indicators provide directly measured data (score 3).

The remotely sensed inputs are variable (score 2).

Measurement error

Score 1 out of 3

Error is not able to be quantified until the second round of assessments is completed.

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Methods for modelling catchment pollutant loads

This report summarises the data and methods used for reporting progress towards the Reef Water Quality Protection Plan 2013 (Reef Plan, Australian and Queensland governments 2013) targets for catchment pollutant loads in the Great Barrier Reef Report Card 2016.

The targets for catchment pollutant loads are as follows:

- At least a 50 percent reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen loads in priority areas by 2018.
- At least a 20 percent reduction in anthropogenic end-of-catchment loads of sediment and particulate nutrients in priority areas by 2018.
- At least a 60 percent reduction in end-of-catchment pesticide loads in priority areas by 2018.

Catchment modelling

The Source Catchments modelling framework (eWater, 2010) is used to model pollutant loads for the 35 catchments affected by land management practices in the Great Barrier Reef region.

This catchment-scale water quantity and quality model uses a node link network to represent the stream (Figure 1). The model generates run-off and pollutant loads for each functional unit (land use) within a sub-catchment, and runoff and pollutants are transported from a sub-catchment through the stream network via nodes and links to the end of the catchment.

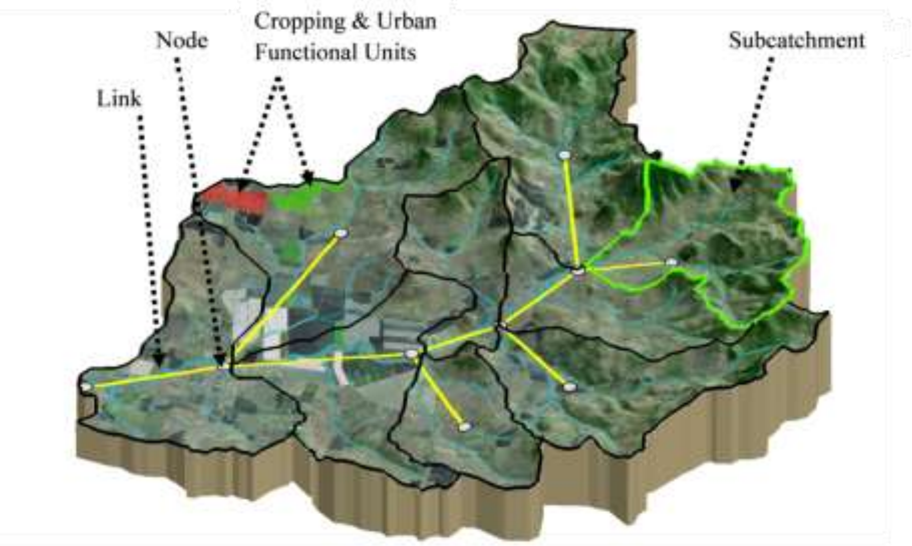

Figure 1: Example of a functional unit (FU) and node-link network generated in Source Catchments. These components represent the sub-catchment and stream network

The Source Catchment model runs at a daily time-step which allows for the exploration of the interactions of climate and management at a range of time-steps. However, for the Reef report card, average annual catchment loads are reported.

The model was run using a fixed climate period from 1986 to 2014 to remove the influence of climate on estimated load reductions. The latest land-use mapping (DSITIA, 2012) was used to describe the spatial extent of each agricultural land use for the baseline year.

The pollutants modelled were:

- fine and coarse sediment
- dissolved and particulate nutrients
- five photosystem II herbicides.

The Paddock to Reef Integrated Monitoring, Modelling and Reporting Program has developed water quality risk frameworks for each agricultural industry. These frameworks articulate best practice in relation to the Reef Plan adoption targets. These practices are described in terms of their relative water quality risk, from low to high. This is a departure from the ABCD management practice frameworks which were the basis for prioritising and reporting investments under Reef Plan 2009. See the Management Practice Methods report for more information about the risk frameworks.

