

# Methods

## Great Barrier Reef

### Report Card 2014

Australian Government

Queensland Government

## Management practice methods

This report summarises the development of revised management practice baselines for the Reef Water Quality Protection Plan (Reef Plan) 2013 and how progress towards the Reef Plan land management target is measured. The target is:

- 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.

**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 Plan 2013 adoption target. Features of the water quality risk frameworks are:

- The suite of practices relevant to each pollutant are described in the frameworks. This does not mean all of the practices in the production system, only those practices that pose the greatest potential water quality risk through movement of sediments, nutrients or pesticides off-farm.
- 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 that targeted by Reef Plan 2013 investments.

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.

For the purpose of describing industry status and progress in relation to the Reef Plan 2013 adoption target, best management practice is defined as the area managed under low and moderate-low risk levels.

**Table 1: Classification of management practices in the grazing industry based on relative risk to water quality**

| **2013 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 condition (A/B) 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 |
| **Previous Reef Plan 2009 "ABCD" nomenclature** | A | B | C | D |

For cropping systems, the water quality risk framework describes management practices related to nutrients, pesticides, sediments and water. For grazing systems, the framework describes management practices related to the dominant sources of soil erosion: pasture (hillslope), streambank and gully erosion.

**Table 2: Classification of management practices in the cropping industries (sugarcane, bananas, grains and horticulture)**

| 2013 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 |
| **Previous Reef Plan 2009 "ABCD" nomenclature** | | | | |
| **Sugarcane** | A | B | C | D |
| **Grains** | A | B | C/D | |
| **Horticulture** | A | B | C/D | |
| **Bananas** | Not applicable – Bananas were not previously described separately (they were included in Horticulture). | | | |

Water quality risk frameworks provide the basis for describing:

- Industry status in relation to best management practice systems. The Paddock to Reef program has developed new management practice baselines to correspond with the revised targets, actions and investments under Reef Plan 2013.
- Annual progress from the 2013 baseline towards the 90 per cent adoption target.

**Establishing farm management baselines for Reef Plan 2013**

Management practice and management system benchmarks have been developed for each agricultural industry sector and for each major river basin within each region. There are varying levels of uncertainty or confidence in these benchmarks, for many reasons.

**Table 3: Summary of data sources and uncertainty around management system baselines developed for Reef Plan 2013**

| Industry | Primary data sources | Confidence in management system baselines | Sources of uncertainty |
|---|---|---|---|
| **Bananas** | • 1:1 growers survey<br>• Banana Best management Practice (BMP) Guide (anonymous, aggregated)<br>• Reef Programme grant applications (anonymous) | Good | • High level of heterogeneity within the industry, particularly with respect to farm size. There are a relatively small number of very large farms which can skew results. |
| **Grains** | • Grains Best Management Practice (BMP) program (anonymous)<br>• Expert agronomist workshops | High | • Over 80% of industry represented in baseline sample. However there are some Grains BMP questions which do not allow discrimination of practices at a fine level. |
| **Grazing** | • Grazier 1:1 survey | Good | • Survey has enabled an excellent appreciation of farm management. However, there is an assumption that good management is analogous to good resource condition. |

| | | | |
|---|---|---|---|
| | | | • Some river basins have insufficient sample size to develop a specific baseline. |
| **Horticulture** | Growcom Farm Management System (FMS) (anonymous) | High | • Very large proportion of industry represented in baseline sample (depending on region). However, there are some Growcom FMS questions which do not allow discrimination of practices at a fine level. |
| **Industry** | **Primary data sources** | **Confidence in management system baselines** | **Sources of uncertainty** |
| **Sugarcane** | • 1:1 grower surveys<br>• Smartcane Best Management Practice (BMP) program (anonymous, aggregated)<br>• Reef Programme grant applications (anonymous) | High | • Uncertainty around management related to timing of fertiliser and herbicide applications. Mostly relates to variance in interpretation from field staff capturing data on-farm. |

**Grazing**

The prevalence of different management practices in grazing businesses was determined by surveying 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. The framework 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 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). Table 4 provides an example for one question that relates to the objective determination of 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 |

This survey question (Table 4) accounts for 10 per cent of the total water quality risk score for practices related to pasture (hillslope) erosion. 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 pasture (hillslope) erosion was derived through combining the 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 practice.

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

| Erosion process | Water quality risk rating | | | |
|---|---|---|---|---|
| | Low | Low-moderate | Moderate | High |
| **Pasture (hillslope)** | 81-100 | 59-80 | 33-58 | 0-32 |
| **Streambank** | 100 | 66-99 | 33-65 | 0 |
| **Gully** | 85-100 | 62-84 | 32-61 | 0-31 |

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

| Erosion process | Management category (each informed by a suite of practices) | Weighting |
|---|---|---|
| **Pasture (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 groundcover at the end of the dry season, informed by (1) knowledge of groundcover 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% |
| | **Pasture (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 | 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 Pasture (**hillslope) erosion assessment | 30% |
| | **Gully erosion assessment** | 100% |

Grazing management system baselines for Reef Plan 2013 were based on management system ratings for individual businesses, aggregated to form baselines for representative river basins within regions. These individual ratings and baselines were reviewed by regional experts and compared with congruent 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 river basin level, the baseline for the entire region was used.

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

| Region | Rangelands | Wet coastal | Area represented (% 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*.

**Sugarcane**

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

**Table 8: Key management categories articulated in the water quality risk framework for sugarcane**

| 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 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 the key management practices in the sugarcane industry was estimated through a benchmarking process conducted throughout 2013-2014.

- A suite of questions directly relating to the water quality risk framework was the basis of a survey conducted by regional Natural Resource Management organisations on behalf of the Paddock to Reef program. Sampling was targeted as much as possible to ensure that up to 50 per cent of the respondents had not previously had high levels of engagement with Reef Plan initiatives. In each region, there was a target of a minimum of 100 randomly selected growers across catchments.
- Congruent datasets were obtained through the Smartcane Best Management Practice program and recent applications (2012-2013 and 2013-2014 where available) for the Australian Government's incentive programs.
- In each region, small expert panels were convened to review and confirm the adoption estimates for each practice level, for each management issue. The proportion of growers and area at each level were checked for sensibility and modified if sufficient supporting evidence was available. Supporting evidence included discrete data (mills, local productivity service organisations, specific project data, other data on rates and volumes of nutrient and pesticide use) and weight of local opinion.

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

**Bananas**

The water quality risk framework for bananas is based on the Australian Banana Grower's Council (ABGC) Banana Best Management Practice Guide. The specific practices that are most relevant to water quality risk were collated into a focused framework that also aligns with the management practice monitoring system utilised by Terrain Natural Resource Management (the regional Natural Resource Management organisation in the Wet Tropics). Prioritising and weighting these practices for relative water quality risk occurred through 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 that are commonly used in bananas have relatively low ecological toxicity and are not priorities for Reef Plan 2013. Offsite movement of these products - when it occurs - is largely a function of runoff and soil loss, which is a focal area in the framework.

**Table 9: Key management categories articulated in the water quality risk framework for bananas**

| 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** | |
| Timing 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 key management practices in the Wet Tropics was estimated through a benchmarking process conducted during 2013-2014. There was no data available to support the development of a baseline for the banana production areas of southern Cape York, although this may change during 2015. 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 as a component of 2012-2013 applications for the Australian Government's Reef Rescue program.
- Aggregated anonymous data from the Banana BMP Guide, available for discussion while reviewing adoption benchmarks with experienced extension officers.

**Horticulture**

The water quality risk framework for the horticulture industry is based on the Water Quality module of the Growcom Farm Management System (FMS). The 50 management issues covered in the FMS module were reviewed in collaboration with Growcom to focus on a smaller subset of 17 management issues with the greatest influence on offsite water quality.

