Wetland condition methods

Great Barrier Reef

Report Card 2016

Reef Water Quality Protection Plan

Australian Government

Queensland Government

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.

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[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.

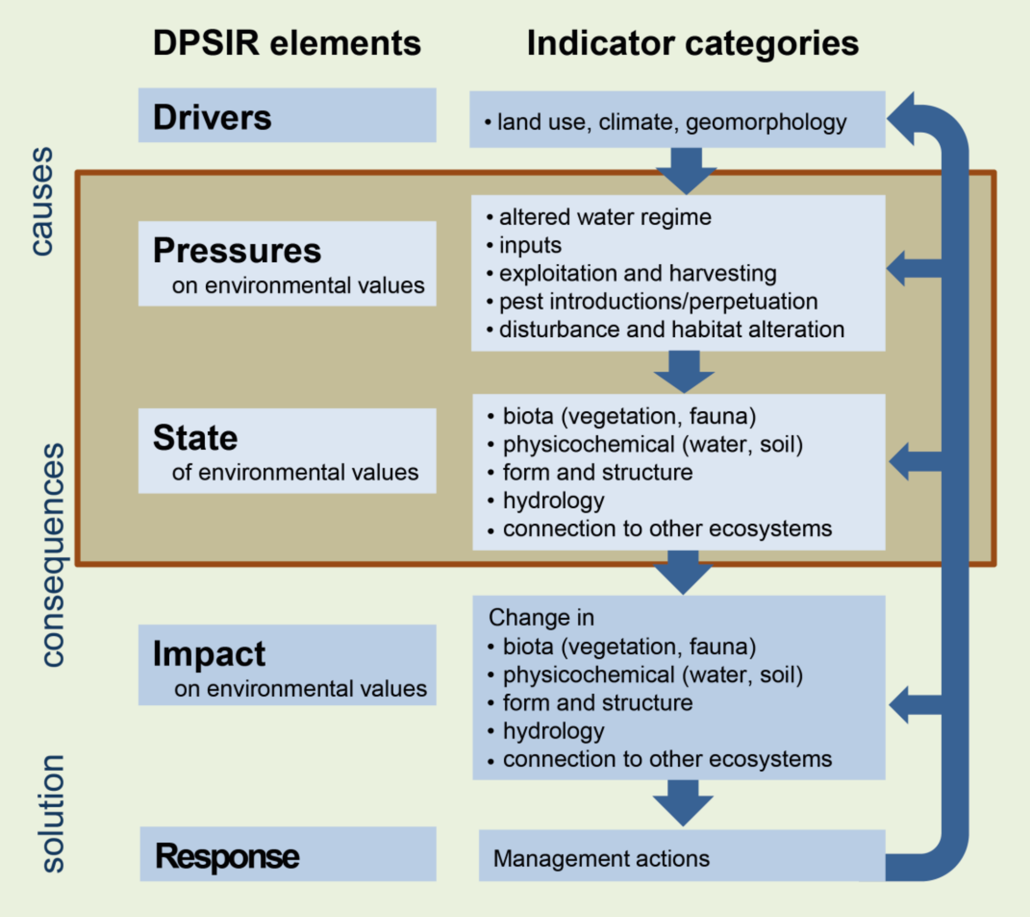


Figure 1: Conceptual framework for wetland monitoring program. The assessment tool (WFAT–M) directly assesses pressure and state (outlined) and can assess impact over time.

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

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

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 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).