To reflect the reported change in adoption of improved management practices, three scenarios are run:

- pre-development (prior to agricultural development)
- the baseline (i.e. representing land management practices in 2013)
- then each subsequent year with the proportion of land managed using defined practices adjusted each year.

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 land management to be reported.

For the baseline scenario, key land uses were modelled including grazing, sugarcane, cropping, horticulture and forestry.

Modelled load estimates were validated against field data collected at 25 monitoring sites across the Great Barrier Reef catchments. For further information on the model validation processes, refer to Waters et al. (2014).

The catchment loads modelling program undergoes an external peer review every three years. The program was reviewed in 2012 and again in 2015. Prior to the release of each Reef report card, modelled load estimates are reviewed both internally and externally.

Management practice change

The Reef Plan's management practice adoption 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 the modelling technical reports listed under 'Further reading' at the end of this report.

Improvements in grazing management (in particular, vegetation cover management) through riparian and streambank fencing were also modelled. Spatial data on the length of stream and gully fencing were supplied by regional natural resource management (NRM) bodies.

Modelling assumptions

- Loads reported for each Reef 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 data (DSITIA, 2012).
- Paddock model runs that were 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.
- Application rates of pesticides and fertilisers that were used to populate the paddock models were derived through consultation with relevant industry groups and regional NRM bodies.
- Practice adoption areas represented in the model were applied at the spatial scale of the data supplied by regional NRM bodies.
- The water quality benefits from adopting a management practice change were assigned in the year that on ground works were implemented
- It is important to note that these modelled load reductions are based on improved land management adoption data supplied by industry and regional NRM bodies. 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 publicly available version of the eWater Source Catchments model (www.ewater.org.au) was modified to incorporate hillslope constituent generation from the most appropriate paddock models for cropping and sugarcane areas, and the Revised Universal Soil Loss Equation (RUSLE) for grazing. In addition, gully and streambank erosion and floodplain, channel and reservoir deposition processes were based on the SedNet/ANNEX approach (Wilkinson et al., 2014). 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's reef catchments.

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 an output time-series 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 groundcover 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 2012–13 land management. 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 anthropogenic load was calculated as the total baseline load less the pre-development load.

Load reductions

To reflect investment in improved management practices since 2012–13, 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 (Figure 2).

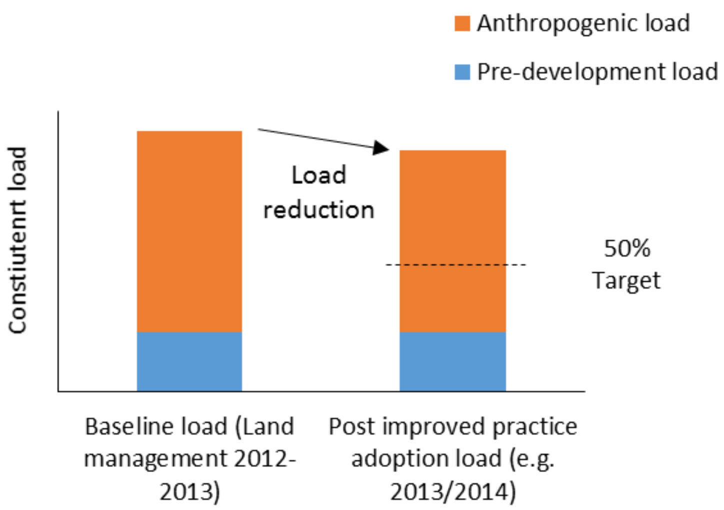

Figure 2: Example of modelled pre-development and anthropogenic pollutant loads, and the load reduction following investment in improved practices.

Modelling improvements

As part of the continuous program improvement, updated model input layers are incorporated into the model when they become available. Paddock to Reef program phase 2 improvements already implemented include: seasonal ground cover, improved soils layer, extended modelling climate period and hydrology parameter updates, finer resolution topographic data, and expanded water quality monitoring data sets. Improvements to the paddock modelling include more detailed modelling of bananas and grains, as well as representation of water-recycling pits in the lower Burdekin region.