**Table 10: Key management categories articulated in the water quality risk framework for horticulture**

| 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 | 40% |
| **Water** | |
| Irrigation scheduling | 30% |
| Matching irrigation interval and volume with crop requirements | 50% |
| Water recapture and use | 20% |

Anonymous data from growers completing FMS modules during 2012-2014 was analysed to develop management system 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 regions. FMS data was not available for the Wet Tropics and the Mackay Whitsunday regions (where there is no current Reef Plan investment focus on horticulture).

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

| Region | Businesses | Area |
|---|---|---|
| Burnett Mary | 303 | 21,900 ha |
| Fitzroy | 45 | 2,025 ha |
| Burdekin | 122 | 22,056 ha |

**Grains**

The water quality risk framework for the grains farming industry is based on a range of key management areas selected from four modules of the Grains Best Management Practice (BMP) program. Eighteen management issues were assigned weightings according to their potential for influencing offsite water quality. These weightings were developed through a review process including 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 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% |
| 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 to develop management system 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 river basin level, the baseline for the entire region was used.

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

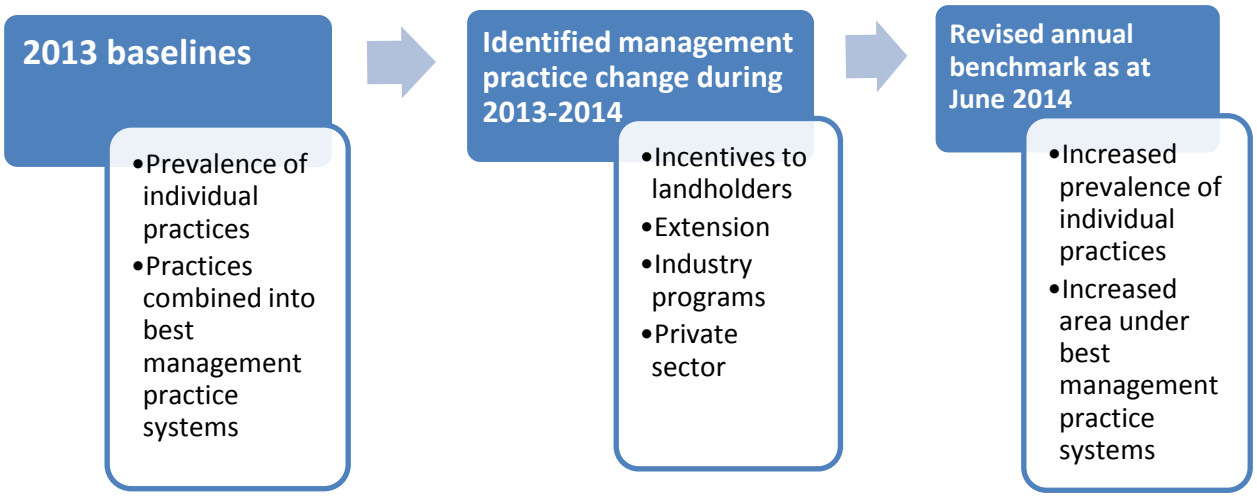
- Sediment (runoff and soil loss): 301
- Pesticides: 327
- Nutrients: 262

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

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

**Describing annual progress toward the Reef Plan 2013 adoption target**

Management practice baselines are available for each of the critical practices, for each agricultural industry, in each region (and river basin). At the farm scale, these management practices combine to form a management system. Progress in terms of 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.




The limitations with this approach are:

- Management change is identified where and when it is reported to have occurred. This relies largely on organisations adequately reporting on their activities *and what the impacts of those activities are*. The Paddock to Reef program describes and reports on the impacts of change for which there is reasonable and sensible evidence.
- 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 method can appropriately reflect regression if necessary.

**Evidence of management practice change**

Organisations receiving funding through Reef Plan 2013 for the purpose of improving adoption of best management practice are required to report the impacts of their work as per the relevant industry water quality risk framework.

This occurs through reporting on how individual farm enterprises are managed – the practice descriptions in water quality risk frameworks – both before an intervention and after (as a result of) that intervention. The 'intervention' may be in the form of a financial incentive, capacity building extension, industry training or self-driven change.

The degree of adoption of best management practice during 2013-2014 is likely to be a conservative estimate.

There were many investments aiming at facilitating the adoption of best management practice on farms during 2013-2014. However, not all of these were able to provide evidence of change. In some instances, this was due to no or inadequate impact evaluation, or because the impacts will not be apparent until later. There are several programs and projects that will report impacts for the first time in 2014-2015.

**Table 14: Interventions with evidence of adoption of best practice during 2013-2014**

| Investment | Delivery | Industry | Regions | Level of detail |
|---|---|---|---|---|
| Reef Programme (Australian Government) | Regional NRM organisations | Sugarcane, grazing, horticulture, bananas, grains | Burnett Mary, Fitzroy, Mackay Whitsunday, Burdekin, Wet Tropics | Detailed descriptions of relevant farm practices before and after investments.<br>Exact location and area of investments (GIS). |
| Queensland Government extension supporting | DAF, DEHP | Sugarcane | Burnett Mary, Mackay Whitsunday, Burdekin, Wet | Detailed description of practice that changed.<br>Independent follow-up evaluation of extension |

| | | | | |
|---|---|---|---|---|
| industry BMP programs* | | | Tropics | activities to confirm adoption rate. Estimates/actual area of impact, attributed to river basin. |
| Private | Consultancy (Resource Consulting Services) | Grazing | Fitzroy, Burdekin | Completion of Grazing for Profit course by 20 businesses. Included on conservative assumption of 70% adoption rate, applied to hillslope management only. Region level spatial detail only. |

**sugarcane extension impacts captured during 2013-2014. Grazing extension impacts have been identified and will be included in 2014-2015 reporting.*

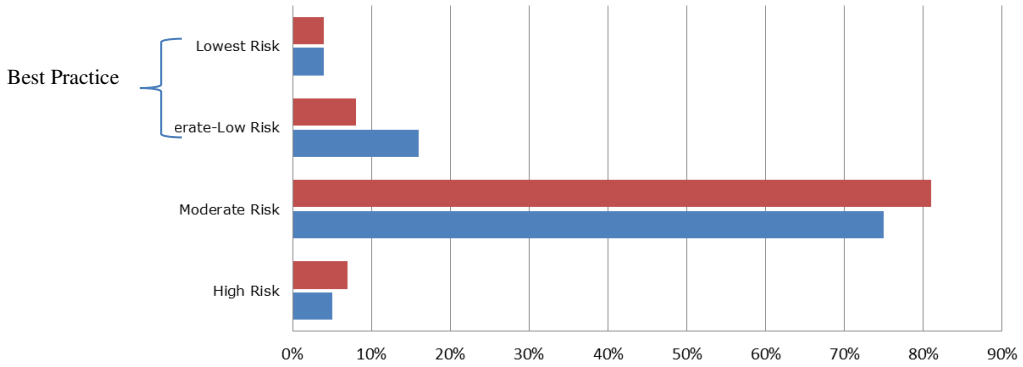
**Tracking the adoption of individual practices**

The Paddock to Reef program monitors the adoption of the most important management practices over time, which is important for prioritising investments and for understanding the impacts of the broader management practice system. Practice change reporting, linked to spatial reporting, means that practice adoption can be tracked at a fine or broad scale.

The example below describes the change in the level of adoption of practices related to targeting the application of herbicides in sugarcane at a regional level.

For all sectors, best management practice *systems* for sediment, nutrient or pesticide management are described by aggregating the adoption levels of each major component practice according to their framework weighting.

**Targeting application of herbcides in sugarcane - Wet Tropics NRM Region**




| | High Risk | Moderate Risk | Best Moderate Low Risk | Lowest Risk |
|---|---|---|---|---|
| 2013 Baseline | 7% | 81% | 8% | 4% |
| 2014 Revised Baseline | 5% | 75% | 16% | 4% |

**Describing progress**

Management practices that are at the 'moderate-low risk' and 'lowest risk levels' are taken to be best management practices. These are summed to describe the proportion of area managed at best practice. In the example above (at the individual practice level), the area managed at best practice in the 2013 baseline was 12 per cent, increasing to 20 per cent by June 2014.