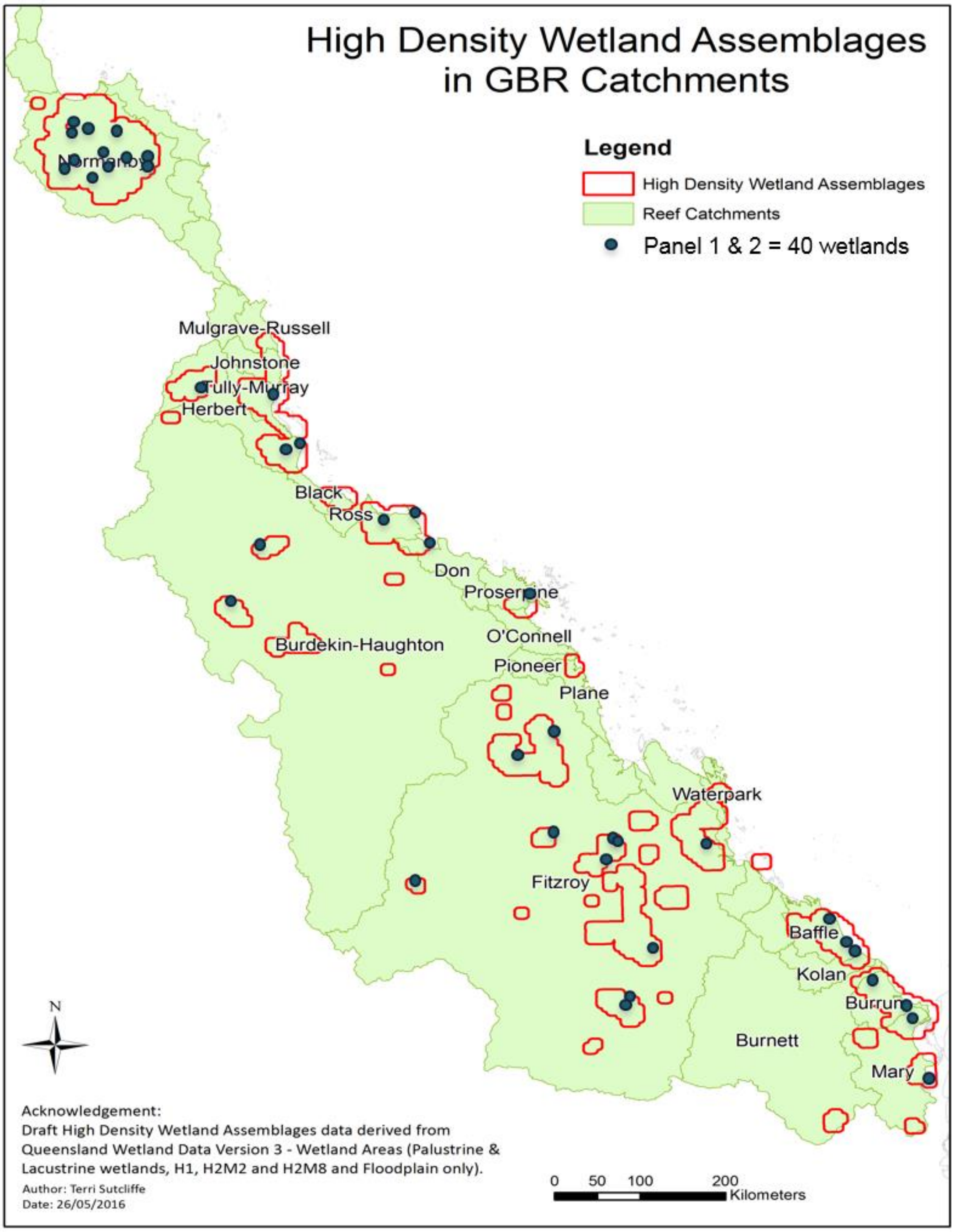


Figure 2: Extent of the sub-population of floodplain wetlands chosen for reporting on the target. Areas with dense aggregations of floodplain wetlands defined using the 'point density' tool in ArcGIS Spatial Analyst are outlined in red. Within those areas the GRTS spatially balanced random sample for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