A desktop gully-mapping program is continuing to improve the spatial representation of gullies in the models. When updated gully maps become available, these have been incorporated (areas included to date are the Normanby, Burdekin and Fitzroy catchments).

In sugarcane, loss of dissolved inorganic nitrogen (DIN) below the root zone can be a major loss pathway for nitrogen. This process was not represented previously in the model but functionality has now been added to enable a proportion of sugarcane DIN lost below the root zone to be returned to the stream. Loads now better reflect monitored data and this addition allows improved nitrogen management to be reflected in drainage run-off.

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:

$$\text{Reduction in load (\%)} = \frac{\text{(anthropogenic baseline load – anthropogenic change) x 100}}{\text{Anthropogenic baseline load}}$$

Modelled total suspended sediment, nitrogen, phosphorus and pesticide loads at the end of the catchment are reported for the total Great Barrier Reef and for the six regions that make up the Great Barrier Reef catchment.

The program now also reports on overall toxic loads for pesticides. A pesticide toxic equivalent load is the calculated load of a pesticide multiplied by the relative toxicity of the pesticide compared to diuron.

Qualitative confidence ranking

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. Catchment loads modelling received a three-bar confidence ranking.

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Catchment pollutant loads – monitoring methods

This report summarises the methods used for monitoring catchment pollutant loads reported in the Great Barrier Reef Report Card 2016.

The targets for catchment pollutant loads are as follows:

- At least a 50 percent reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen loads in priority areas by 2018.
- At least a 20 percent reduction in anthropogenic end-of-catchment loads of sediment and particulate nutrients in priority areas by 2018.
- At least a 60 percent reduction in end-of-catchment pesticide loads in priority areas by 2018.

Monitoring sites

The end-of-system monitoring sites are located at the lowest point in a river or creek, mainly where gauging stations have been established and are being maintained by the Queensland Government Department of Natural Resources and Mines. These sites provide data on the catchment upstream of the site. Sub-catchment sites are located at the lowest point in a sub-catchment (tributary), mainly at existing gauging stations. They provide data on the sub-catchment upstream of the site. Both site types provide field data that is used to calibrate and validate catchment models.

Rainfall data

Rainfall totals and rainfall decile data were obtained from the Bureau of Meteorology National Climate Centre. These data were synthesised using geographic information system tools to display total annual rainfall and annual rainfall deciles for Queensland during the period from 1 July 2015 to 30 June 2016.

River discharge data

River discharge data (the volume of water moving past a point per unit of time in $m^3 s^{-1}$) for monitoring sites were extracted from Hydstra, the surface water database of the Department of Natural Resources and Mines. River discharge data for some monitoring sites were adjusted using timing and flow factors based on the nearest upstream gauging station; or a combination of modelled flow and flow measured by a horizontal acoustic doppler current profiler.

Sampling water quality

Water samples were collected, stored, transported and quality assured and quality controlled in accordance with the *Environmental Protection (Water) Policy Monitoring and Sampling Manual 2009* (www.ehp.qld.gov.au/water/pdf/monitoring-man-2009-v2.pdf). Water quality samples were collected using two methods: manual grab sampling, and automatic grab sampling using refrigerated pump samplers. Intensive sampling (daily or every few hours) was conducted during high flow events and monthly sampling was conducted during low or base-flow (ambient) conditions.

Analysing water quality

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

Calculating pollutant loads

The suitability of the generated water quality monitoring data for use in load calculations was assessed using a sample representivity rating. The most appropriate load calculation method—either the average load (linear interpolation of concentration) or the Beale ratio—was determined by assessing sample coverage and the representivity rating.

Annual loads were calculated for total suspended solids, nutrients (total nitrogen, particulate nitrogen, dissolved organic nitrogen, oxidised nitrogen, ammonium nitrogen, total phosphorus, particulate phosphorus, dissolved organic phosphorus, and dissolved inorganic phosphorus) and pesticides (ametryn, total atrazine, total diuron, hexazinone and tebuthiuron).