Reporting the progress toward the adoption target of 90 per cent includes colour coding based on five categories.

**Table 15: Scoring system**

| Status/progress | Percentage of land managed using best management practice systems | Colour coding |
|---|---|---|
| Very poor progress towards target | 0-22% | Red |
| Poor progress towards target | 23-45% | Orange |
| Moderate progress towards target | 46-67% | Yellow |
| Good progress towards target | 68-89% | Light green |
| Very good progress towards target | 90-100% | Dark green |

## 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 the use of expert opinion and direct measures of error for program components where available. Management practice indicators received a three bar confidence ranking.

## Ground cover methods

The following provides a brief overview of the data and methods used for reporting regional ground cover in Report Card 2014. Further detail about data processing and differences compared to previous report cards can be found in the Ground cover technical report (DSITI 2015 in prep).

### 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, runoff 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 try 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 will also maximise the pasture response to rainfall. Implementation of appropriate and sustainable land management practices, particularly careful management of grazing pressure, can help to maintain or improve ground cover and improve 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 may 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 the species composition of the ground cover can be more pronounced.

### Ground cover data

**Fractional ground cover**

Reporting is based on data derived using the fractional cover method described by Scarth *et al.* (2010). The method measures the proportion of green cover, non-green cover and bare ground using reflectance information from late dry season Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+) and Landsat 8 Operational Land Imager (OLI) satellite imagery. The spatial resolution of Landsat imagery is approximately 30 metres. The return interval of a Landsat satellite is 16 days and the archive of Landsat data used dates from 1987 to 2014. The fractional cover data is calibrated using over 1500 field observations from a range of cover levels and environments. Using the field observations as a basis, a further adjustment is applied to the fractional cover data to account for the influence of trees, shrubs and ground cover fractions measured by the satellite. This results in a data product, fractional ground cover, which effectively removes the influence of trees and shrubs and provides estimates of the level of green ground cover, non-green ground cover and bare ground at ground level. This data product enables reporting in areas of high tree cover (up to 60 per cent foliage projective cover), significantly increasing the area of reporting compared to previous report cards (which only reported in areas up to 15 per cent foliage projective cover). Parts of the Wet Tropics and Cape York regions are reported for the first time. As erosion and runoff are influenced by all types of ground cover, the green and non-green ground cover fractions are summed to produce a total ground cover estimate.

**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. 30m x 30m area) of fractional ground cover for the season, then compositing these to generate a comprehensive regional data set. This approach has the advantage of removing errors and outliers in the data and provides the most spatially comprehensive coverage as there is generally very little missing data due to cloud, cloud shadow or satellite sensor issues. For reporting, spring (September-November) seasonal composites (for the period 1987 to 2014) are used as this best approximates the late dry season.

**Reporting regions and grazing lands**

Reporting is based on the six natural resource management regions which incorporate the Great Barrier Reef region:

- 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 version of land use data provided by the Queensland Land Use Mapping Program (QLUMP) (DSITI, 2012). The most recent version of the mapping is current to 2009 for all reported regions, except for Cape York, which is current to 2013.

A reporting region is, therefore, defined as that part of a natural resource management region which is grazing land and has less than 60 per cent foliage projective cover.

## Reporting ground cover

The Queensland Ground Cover Monitoring Program reports progress against the target using ground cover monitoring data derived from Landsat satellite imagery, calibrated by field data. While it is acknowledged that a range of factors influence ground cover levels, reporting is focused only on information which describes regional ground cover levels in the current and historical context. Rainfall data is provided 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 to account for the influence of climate, land management and soil type. These are more appropriate for monitoring local scale variability and differences in ground cover levels, but are of limited use for regional scale reporting. Products which prove useful for describing ground cover levels at the regional scale will be incorporated into future reporting. It is also important to note that the ground cover target may be revised in the future to account for regional differences.

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. 30m x 30m area) and then summarised (i.e. averaged) for each of the regions.

Statistics reported include:

- 2014 mean late dry season ground cover
- 27-year mean late dry season ground cover (1987 to 2014)
- percentage of the region's reporting area with late dry season ground cover less than 70 per cent in 2014
- percentage of the region's reporting area with mean late dry season ground cover less than 70 per cent for the 27-year period, 1987 to 2014

Ground cover distribution graphs and a map of ground cover percentages have been provided for the Great Barrier Reef and each region as a visual representation of the above statistics. A map of ground cover decile rankings provides information on ground cover levels in 2014 compared to long-term mean ground cover levels.

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. Burdekin or Fitzroy). The mean ground cover is, therefore, indicative of general levels of ground cover within the reporting region. Note that the reporting regions are further divided into catchments (and sub-catchments for larger catchments) in the Ground cover technical report (DSITI 2015 in prep).

### 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 drier seasons results in lower ground cover levels. Rainfall data was obtained from SILO as a five kilometre grid (https://www.longpaddock.qld.gov.au/silo/). The mean annual rainfall was then calculated from September to September for each year from 1986 to align the annual rainfall with the late dry season reporting period for each reporting region.

### Qualitative confidence ranking

Confidence

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 the use of expert opinion and direct measures of error for program components where available. Ground cover received a four bar confidence ranking.

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## Wetlands extent methods

The extent of wetlands in 2013 and changes in extent since 2001, 2005 and 2009 are reported. Change in extent is reported as a percentage of the 2009 extent data, so catchments of different sizes can be compared. The corresponding change in area (hectares) is also presented. Information on the historical loss of wetlands is provided by comparing current extent with pre-European (pre-clearing) extent.

The change in extent of wetlands is based on the Queensland Wetlands Program wetland mapping version 4. A large fraction of the wetland mapping changes are based on changes in the extent of remnant vegetation captured in the Queensland regional ecosystem mapping version 9.

Wetland mapping draws on remote sensing, topographic mapping and regional ecosystem mapping to identify wetlands based on both water bodies and vegetation. Wetland assessment defines waterbody extent using imagery from wet years, so that fluctuations between wet and dry years are not reported as changes in wetland extent (Environmental Protection Agency 2005).

The remote sensing component of the wetland mapping method cannot be applied to map pre-clearing water bodies because it relies on satellite imagery. Therefore, regional ecosystem mapping (Neldner et al. 2012) is used to assess changes in wetland extent over the longer term. Specifically, regional ecosystem mapping is used to compare the extent of remnant wetland regional ecosystems with their pre-clearing extent.

Information is summarised into three wetland systems:

1) Vegetated freshwater swamp (palustrine) systems are wetlands with more than 30 per cent emergent vegetation cover, or waterbodies less than eight hectares and less than two metres deep.

2) Lake (lacustrine) systems are wetlands with less than 30 per cent emergent vegetation cover (but excluding riverine channels and associated fringing vegetation). Areas of open water less than eight hectares are classified as vegetated freshwater swamp systems unless the water is more than two metres deep.

3) Mangroves and salt flats (estuarine) wetlands occur in areas that are periodically inundated by sea water. They are dominated by salt tolerant vegetation including mangroves, salt flat or salt marsh communities. Coastal waters that are also components of the estuarine wetland system and rivers are not included in this analysis.

**Limitations and future improvements**

Wetland mapping is continually reviewed and updated, where necessary, to improve its accuracy. Report Card 2014 includes updated baseline estimates of the historical clearing and extent of wetlands in 2001, 2005 and 2009, as well as new information about the extent of wetlands in 2013.

The baseline and estimates for previous periods have been updated to incorporate improved knowledge and correct errors identified in previous map versions. This ensures that reported changes in wetland extent reflect the net outcome of losses and gains rather than changes in map accuracy or scale.