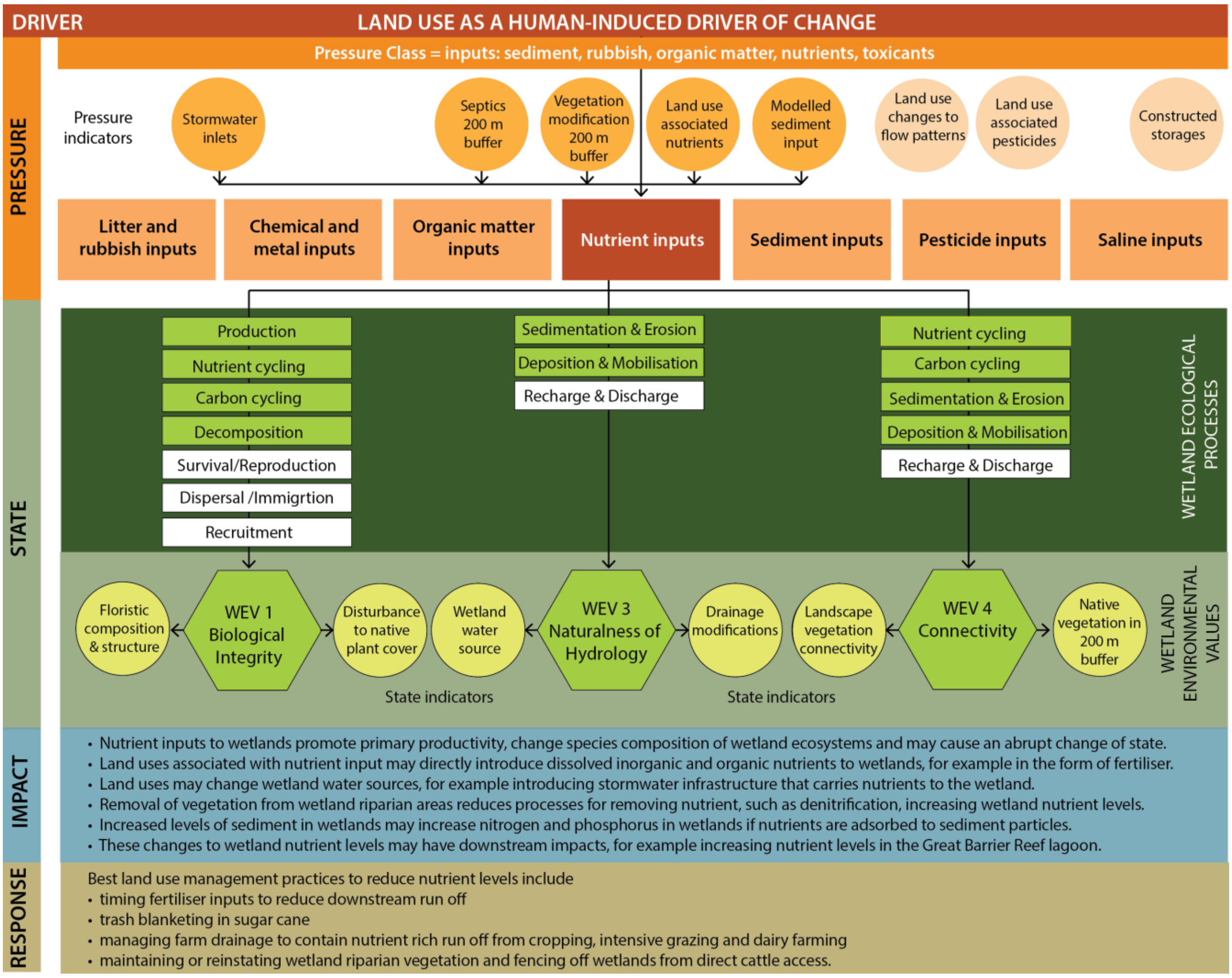


Figure 3: A Driver–Pressure–State–Impact–Response conceptual model showing an example of anthropogenic input pressures to wetlands, focusing on nutrients. The relationships between anthropogenic *pressures* and the *state of wetland values* are mediated by wetland ecological processes. Individual pressures 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.

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

- Individual indicators are assessed on ordinal scales with scores generally ranging from one to five.

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.