Loads were calculated using the Loads Tool component of the software Water Quality Analyser version 2.1.1.6.

Calculating toxic loads

A pesticide toxic-equivalent load (toxic load) is the calculated load of a pesticide multiplied by the relative toxicity of the pesticide compared to that of diuron (Smith et al., 2017a, b) and is expressed as an equivalent mass of diuron, i.e. diuron-equivalent kilograms. The total toxic load is calculated by summing the toxic loads of all pesticides that have the same toxic mode of action.

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Marine methods

This report summarises the data and methods used for reporting progress towards the marine targets in the Great Barrier Reef Report Card 2016.

- The marine objective is to ensure that by 2020 the quality of water entering the Reef from broad-scale landuse has no detrimental impact on the health and resilience of the Great Barrier Reef.

Marine Monitoring Program

The Australian Government's Marine Monitoring Program assesses Great Barrier Reef water quality and the long-term health and resilience of key marine ecosystems (inshore coral reefs and seagrasses). A summary of the indicators and methods used to derive Reef report card scores are outlined below.

Detailed methods are available in the annual technical reports published on The Great Barrier Reef Marine Park Authority's website: www.gbrmpa.gov.au/about-the-reef/how-the-reefs-managed/reef-rescue-marine-monitoring-program.

The marine monitoring program has three elements:

- inshore water quality
- seagrass condition
- coral reef condition.

Inshore water quality

Monitoring of year-round water quality includes the measurement of concentrations of organic carbon, inorganic and organic nutrients (nitrogen and phosphorus), silica, coloured dissolved organic matter, chlorophyll *a*, suspended solids (water turbidity), Secchi depth, salinity and pesticides.

Techniques used to monitor water quality include satellite remote sensing, automated data loggers and collection of water samples from research vessels for laboratory analysis. Passive samplers are used to measure the concentration of pesticides in the water column which have become integrated over time (Booij et al., 2007; Shaw et al., 2009).

Monitoring is also conducted in the wet season because the majority of the annual pollutant load to the reef is delivered by flood events (Devlin et al., 2001).

Seagrass condition

Monitoring temporal and spatial variation in the status of inshore seagrass meadows in relation to changes in local water quality is essential for evaluating long-term ecosystem health and resilience.

Monitoring includes an assessment of the seagrass abundance (percent cover) and reproductive effort, which provides an indication of the health of seagrass meadows and their capacity to regenerate following disturbances. Tissue nutrient composition is assessed in the laboratory as an indicator of nutrient enrichment relative to light available for growth (McKenzie et al., 2017).

Figure 1: Monitoring seagrass on the Great Barrier Reef (Image: L. McKenzie, Seagrass-Watch HQ)

Coral reef condition

Monitoring temporal and spatial variation in the status of inshore coral reef communities in relation to changes in local water quality is essential in evaluating long-term ecosystem health.

Monitoring covers a comprehensive set of community attributes including the assessment of hard and soft coral cover, the number of hard coral juvenile colonies (up to five centimetres in diameter), the proportion (per cent) of cover of algae that is macroalgae, the rate of change in coral cover (as an indication of the recovery potential of the reef following a disturbance) and coral community composition (Thompson et al., 2017). Comprehensive water quality measurements are also collected at many of the coral reef sites.

Figure 2: Monitoring coral reefs on the Great Barrier Reef (Image: Australian Institute of Marine Science)

Scoring methods

Synthesising and integrating data and information

The Great Barrier Reef Report Card assesses and scores the condition of inshore water quality, seagrass and coral at the Great Barrier Reef-wide scale and at the regional scale for each of the six natural resource management (NRM) regions: Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary.

A subset of indicators is used to assess and report on water quality, seagrass and coral condition. These indicators are scored on a five-point scale (very good, good, moderate, poor, very poor) and aggregated into a score that describes the overall status of each region and of the Great Barrier Reef as a whole.