Although wetland extent change is typically very small, it is considered indicative of genuine trends in wetland extent rather than being within the margin of error in the mapping. This is primarily because the mapping method focusses on detecting change relative to the 2001 baseline year. This approach is designed to give reliable indications of change in wetland extent, and each detected change is verified using manual checking of imagery and other data. Each release of wetland mapping incorporates improved data for all

previous years (e.g. version 4 mapping includes updated pre-clearing, 2001, 2005, 2009 and 2013 data), so the reported changes in wetland extent are not artefacts of random differences in mapping between years.

It should be noted that summarising wetlands extent across whole regions and at a broad wetland system level can mask variations in wetland loss across parts of the catchment or differential loss for different wetland types. In addition, summarising wetlands into three broad systems can mask variations of the types within these systems.

### 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 the use of expert opinion and direct measures of error for program components where available. Wetland extent received a four bar confidence ranking.

### References

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## Riparian methods

**Why monitor riparian vegetation**

Riparian forest and ground cover is the vegetation beside waterways which can help reduce pollutant flow to the waterways and stabilise the stream bank. Areas which are non-forested and have very low ground cover levels may be areas of concern for soil and nutrient loss to the stream (Lyons *et al.* 2000, Simon and Collison 2002). Maintaining and enhancing riparian forests and ground cover in riparian areas is, therefore, important to minimise impacts on water quality in Great Barrier Reef catchments.

**Reporting riparian vegetation extent for Reef Water Quality Protection Plan 2013**

Riparian vegetation extent is reported every four years. The riparian area is defined as any area within 100 metres of a (mapped) stream or riverine wetland. In this report, riparian vegetation is separated into two components, riparian forest and riparian ground cover. Data derived from Landsat satellite imagery is used to estimate riparian forest and ground cover levels. Statistics reported include:

- the extent of riparian forest and the estimated area remaining of the pre-European extent of riparian forest
- the amount of forest loss in recent history and up to 2013
- the patch size and connectivity of the remaining riparian forests
- the level of ground cover in non-forested riparian areas.

**Data**

Riparian vegetation is measured using Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+) and Landsat 8 Operational Land Imager satellite imagery. The Department of Science, Information Technology and Innovation's Remote Sensing Centre has an extensive archive of Landsat 5, 7 and 8 data acquired between 1984 and 2013. These data have been pre-processed to standardised surface reflectance to enable comparison over time (Flood *et al* 2013). Landsat data have been used by various riparian studies, as reviewed in Goetz (2006). Landsat data has a moderate spatial resolution, with a pixel size of 30 metres. The return interval of a Landsat satellite is 16 days.

**Defining riparian areas**

Riparian areas range from small headwater creeks to major rivers. Many studies have shown the benefits of using GIS and remote sensing to analyse vegetation within a specified distance to a stream (Apan *et al*. 2002; Goetz 2006; Klemas 2001; Narumalani *et al*. 1997; Snyder *et al.* 2005; Yang 2007). A variety of different buffering widths were considered for reporting. Based on the literature and to account for the spatial resolution of the Landsat data, a buffer of 100 metres on both sides of creeks, rivers and riverine wetlands was considered appropriate to sample the riparian area.

To define the riparian area, a 100 metre buffer was applied to two source layers and then merged into a single mapping layer. The two source layers were:

- a drainage layer derived from the Australian Hydrological Geospatial Fabric project, Version 2.1.1 (Bureau of Meteorology 2014)
- 2009 extent of water bodies and riverine wetlands from the Wetland Mapping Project layer (Department of Science, Information Technology, Innovation and the Arts 2013).

Any area within 100 metres of estuarine wetlands or water bodies was then excluded from the final riparian area layer.

The accuracy of the data used varies between products. The drainage layer has been mapped at a variety of scales (1:50,000 - 1:250,000), while the wetland mapping information is at a scale of 1:100,000. The locational accuracy of the drainage lines can result in non-riparian areas being mapped as riparian. It is expected that as new datasets become available, the locational accuracy of drainage lines will be improved.

It is important to note that the riparian area in Report Card 2014 is not the same as the 'Category R' riparian vegetation, defined in Queensland's vegetation management framework (Department of Natural Resources and Mines 2013).

## Monitoring riparian forest

### Mapping riparian forest extent

Riparian forest extent was estimated based on foliage projective cover data derived from Landsat satellite imagery. Foliage projective cover is the percentage of ground area occupied by the vertical projection of foliage (Armston *et al.* 2009, Kitchen *et al.* 2010). The Landsat wooded foliage project cover product has prediction errors of 10.8 per cent (Kitchen *et al.* 2010) based on a large number of field sites across Queensland.

The National Forest Inventory has defined the minimum crown cover for forests as 20 per cent (Montreal Process Implementation Group for Australia 2008). Scarth *et al.* (2008) showed that foliage project cover of 11 per cent is equivalent to approximately 20 per cent crown cover. Therefore, areas with foliage projective cover of at least 11 per cent are considered forested.

### Historical and recent riparian vegetation loss

Historical and recent losses of riparian vegetation were analysed using woody vegetation change data from the Statewide Landcover and Trees Study (Department of Science, Information Technology, Innovation and the Arts 2014) and 'pre-European' forest data. The pre-European forests are defined as areas assessed as woody (forested) before European settlement (Neldner *et al*. 2005).

These data were derived from pre-clearing Regional Ecosystem mapping (Accad *et al*. 2001). The recent losses relate only to anthropogenic clearing. They do not include vegetation loss from natural events, such as cyclones and drought stress.

Riparian forest loss is reported for three time periods for the Great Barrier Reef regions:

- pre-European settlement to 2013, to provide an estimate of the extent of modification to riparian vegetation in each of the regions
- from 1988 to 2013, for historical vegetation clearing trends
- 2001 to 2005, 2005 to 2009 and 2009 to 2013 for recent vegetation clearing trends.

### Riparian forest patch size and connectivity

Landscape metrics describe the size and connectivity of forest patches, aiding finer scale analysis of forested riparian areas. These data can help prioritise restoration efforts (Fernandes *et al.* 2011) and measure fragmentation over time (Apan *et al.* 2002).

The Patch Size and Connectivity Index (PSCI) approach was developed specifically for riparian forests. It is a novel approach that builds on the proximity index of Gustafson and Parker (1992) by accounting for the initial patch size as well as the distance and size of neighbouring riparian forest patches. It is expressed as a proportion of an ideal 100 per cent forested scenario, to provide a more detailed measure of connectivity.

The Patch Size and Connectivity Index analyses the size of patches and the distance between them. It allows comparisons between catchments, and within the same catchment over time. As vegetation extent is increased, the Patch Size and Connectivity Index value will also increase. This indicates that riparian forest patches have become larger and more connected at the landscape scale. Alternatively, as patches either become smaller or the distance between them increases, the Patch Size and Connectivity Index value will decrease (Figure 1). This indicates a loss of connectivity at the landscape scale. A value of 100 would indicate fully connected riparian forests while a value of less than 40 indicates no connectivity.

More information about the Patch Size and Connectivity Index will be available in the Riparian technical report (DSITI 2015 in prep).