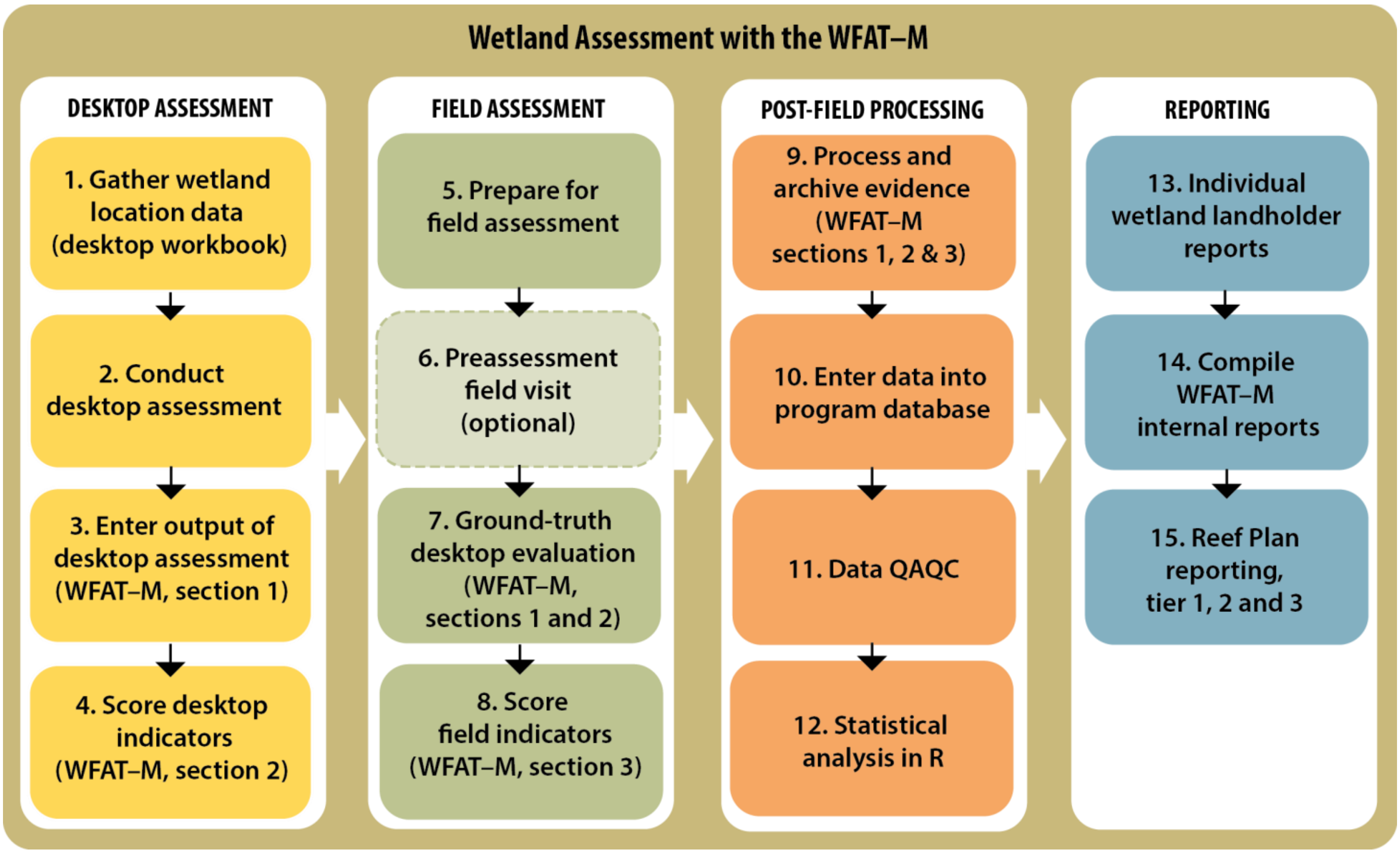


Figure 4: Wetland assessment and reporting workflow using the WFAT–M

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 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'

[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.

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 α = .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.

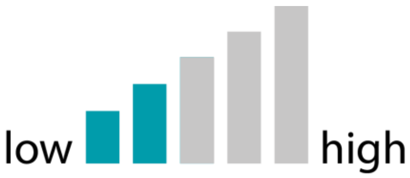
A similar analysis was performed on the data gathered for 41 wetlands during the 2015–16 baseline assessments and the landscape hazard scores for these wetlands were again significantly correlated with both overall pressure on wetland environmental values and state of wetland environmental values, although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

Qualitative confidence rankings

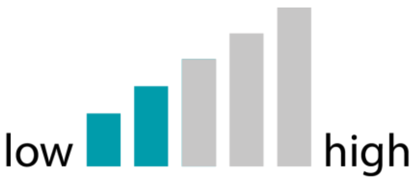
A multi-criteria analysis was used to qualitatively score the confidence in each indicator used in the Reef report card, from low to high (Australian and Queensland Governments, 2016). The approach combined expert opinion and direct measures of error for program components where available.

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.

References

Arthington, AH, Marshall, J, Rayment, G, Hunter, H and Bunn, S 1997, 'Potential impacts of sugarcane production on the riparian and freshwater environment', in BA Keating and JR Wilson (eds), *Intensive sugar cane production: meeting the challenges beyond 2000*, CAB International, Wallingford, United Kingdom, pp. 403–421.

Australian and Queensland governments, 2009. *Reef Water Quality Protection Plan 2009: For the Great Barrier Reef World Heritage Area and adjacent catchments*, Queensland Department of Premier and Cabinet, Brisbane.

Australian and Queensland governments, 2013. *Reef Water Quality Protection Plan 2013: Securing the health and resilience of the Great Barrier Reef World Heritage Area and adjacent catchments*, Queensland Department of Premier and Cabinet, Brisbane.

Australian and Queensland governments, 2015, *Great Barrier Reef Report Card 2014: Wetland Extent Results*, State of Queensland, Brisbane.

Australian and Queensland governments, 2016, *Scoring system: Great Barrier Reef Report Card 2015*, State of Queensland, Brisbane.

Brodie, JE & Mitchell, AW, 2005, 'Nutrients in Australian tropical rivers: changes with agricultural development and implications for receiving environments', *Marine and Freshwater Research*, vol. 56, pp. 279–302.

Brodie, J, Waterhouse, J, Schaffelke, B, Johnson, J, Kroon, F, Thorburn, P, Rolfe, J, Lewis, S, Warne, M, Fabricius, K, McKenzie, L, & Devlin, M 2013, *Reef Water Quality Scientific Consensus Statement 2013*, Department of the Premier and Cabinet, Queensland Government, Brisbane.