An overview of the methods used to calculate the scores is provided below. Reef-wide scores are standardised by the area of each region, while regional scores are unweighted averages. Detailed information is available in the technical reports on the Marine Monitoring Program website: www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/reef-2050-marine-monitoring-program/marine-monitoring-program-publications).

Inshore water quality

In 2015–16, the water quality metric was revised as an initial step towards integrating multiple streams of data to measure and report on water quality. The previous metric relied exclusively on satellite data. The new metric is underpinned by the eReefs biogeochemical model and integrates data from satellite images for improved accuracy in what is commonly referred to as data assimilation. The new metric considers all six NRM regions in calculating the Reef-wide score and is based on open coastal waters.

The regional models of eReefs include coupled hydrodynamic, sediment and biogeochemistry models for the inshore open coastal waters of the Reef. eReefs allows quantification of the impacts of rivers and atmospheric forcing on circulation patterns and biogeochemical cycles such as water clarity, nutrients, plankton and benthic plants. The skill of the model has been assessed over six years (see http://ereefs.info).

Data assimilation further improves the model's skill and provides a single best estimate of the biogeochemical state of the Reef by combining both modelling and observations. Data assimilation systems quantify the difference between a modelled state and an observed state, and improve the modelled state by incorporating the observed state into the simulation.

For the 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, sediments, 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 new 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. For further details on the data assimilation technique and integrity of observations, see (Robillot et a;., 2017).

Measures of chlorophyll *a*, Secchi depth (derived as the inverse of Kd (490)) and total suspended solids (derived as Ecology Fine Inorganics (EFI) multiplied by 1000) were extracted from depth layer 44 of the assimilated eReefs biogeochemical model at a 4x4 kilometre spatial resolution and daily temporal resolution. Observations from each of these measures (chlorophyll *a*, Secchi depth and total suspended solids, or TSS) were partitioned into water years (October 1st through to September 30th) and into zones representing combinations of the NRM regions and cross-shelf water bodies (GBRMPA 2010). The enclosed coastal water body was excluded due to limitations associated with the 4-km model resolution near the coastline. The site-level data (4x4 km) for each of the three measures was standardised to indices on a continuous scale of zero (very poor) to 100 (very good). This was 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).

For each zone, the daily indices for each measure were aggregated (averaged) into annual scores (Robillot et al., 2017). Scores for Secchi depth were aggregated with the chlorophyll *a* score to yield a single score for water quality per zone, which was weighted by the area of the open coastal waters. TSS was not included in the final calculation of the water quality metric due to concerns about the lack of representation of fine sediments in the eReefs biogeochemical model.

All reported scores were mapped onto a five-point (A–E) colour-coded grading scale (Table 1).

Table 1: The colour-coded inshore water quality scoring system

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

Exposure to turbidity

Wet-season maps derived from satellite imagery (weekly composites, frequency maps and surface exposure maps) are also used to monitor water quality conditions in the Great Barrier Reef. Water types are characterised using remote-sensing imagery to assess the broadscale coastal water quality during the wet season and the composition and spatial variability of river plumes.

Coastal waters are classified into three water types:

- Primary – brownish waters with very high turbidity, low salinity (0–10 ppt), and the highest concentrations of colour dissolved organic matter (CDOM) and TSS
- Secondary – greenish waters with intermediate salinity, elevated CDOM concentrations, and reduced TSS due to sedimentation, where phytoplankton growth is prompted by the increased light (due to lower TSS) and the high nutrient availability delivered by the river plumes
- Tertiary – greenish-blue waters with low TSS concentrations, and above-ambient concentrations of chlorophyll *a* and CDOM.

For the wet season, water type maps show a well-documented inshore-to-offshore spatial pattern, with the highest frequency of the primary water type in the coastal areas, and the highest frequency of the tertiary water type in offshore areas.