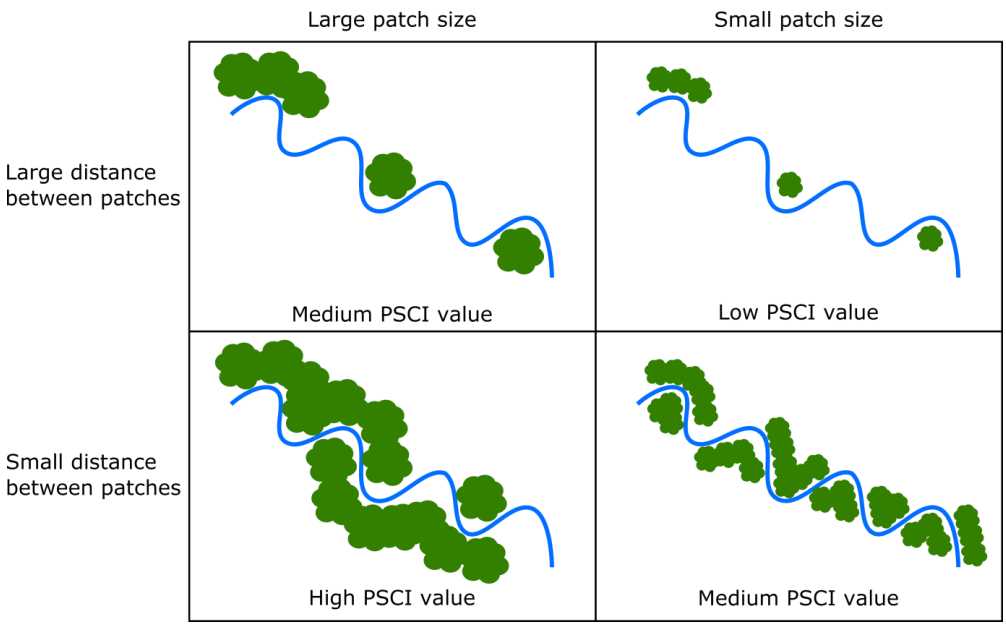


*Figure 1: An example of high, medium and low Patch Size and Connectivity Index (PSCI) values. Catchments with large riparian patches have a medium PSCI value if the distance between patches is large or a high PSCI value if distance between patches is small. In contrast, catchments with small riparian forest patches will have a low PSCI value if the distance between patches is large or a medium PSCI value if the distances are small.*

A second metric is used to quantify the number of riparian forest patches per kilometre of stream network. The Normalised Patch Density (NPD) differs from the Patch Size and Connectivity Index as it provides a measure of the linear connectivity of riparian forest along the stream network. This measure is normalised to account for the different proportion of each catchment's riparian area that is forested.

In contrast to the Patch Size and Connectivity Index, a low Normalised Patch Density value indicates higher linear connectivity while a high Normalised Patch Density value indicates lower linear connectivity (Figure 2). For example, regions such as Cape York have a low number of riparian forest patches, but each patch is very large and the total forested area is also large. This region has a very low Normalised Patch Density value but a high Patch Size and Connectivity Index value. In contrast, the Fitzroy region has a high number of riparian forest patches, yet each patch is small. The Fitzroy region has a high Normalised Patch Density value and a relatively low Patch Size and Connectivity Index value.

More information about the Normalised Patch Density will be available in the Riparian technical report (DSITI 2015 in prep).

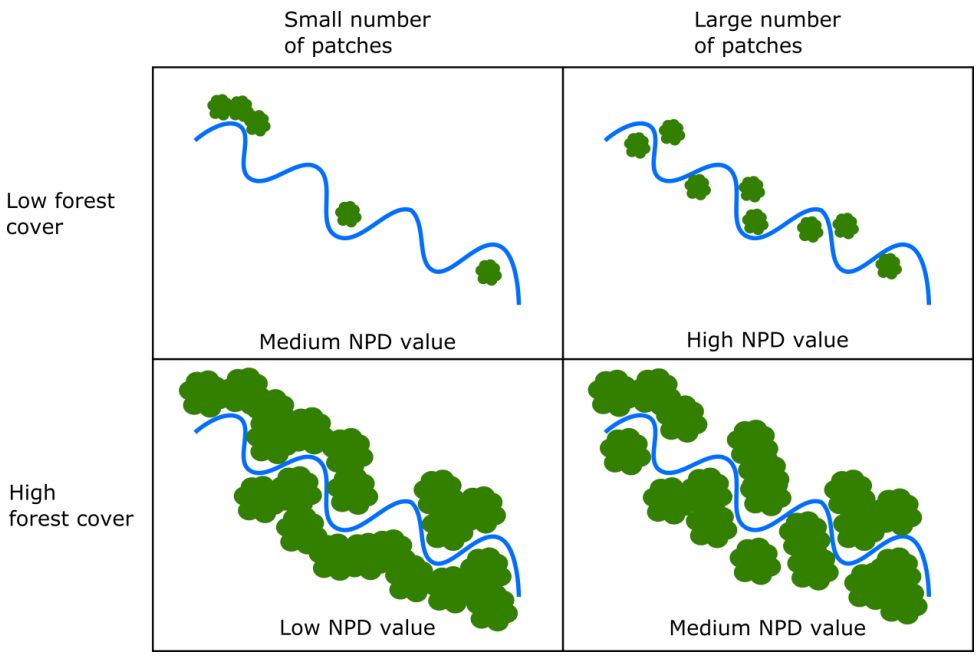


*Figure 2: An example of high, medium and low Normalised Patch Density (NPD) values. Catchments with a small number of riparian patches will have a medium NPD value if the overall forested proportion is low or a low NDP value if the overall forested proportion is high. In contrast, a catchment with a large number of patches will have a high NDP value if the overall forested proportion is low or a medium NPD value if the overall forested proportion is high.*

As progress towards the target is reported over time, it is expected that an increase in riparian vegetation will lead to an increase in each region's Patch Size and Connectivity Index value and a decrease in the Normalised Patch Density value.

**Monitoring ground cover in riparian areas**

Ground cover is defined as all non-forest plant cover near the soil surface and all litter including tree litter. Ground cover reporting in riparian areas is based on seasonal data derived using the fractional cover method described by Scarth *et al.* (2010). The method measures the proportion of green cover, non-green cover and bare ground using reflectance information from late dry season Landsat 5 (TM), 7 (ETM+) and 8 (OLI) satellite imagery. The fractional cover data is calibrated using over 1500 field observations from a range of cover levels and environments. Using the field observations as a basis, a further adjustment is applied to the fractional cover data to account for the influence of trees, shrubs and ground cover fractions measured by the satellite. This results in a data product, fractional ground cover, which effectively removes the influence of trees and shrubs and provides estimates of the level of green ground cover, non-green ground cover and bare ground at ground level. Fractional ground cover is the basis for ground cover reporting.

A seasonal fractional cover product has been produced for the September to November period to best represent the late dry season cover for 2013 using the methods described by Flood (2013). This method selects the most statistically representative cover value for this period for each pixel. This method requires at least three valid pixels, or there will be gaps due to missing data. For these areas, additional data from individual dates of fractional cover were used to infill areas with valid pixels. If there are no valid pixels to infill the gap, it is classified as missing data. Areas with persistent cloud cover or water have missing data.

In non-forest riparian areas, the green and non-green fractions are combined to produce total cover. This is reported for the late dry season for 2013. This is classified into three classes: greater than 70 per cent, 30 to 70 per cent and less than 30 per cent ground cover. Very low ground cover can indicate degraded areas, such as gullies. It may also be present naturally in areas containing sandbars, sand dunes and rocky streams.

## Qualitative confidence ranking

Confidence

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 the use of expert opinion and direct measures of error for program components where available. Riparian vegetation extent received a three bar confidence ranking.

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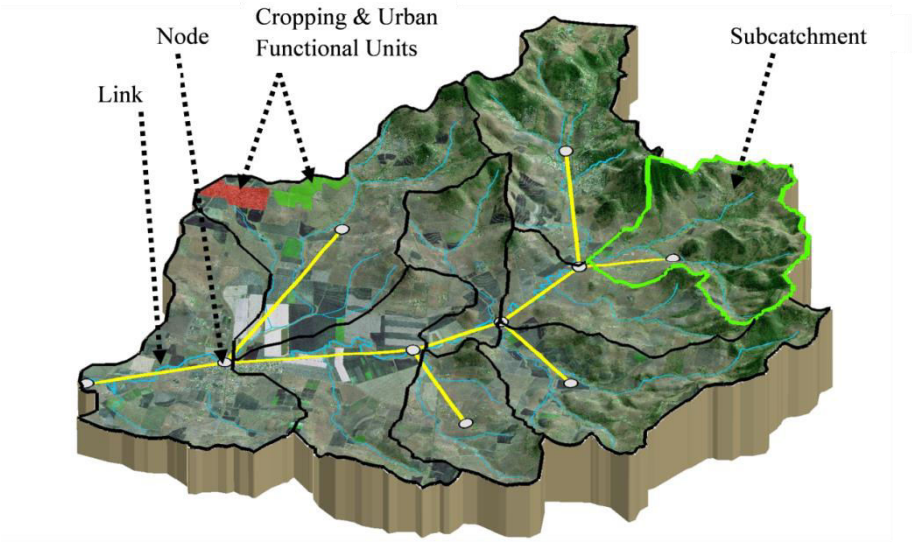
## Catchment pollutant loads methods

### Catchment modelling

The Source Catchments modelling framework (eWater 2010) is used to model pollutant loads for the 35 catchments in the Great Barrier Reef region. It is a catchment scale water quantity and quality model which uses a node link network to represent the stream. The model generates runoff and pollutant loads for each functional unit (landuse) 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.