Bunn, SE & Arthington, AH, 2002, 'Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity', *Environmental Management*, vol. 30, pp. 492–507.

Clayton, PD, Fielder, DP, Howell, S and Hill, CJ 2006, *Aquatic Biodiversity Assessment and Mapping Method (AquaBAMM): a conservation values assessment tool for wetlands with trial application in the Burnett River catchment*, Environmental Protection Agency, Brisbane.

DEHP—see Department of Environment and Heritage Protection

Department of Environment and Heritage Protection, 2016, *Wetlands in the Great Barrier Reef Management Strategy 2016–21*, State of Queensland, Brisbane.

Department of Science Information Technology and Innovation, 2015, *A landscape hazard assessment for wetlands in the Great Barrier Reef catchment*, Queensland Government, Brisbane.

DSITI—see Department of Science Information Technology and Innovation

GBRMPA—see Great Barrier Reef Marine Park Authority

Great Barrier Reef Marine Park Authority, 2012, *Informing the outlook for Great Barrier Reef coastal ecosystems*, Great Barrier Reef Marine Park Authority, Townsville.

Great Barrier Reef Marine Park Authority, 2014, *Great Barrier Reef Outlook Report 2014*, Commonwealth of Australia, Townsville.

Kroon, F & Brodie, J 2009, 'Catchment management and the health of coastal ecosystems: synthesis and future research'. *Marine and Freshwater Research*, vol. 60, pp. 1196–1200.

Larsen, DP, Olsen, AR & Stevens DL Jnr 2008, 'Using a master sample to integrate stream monitoring programs. Journal of Agricultural', *Biological and Environmental Statistics*, vol. 13, pp. 243–254.

Norman, G 2010, 'Likert scales, levels of measurement and the 'laws' of statistics', *Advances in Health Science Education*, vol. 15, pp. 625–632.

Perna, C, O'Connor, R & Cook, B 2012, *Hydroecology of the lower Burdekin River alluvial aquifer and associated groundwater dependent ecosystems*, Department of Environment and Resource Management, Queensland Government, Brisbane.

Schaffelke, B, Anthony, K, Blake, J, Brodie, J, Collier, C, Devlin, M, Fabricius, K, Martin, K, McKenzie, L, Negri, A, Ronan, M, Thompson, A & Warne, M 2013, *Reef Water Quality Scientific Consensus Statement 2013: Chapter 1, Marine and Coastal ecosystem impacts*, Reef Water Quality Protection Plan Secretariat, Brisbane.

Scheltinga, DM, Moss, A, Pollett, A & Pennay, C (unpublished) *A framework for assessing the health of, and risk to, Queensland's lacustrine (lake) and palustrine (swamp) wetlands*, Department of Environment and Resource Management, Brisbane.

Sheaves, M, Brookes, J, Coles, R, Freckleton, M, Groves, P, Johnston, R & Winberg, P 2014, 'Repairs and revitalisation of Australia's tropical estuaries and coastal wetlands: opportunities and constraints for the reinstatement of lost function and productivity', *Marine Policy*, vol. 47, pp. 23–38.

Stevens, DL & Olsen, AR 2004, 'Spatially balanced sampling of natural resources', *Journal of the American Statistical Association*, vol. 99, pp. 262–278.

Tilden, J, Borschmann, G, Walsh, C, Mayger, B & Vandergragt, M, 2015 *Great Barrier Reef catchments wetland monitoring pilot study: Assessment methods and monitoring design*, Department of Science, Information Technology and Innovation, Brisbane, Queensland.

Tilden, J & Vandergragt, M 2017, *Great Barrier Reef Catchments Wetland Monitoring Program: Proposed analysis methods,* Queensland Department of Science, Information Technology and Innovation, Brisbane.

Verhoeven, TAJ, Arnheimer, B, Yin, C & Hefting, MM 2006, 'Regional and global concerns over wetlands and water quality', *Trends in Ecology and Evolution*, vol. 21, pp. 96–103.

Waterhouse, J, Brodie, J, Lewis, S & Audas, D 2016, 'Land-sea connectivity, ecohydrology and holistic management of the Great Barrier Reef and its catchments: time for a change', *Ecohydrology and Hydrobiology*, vol. 16, pp. 45–57.

Waterhouse, J, Schaffelke, B, Bartley, R, Eberhard, R, Brodie, J, Star, M, Thorburn, P, Rolfe, J, Ronan, M, Taylor, B, & Kroon, F 2017, *Scientific Consensus Statement 2017: Land use impacts on Great Barrier Reef water quality and ecosystem condition*, State of Queensland, Brisbane.