Wet-season frequency maps are used to assess the frequency, on a weekly basis, with which an area was exposed to turbid waters and the three water types over the wet season. The frequency maps are categorised in five equally spaced classes to represent different levels of exposure to turbid waters. To evaluate the susceptibility of Reef communities, the frequency maps are overlaid with coral reef and seagrass meadow distributions to identify which communities are likely exposed to land-sourced contaminants. The lowest exposure categories (I and II) are characterised by low exposure frequencies of the primary and secondary water types, and the highest exposure categories (III and IV) are characterised by high exposure frequencies of primary and secondary water types. The exposure categories have yet to be validated against ecological data, so they represent relative levels of risk. In addition, the exposure information is based on surface water quality conditions, which does not necessarily represent the exposure of benthic communities.

An ocean colour-based model is used to estimate the dispersion of loads of dissolved inorganic nitrogen and TSS discharged from the rivers in the Reef catchments, and examine their exposure and influence across the Reef lagoon. The model combines in-situ data, MODIS satellite imagery and modelled annual end-of-catchment loads from all 35 Reef basins. In the model, monitored and modelled end-of-catchment wet-season (November to May) loads provide the mass of constituents delivered to the Reef, in-situ data provides the pollutant mass dispersed within river plumes, and satellite imagery provides the direction and intensity of pollutant mass dispersed throughout the Reef lagoon.

The eReefs hydrodynamic model also provides an estimate of the boundary of plume extent in the wet season (tracer maps). It also produces annual maps of average concentrations of dissolved inorganic nitrogen and TSS and loadings in the Reef waters. The difference between end-of-catchments loads for the current year and for estimated pre-development (using the same river flow) can also be mapped.

Site-specific water quality

Water quality for specific sites where the mean or median concentrations of parameters did not meet available water quality guidelines (Great Barrier Reef Marine Park Authority, 2010) is described in the Reef report card 2016. In 2015–16, the spatial and temporal frequency of site-specific water quality monitoring increased in four focus regions:

- Wet Tropics (Tully basin)
- Wet Tropics (Mulgrave-Russell basin)
- Burdekin
- Mackay Whitsunday (O'Connell basin).

A detailed analysis by Waterhouse et al. (2017) of trends in parameters (turbidity/water clarity, chlorophyll *a* and concentrations of particulate nitrogen and phosphorus) relative to the water quality guidelines is available on the Marine Monitoring Program website: www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/reef-2050-marine-monitoring-program.

Site-specific water quality data are not included in the water quality metric scores, but are used to cross-reference modelled outputs. This is because, while the overall trends are generally consistent, the data are collected at different spatial and temporal scales that are not directly comparable.

Pesticides

The reference to pesticides in the Reef report card includes all herbicides, insecticides and other chemicals used to treat pests and weeds.

Pesticides are monitored using two methods (Grant et al., 2017):

- Passive samplers are deployed in both wet and dry seasons and provide an integrated assessment of pesticide concentrations over time (Booij et al., 2007; Shaw et al., 2009).
- Grab samples are collected in flood plumes during the wet season to give an indication of peak pesticide concentrations and dispersal patterns of pesticides from river mouths.

The most frequently detected pesticides in inshore waters are herbicides that act to inhibit the photosystem II (PSII) of plants: diuron, atrazine, hexazinone, simazine and tebuthiuron (Kapernick et al., 2007; Lewis et al., 2009; Packett et al., 2009; Mitchell et al., 2005; Haynes et al., 2000a). These PSII herbicides are used to control weeds in the sugarcane, horticulture, grazing and grain-cropping industries, but may also have a negative impact on non-target organisms such as algae, corals and seagrass when discharged into the Reef lagoon (Magnusson et al., 2008; Jones and Kerswell, 2003; Haynes et al., 2000b).

An index has been developed using PSII herbicide equivalent (PSII-HEq) concentrations to assess the potential combined toxicity of these herbicides relative to the guidelines. The PSII-HEq concentration incorporates the relative potency and abundance of individual PSII herbicides compared to a reference PSII herbicide—diuron. The index has five categories of ecological risk (Table 1). Concentrations detected at the lowest level (Category 5) are not expected to impact seagrass or coral, while at the highest level (Category 1) demonstrated effects on the growth and death of aquatic plants and animals exposed to the pesticide have been reported.