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

Source Catchments 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 report card, average annual catchment loads are reported.

The model was run for each scenario using a fixed climate period from 1986 to 2014 to remove the influence of climate on estimated load reductions. The latest land use mapping (Department of Science, Information Technology, Innovation and the Arts, 2012) was used to describe the spatial extent of each agricultural land use for the baseline year.

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 target.

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 Management Practice methods for more information about the frameworks.

Three scenarios are run each year: predevelopment, the baseline (2013) then each subsequent year with the proportion of land managed using lowest risk to high risk practices adjusted each year, following the adoption of improved management practices.

The proportion of land managed using lowest risk to high risk 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.

Fine and coarse sediment, dissolved and particulate nutrients and five photosystem II pesticides were modelled. Key land uses were modelled for the baseline scenario including grazing, cane, cropping, horticulture and forestry.

Modelled load estimates are validated against monitored data at 25 sites across the Great Barrier Reef catchments. For further information on the model validation processes, see Waters et al. 2014.

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

**Management practice change**

The management practice adoption frameworks describe and categorise farming practices according to recognised water quality improvements at a 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, bananas and grazing areas of the Great Barrier Reef catchments. For details on how management practice changes are represented in the modelling, see the modelling technical reports volume 1-7 (references are listed in further reading below).

Improved grazing management (in particular vegetation cover management) through riparian and streambank fencing was also modelled. Spatial data on the length of stream and gully fencing were provided by regional bodies.

**Modelling assumptions**

- Loads reported for each report card reflect the relative change in modelled average annual loads for the specified model run period (1986 to 2014)
- Land use areas in the model are static over the model run period and were based on the latest available Queensland Land use Mapping Program (QLUMP) data (Department of Science, Information Technology, Innovation and the Arts, 2012)
- Paddock model runs 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 used to populate the paddock models were derived through consultation with relevant industry groups and regional bodies
- Practice adoption areas represented in the model are applied at the spatial scale of the data supplied by regional Natural Resource Management bodies
- The water quality benefits from adopting a management practice change are assigned in the year that investment occurs
- It is important to note that these are modelled load reductions based on improved land management adoption data supplied by industry and regional Natural Resource Management groups. Results are, therefore, indicative of the likely effects of adoption of improved land management practices for a given scenario rather than a measured reduction in load

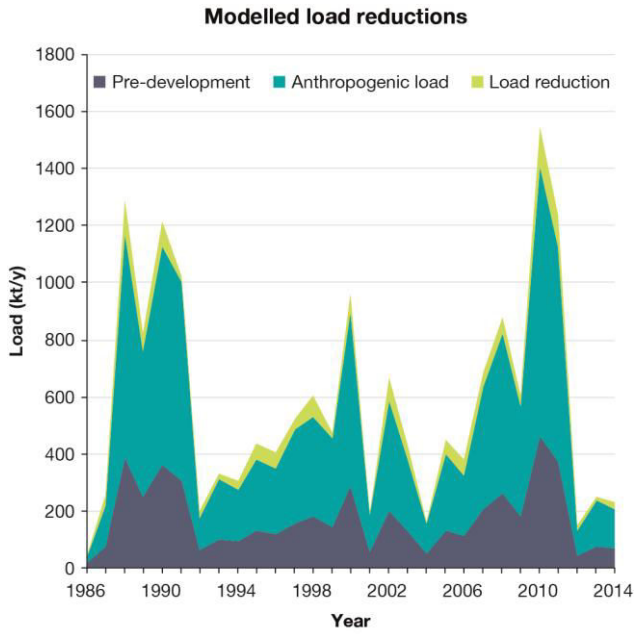
**Linking paddock and catchment models**
The commercial Source Catchments model was modified to incorporate hillslope generation from the most appropriate paddock models for cropping and sugarcane areas, and the Revised Universal Soil Loss Equation (RUSLE) for grazing. In addition, gully and streambank erosion and floodplain deposition processes were added based on the SedNet/ANNEX approach (Wilkinson et al. 2004). A more detailed description can be found in Ellis and Searle (2013). These features were incorporated to better represent the erosion processes observed in the summer dominant rainfall areas of Northern Australian reef catchments.

Two approaches were used to represent improved land management practices in Source Catchments depending on the land use of interest. 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 lowest risk to high risk management practices within each land use were identified. 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) (Keating et al 2003) was used. Each of the climate/soil combinations was also modelled to represent different levels of lowest risk to high risk management practices.

In the second approach, the RUSLE model has been written into Source Catchments to model hillslope soil erosion in grazing lands, where 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, e.g. 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 map of areas of lowest risk to high risk management practices as provided by regional Natural Resource Management groups annually. The outputs from each of the modelled land management practices were accumulated into a single land use time-series for a sub-catchment. All loads were then aggregated at a sub-catchment scale and routed through the stream network.

**Total load**
The total baseline load was the load modelled as at 2012-2013 land management within each Great Barrier Reef catchment. A pre-development land use map was also developed and modelled. The model was then run for a 28-year period to establish the total load over this period. Thus, the anthropogenic load was the total baseline load less the pre-development load.

**Load reductions**
The model was then re-run for the same climate period using updated proportions of lowest risk to high risk management practice areas to reflect investment in improved management practices since 2012-2013. The relative change in pollutant loads from the anthropogenic baseline after investment reflects the load reduction due to changes in management practices.




*Example of modelled loads for natural (pre-development), human-caused (anthropogenic) and the load reduction following investment in improved practices.*

**Modelling improvements**

As part of the continuous program improvement, updated model input layers are incorporated when they become available. Paddock to Reef program phase 2 improvements already implemented include: seasonal ground cover, improved soils layer, better climate and flow data, finer resolution topographic data and expanded water quality monitoring data. 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.

Gullies, scalds and stream bank erosion are modelled based on scientifically peer reviewed process understanding. Where updated gully maps are available these have been incorporated (areas included to date are the Normanby, Burdekin and Fitzroy catchments). A significant gully mapping program is continuing and further updates will be incorporated.

Pollutants losses via groundwater, such as nitrogen leaching through soils, are monitored at the Paddock to Reef farm trial sites and modelled through the paddock models. From Phase 2, the catchment modelling now represents this pollutant loss pathway as well.

**How the information is reported**

Progress towards Reef Plan 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 from:**

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

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 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 the use of 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

**Monitoring sites**
The end-of-system monitoring sites are located at the lowest point in a river or creek, predominantly where gauging stations have been established and maintained by the Department of Natural Resources and Mines. These provide data on all of the catchment upstream of the site. Sub-catchment sites are located at the lowest point in a sub-catchment (tributary) predominantly at existing gauging stations. They provide data on all of the sub-catchment upstream of the site. Both provide data to validate catchment models.

**Rainfall**
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 from 1 July 2013 – 30 June 2014.

**River discharge**
River discharge data (the volume of water moving past a point per unit time in $m^3 s^{-1}$) for monitoring sites were extracted from the Department of Natural Resources and Mines, Surface Water Database (Hydstra). River discharge data for some monitoring sites were adjusted using a timing and flow factors based on the nearest upstream gauging station; or were modelled.