Table 2: The PSII herbicide equivalent (HEq) index is used to assess ecological risk of PSII herbicides across the Reef

Risk category	PSII-HEq concentration ($ng.L^{-1}$)	Description
5	≤ 10	No published scientific papers demonstrate any effects on plants or animals based on toxicity or a reduction in photosynthesis. The upper limit of this category is also the detection limit for pesticide concentrations determined in field-collected water samples.
4	11–50	Published scientific observations of reduced photosynthesis for two diatoms.
3	51–250	Published scientific observations of reduced photosynthesis for two seagrass species and three diatoms.
2	251–900	Published scientific observations of reduced photosynthesis for three coral species.
1	> 901	Published scientific papers demonstrate effects on the growth and death of aquatic plants and animals exposed to the pesticide.

The Department of Science, Information Technology and Innovation's proposed marine diuron water quality guideline value for 99 per cent species protection (which is also applicable to the PSII-HEq concentration because diuron is the reference herbicide) is 430 ng L^{-1}, which falls within Category 2 on the PSII-HEq index. Although categories 3 and 4 fall below this guideline, they still represent biologically relevant concentrations. However, the following points about category 3 and 4 concentrations should be noted:

- The published scientific papers indicate that the reductions in photosynthesis at these concentrations are reversible when the organism is no longer exposed to the pesticide.
- Detecting a pesticide at these concentrations does not necessarily mean that there will be an ecological effect on the plants and animals present. In particular, prolonged (i.e. chronic) exposure at these concentrations may be required to elicit an adverse effect.
- Categories 3 and 4 have been included as they indicate an additional level of stress that plants and animals may be exposed to. When combined with other stressors (e.g. sediment, temperature, salinity, pH, storm damage and elevated nutrient concentrations), the ability of these organisms to recover may be reduced.

Classifying the data into index categories provides an indication of the extent and frequency of exposure to PSII herbicides at a given site (and the potential consequences for marine organisms). The PSII-HEq concentrations used in the index are calculated from the combined toxicity of diuron, hexazinone, atrazine and its breakdown products, tebuthiuron, ametryn, prometryn, simazine, terbutryn and flumeturon, all of which are used to control weeds and other plant species in the Reef catchment and all of which are regularly detected in the Marine Park.

While the PSII-HEq index is used for assessing ecological risk in the Reef report card 2016, an alternative method is expected to be included in future reports. This method predicts the proportion of species in an ecosystem that may be adversely affected by exposure to a mixture of pesticides, known as the multisubstance potentially affected fraction, or ms-PAF (Traas et al., 2002). The recommended protection level for the Reef is ≤1% of species affected. This approach can be used to assess the combined risk from pesticides with the same toxic mode of action (as with the PSII-HEq index), and for pesticides with different modes of action. The latter allows inclusion of emerging pesticides that have been identified as alternatives to the traditional PSII herbicides, and which are increasingly being used in the Reef catchments. The ms-PAF approach is based on species sensitivity distributions, which are also used to derive water quality guidelines. The transition from evaluation of risk based on single species data to multiple species using species sensitivity distributions is underway (Grant et al., 2017), but requires further validation for the marine environment before it can be included in the Reef report card scores.

Seagrass

Abundance, reproductive effort and tissue nutrient status are used to assess and report on inshore seagrass condition (McKenzie et al., 2017).

Seagrass abundance is assessed as the average percent cover of seagrass per monitoring site according to the seagrass abundance guidelines documented by McKenzie et al. (2015) and McKenzie et al. (2003).The 80th, 50th and 20th percentiles used to define the guidelines are recommended for Queensland Water Quality Guidelines (Department of Environment and Heritage Protection, 2009) and there is no evidence to suggest that applying this approach to assess the condition and trend of Reef seagrass meadows would be inappropriate. Developing guidelines for individual sites requires 3–10 years of monitoring data with a minimum of 18 observations with no identified impacts, depending on the variability for the site. This sample size is reasonably close to the recommendation of 24 data values in the ANZECC and ARMCANZ (2000) water quality guidelines. By plotting the percentile estimates with increasing sample size, the reduction in error becomes apparent as it moves towards the true value (McKenzie et al., 2015). The seagrass abundance guidelines can then be applied to determine seagrass condition for each monitoring event. For example, if median abundance is at, or above, the 50th percentile for that site, the condition is considered 'good'.