**Water quality sampling**
Water samples were collected, stored, transported and quality assured and quality controlled in accordance with the Environmental Protection (Water) Policy Monitoring and Sampling Manual (https://www.ehp.qld.gov.au/water/pdf/monitoring-man-2009-v2.pdf). Water quality samples were collected using two different sampling 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.

**Water quality sample analysis**
Total suspended solids and nutrient analyses were undertaken by the Science Division Chemistry Centre (Dutton Park, Queensland). Queensland Health Forensic and Scientific Services Organics Laboratory (Coopers Plains, Queensland) analysed water samples for pesticides. Both laboratories are accredited for the analyses conducted by the National Association of Testing Authorities (NATA).

**Loads calculation**
The suitability of the generated water quality monitoring data for load calculations was assessed – using a sample representivity rating. The most appropriate load calculation method (i.e. 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 (i.e. total nitrogen, particulate nitrogen, dissolved organic nitrogen, oxidised nitrogen, ammonium nitrogen, total phosphorus, particulate phosphorus, dissolved organic phosphorus, and dissolved inorganic phosphorus) and pesticides (i.e. ametryn, total atrazine, total diuron, hexazinone and tebuthiuron). Loads were calculated using the Loads Tool component of the software Water Quality Analyser versions 2.1.1.4 and 2.1.1.6.

**Toxic loads calculation**
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., in review) and is expressed as an equivalent mass of diuron, i.e. diuron equivalent kilogram. The total toxic load is calculated by summing the toxic loads of all pesticides that have the same toxic mode of action.

## Marine methods

### Marine Monitoring Program

The Australian Government's Marine Monitoring Program assesses water quality and the long-term health of key marine ecosystems (inshore coral reefs and seagrasses) in the inshore waters of the Great Barrier Reef. The three elements of the program are outlined below.

More information about the Marine Monitoring Program is available from the Great Barrier Reef Marine Park Authority website (http://www.gbrmpa.gov.au/about-the-reef/how-the-reefs-managed/reef-rescue-marine-monitoring-program).

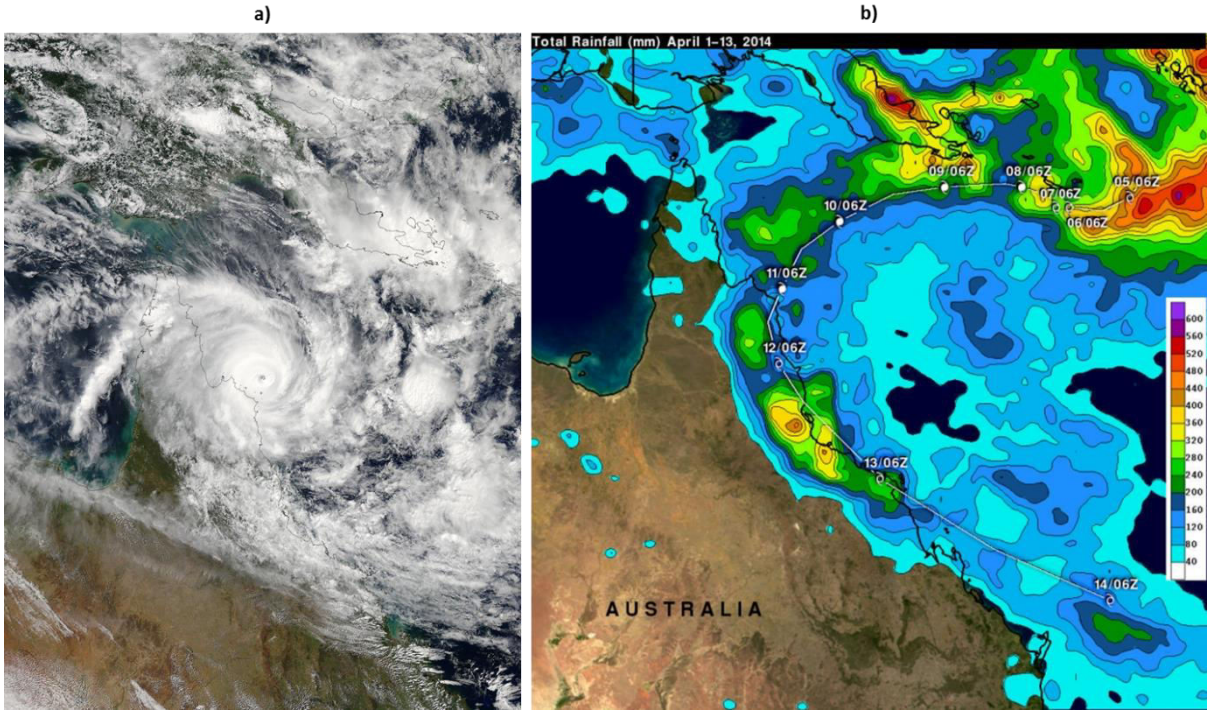
### Inshore water quality

#### Ambient inshore water quality

Monitoring includes the measurement of concentrations of nutrients (nitrogen and phosphorus), chlorophyll *a*, suspended solids (water turbidity) 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 integrated over time (Booij et al., 2007; Shaw & Mueller, 2009).

#### Flood plume dynamics

The majority of the annual pollutant load to the reef is delivered by flood events in the wet season (Devlin et al. 2001). Monitoring of water quality during flood events includes the measurement of salinity, concentrations of nutrients, chlorophyll *a*, suspended solids (water turbidity) and pesticides. The movement of the flood plume across inshore waters of the reef is assessed using images from remote sensing.




*a) NASA's Aqua true colour satellite images of Tropical Cyclone Ita (April 11, 2014). NASA image courtesy Jeff Schmaltz, LANCE/EOSDIS MODIS Rapid Response Team at NASA GSFC.*
*b) Tropical Rainfall Measuring Mission (TRMM) satellite rainfall map covers the path of Tropical Cyclone Ita from April 2-14 2014. Highest isolated rainfall was estimated around 400 mm/15.7 inches west of both Ingham and Townsville, Queensland. Tropical Cyclone Ita's locations at 0600 UTC are shown overlaid in white. Image Credit: SSAI/NASA/JAXA, Hal Pierce*

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

Monitoring includes an assessment of the seagrass abundance (per cent 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.


*Seagrass monitoring 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, macroalgae cover and the rate of change in coral cover as an indication of the recovery potential of the reef following a disturbance (Thompson and Dolman, 2010). Comprehensive water quality measurements are also collected at many of the coral reef sites.


*Coral reefs being monitored on the Great Barrier Reef. (Image: Australian Institute of Marine Science.)*

## Great Barrier Reef-wide and regional report card assessment scores

### Synthesis and integration of data and information

The report card provides assessment scores for the condition of inshore water quality, seagrass and coral at Great Barrier Reef-wide and regional scales.

A sub-set of indicators are 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 the Great Barrier Reef and each individual region.

An overview of the methods used to calculate the Great Barrier Reef-wide and regional scores is provided below. Great Barrier Reef-wide scores are standardised by the area of each region, while regional scores are unweighted averages. Detailed information is available from the technical reports on the Marine Monitoring Program website (http://www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/reef-2050-marine-monitoring-program/marine-monitoring-program-publications). All scoring methods have been reviewed and improvements will be implemented for the next report card.

### Remotely sensed inshore water quality

Near-surface concentrations of chlorophyll *a* and total suspended solids from remotely sensed images are used to assess and report on inshore water quality. Chlorophyll *a* is a measure of phytoplankton biomass that is related to the amount of available nutrients in the water column and therefore the productivity of the system. Total suspended solids is a measure of all particulate matter in the water column, including sediment. These two parameters are assessed against their relevant Great Barrier Reef Water Quality Guideline (GBRMPA, 2010) trigger values as the proportion of the inshore water body where the annual mean value does not exceed the Great Barrier Reef Water Quality Guidelines. Inshore waters include enclosed and open coastal waters as defined in the Great Barrier Reef Water Quality Guidelines. Chlorophyll *a* and total suspended solids have been chosen as the best information currently available to describe the water quality over a large spatial area with linkages to the Reef Water Quality Protection Plan 2013 targets.

The accuracy of water quality estimates from satellites is limited in the Cape York and Burnett Mary regions, because of the amount of on-ground data available for validation. These regions are excluded from overall assessments of Great Barrier Reef water quality and reef condition. It is also important to note that the number of remotely sensed images available in the wet season is substantially lower than in the dry season due to high cloud cover, so there is greater uncertainty in the wet season. In 2011-2012, there were major improvements to the remote sensing methods and the full historical time-series has been updated by the Bureau of Meteorology and is available through the eReefs Marine Water Quality Dashboard http://www.bom.gov.au/marinewaterquality/

### Seagrass

Abundance, reproductive effort and tissue nutrient status are used to assess and report on inshore seagrass condition. Seagrass abundance is an assessment of the average per cent cover of seagrass per monitoring site in relation to the Seagrass Abundance Guidelines (McKenzie 2009). The 80th, 50th and 20th percentiles were used to define the Seagrass Abundance Guidelines, as these are recommended for water quality guidelines (Department of Environment and Resource Management 2009) and there is no evidence that this approach would not be appropriate for seagrass meadows in the Great Barrier Reef. Developing guidelines for individual sites requires three to 10 years of monitoring with a minimum of 18 or more observations with no identified impacts, depending on the variability for the site. 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 50$^{th}$ percentile for that site, the condition is considered 'good'.
Reproductive effort is the ratio of the average number of reproductive structures on an area basis relative to the long-term average, and provides an indication of the capacity for meadow recovery 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 2013-2014, an additional five Cape York sites (established in 2012), four subtidal sites in the Wet Tropics and Burdekin regions (established in 2008) and one intertidal site in the Burdekin region (established in 2012) were included in the overall assessments of Great Barrier Reef seagrass ecosystem condition. Once seagrass abundance guidelines were developed for the new sites (McKenzie 2009), the full suite of available monitoring data was able to be used to update the seagrass condition assessments from 2012 for Cape York, and from 2008 for the Wet Tropics and Burdekin regions. This resulted in some changes to the historical scores for seagrass condition, which now have greater confidence.

**Corals**

Coral cover, coral cover change, juvenile density and macroalgae cover are used to assess and report on inshore coral reef condition. 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 and to recover from disturbances by estimating the availability of adult broodstock. Coral change is a measure of the observed change in coral cover compared to modelled predictions derived from the preceding three years of information, and provides an indicator of the balance between disturbance and recovery. A healthy and resilient coral reef is expected to show an increase in coral cover during periods free from disturbances.

Juvenile density is a measure of the abundance of hard coral juveniles per area of available space, and indicates the potential of the community to recover from disturbances or stress. Macroalgal cover is a measure of the abundance of 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 space or producing chemical deterrents that limit coral recruitment and growth. No coral monitoring occurs in the Cape York or Burnett Mary regions under the Marine Monitoring Program.

**Additional site-specific information**

To complement Reef-wide and regional water quality scores derived from remote sensing, the Report Card provides additional, site-specific information on water quality and detected pesticides.

**Site-specific water quality**

Site-specific water quality data are reported using an interim water quality index based on the monitoring data and expert opinion. The index aggregates scores for four indicators of water quality parameters (turbidity/water clarity, chlorophyll *a* and concentrations of particulate nitrogen and phosphorus) relative to the Great Barrier Reef Water Quality Guidelines (GBRMPA 2010), using three-year running means to give an overall rating for each of the fixed sampling sites. Decision rules for the water quality index are outlined in more detail in Thompson *et al.* 2014 (http://elibrary.gbrmpa.gov.au/jspui/browse?type=series&order=ASC&rpp=20&value=Marine+Monitoring+Program+-+Inshore+Water+Quality ).

The site-specific information is currently not incorporated into the water quality scores for the report card. Note that scores derived from remote sensing are not directly comparable to index scores. The method for assessing water quality is undergoing further development and in the future will combine site-specific information and remote sensing to give an overall score.

**Pesticides**

Pesticides are monitored using two methods: grab samples of pesticides collected in flood plumes during the wet season give an indication of peak concentrations, and passive samplers provide an integrated assessment of pesticide concentrations over time in wet and dry seasons (Booij et al., 2007; Shaw & Mueller, 2009). The most frequently detected pesticides in inshore waters include those herbicides that inhibit the photosynthetic pathway (PSII) of plants: diuron, atrazine, hexazinone, simazine and tebuthiuron (Haynes et

al., 2000a; Mitchell et al. 2005; Kapernick et al. 2006; Lewis et al. 2009; Packett et al. 2009). These PSII herbicides may also have a negative impact on non-target organisms such as algae, corals and seagrass (Magnusson et al., 2008; Jones and Kerswell, 2003; Haynes et al., 2000(b)).

An index (Table 1) has been developed using PSII herbicide equivalent concentrations to assess the potential combined toxicity of these pesticides relative to the Great Barrier Reef Water Quality Guidelines. The PSII herbicide equivalent concentration incorporates the relative potency and abundance of individual PSII herbicides compared to a reference PSII herbicide, diuron. For reporting purposes, the index has five categories: concentrations detected at the lowest category 5 levels are not expected to have an impact on seagrass or coral, while the highest category 1 levels correspond to the guideline for diuron set for the protection of 99 per cent of species (http://www.gbrmpa.gov.au/about-the-reef/how-the-reefs-managed/water-quality-in-the-great-barrier-reef/water-quality-guidelines-for-the-great-barrier-reef).

*Table 1: PSII Herbicide Equivalent (HEq) Index developed as an indicator for reporting of PSII herbicides across the reef. Note that Category 1 is higher than Category 5.*

| Category | Concentration ($ng.L^{-1}$) | Description |
|---|---|---|
| 5 | **PSII-HEq ≤ 10** | No published scientific papers that 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 | **10 < PSII-HEq ≤ 50** | Published scientific observations of reduced photosynthesis for two diatoms. |
| 3 | **50 < PSII-HEq < 250** | Published scientific observations of reduced photosynthesis for two seagrass species and three diatoms. |
| 2 | **250 ≤ PSII-HEq ≤ 900** | Published scientific observations of reduced photosynthesis for three coral species. |
| 1 | **PSII-HEq > 900** | Published scientific papers that demonstrate effects on the growth and death of aquatic plants and animals exposed to the pesticide. This concentration represents a level at which 99 per cent of tropical marine plants and animals are protected, using diuron as the reference chemical. |

Note that concentrations of pesticides at Categories 2 to 4 represent biologically relevant concentrations. However:

- 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.
- These categories have been included as they indicate an additional level of stress that plants and animals may be exposed to in the Marine Park. In combination with a range of other stressors (e.g. sediment, temperature, salinity, pH, storm damage and elevated nutrient concentrations) the ability of these plant and animal species to recover from impacts may be reduced.

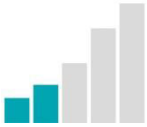
Classifying the data into index categories provides an indication of the extent and frequency of exposure to PSII herbicides at a given site (and the potential consequences for marine organisms). The PSII herbicide equivalent concentrations used in the index are calculated from the combined toxicity of diuron, hexazinone, atrazine and its breakdown products, tebuthiuron, ametryn, prometryn, simazine, metolachlor, terbutryn,

flumeturon and imidacloprid, all of which are used to control weeds and other plant species in the Great Barrier Reef catchment and are regularly found in the Marine Park. Note that reference to pesticides in the report includes all herbicides, insecticides and other chemicals used to treat pest or weed species.

**Qualitative confidence rankings**

**Remote sensed water quality**

Confidence



**Seagrass**

Confidence

**Coral**

Confidence

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 the use of expert opinion and direct measures of error for program components where available. Remote sensed water quality received a two bar confidence ranking, seagrass received a four bar confidence ranking and coral received a four bar confidence ranking.

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