Reproductive effort is the ratio of the average number of reproductive structures (spathes, fruits, female and male flowers) of plants on an area basis relative to the long-term average. It provides an indication of the capacity for seagrass meadows to recover following disturbances.

The nutrient status of seagrass is based on the ratio of carbon to nitrogen in leaf tissue, and reflects the level of nutrients in the surrounding waters relative to the amount of light the plant is receiving to grow.

In 2015–16, seagrass was monitored in five representative habitat types throughout the Reef: estuarine, coastal intertidal, coastal subtidal, reef intertidal and reef subtidal meadows. The additional Cape York sites (established in 2012), four subtidal sites in the Wet Tropics and Burdekin regions (established in 2008), and two intertidal sites in the Burdekin region (established in 2012) were included in the overall assessments of Reef seagrass ecosystem condition. Also included were additional sites in Cape York (Lloyd Bay), Wet Tropics (Goold Island and Missionary Bay), Burdekin (Shelley Beach), Mackay Whitsunday (Hydeaway Bay, Pioneer Bay, Tongue Bay and Newry Bay) and Burnett Mary (Burrum Heads) monitored by Seagrass-Watch and by QPWS drop-camera programs, which included monitoring the presence of foundation and other seagrass species (McKenzie et al., 2017).

Corals

Five indicators are now used to assess and report on inshore coral reef condition—coral cover, coral cover change, juvenile coral density, coral community composition and proportional macroalgal cover. Further detail about the selection and scoring of these indicators is documented in Thompson et a;., (2017).

Coral cover is a measure of the abundance of hard and soft corals, and indicates the capacity of coral to persist under the current environmental conditions. Coral cover also represents the availability of brood-stock required for the ongoing supply of future coral generations.

Coral change is a measure of the observed change in hard coral cover compared to modelled predictions. A healthy and resilient coral reef is expected to show an increase in coral cover during periods free from disturbances and this indicator directly assesses the rate of coral cover increase over the rolling four years of monitoring.

Juvenile density is a measure of the abundance of hard-coral juvenile colonies (up to five centimetres in diameter), standardised to the space available for coral settlement. It indicates the ongoing replacement of corals necessary to recover from disturbances or stress.

Coral community composition is a measure of changes in the relative abundance of coral species from a baseline. If the composition of communities moves beyond the standard error of their baseline condition toward a community indicative of higher concentrations of nutrients and turbidity, a score of zero is returned. Conversely, a score of one is given if the change is toward a community indicative of improved water quality conditions (Thompson et al., 2017).

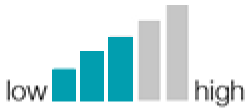
Macroalgal cover is a measure of the proportion of algae cover that is classified as large, fleshy algae. A low score for macroalgae (i.e. poor or very poor) means macroalgal cover is high, which is indicative of poor water quality. Conversely, a high score for macroalgae (i.e. good or very good) means cover is low. High macroalgal cover, once established, reduces the recovery of corals by denying them space or by producing chemical deterrents that limit the recruitment and growth of coral.

Coral monitoring occurs in Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy whereas no coral monitoring occurs in the Cape York or Burnett Mary regions under the Marine Monitoring Program.

Coral scores also incorporate monitoring of inshore reefs undertaken through the Australian Institute of Marine Science's Long-Term Monitoring Program.

Qualitative confidence rankings

eReefs modelled water quality



Seagrass

Coral

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

Water quality received a three-bar confidence ranking, seagrass received a four-bar confidence ranking and coral received a four-bar confidence ranking. Note that confidence rankings for water quality apply to the open coastal area whereas rankings for seagrass and coral reflect the specific sites monitored.

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