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Reef Water Quality Protection Plan 2013

Prioritisation project report

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Figures 16–25 revised November 2014 to show average annual modelled loads from cropping, not grains. The loads/hectare/year values displayed for individual land uses in Figures 21–25 should not be added.

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Foreword

This report focuses on the land-based biophysical systems of the catchments flowing to the Great Barrier Reef lagoon, the impact of transported materials (sediments, nutrients and herbicides) on coral reefs and sea grasses, key ecosystems for the reef and the opportunities to improve agricultural land management practices affecting the quality of the water delivered to the lagoon. The work has been undertaken to support and inform discussion and decisions on funding priorities for investment, particularly through Reef Water Quality Grants (part of the Australian Government Reef Programme).

The analysis aims to sharpen the focus of investment in practice change by identifying the relative contributions of each of the 35 sub-catchments flowing to the reef lagoon to pollutant loads, the relative contribution of the major agricultural industries in each sub-catchment to pollutant loads, the room for improvement in agricultural management practices, and the practices expected to deliver the biggest load reductions. Consideration of the ecological impacts of these pollutants on riverine and estuarine ecosystems, or the contribution these ecosystems make to the reef's ecological health is beyond the scope of this study.

The results of this study provide relative priorities for sub-catchments for investing in cane (nutrient and herbicide management practices) and grazing (sediment management practices). These priorities should be further refined when better information is available on the economic and social costs and benefits of practice change, including the role such changes can play in improving the long-term resilience and sustainability of industries in a changing climate.

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Acknowledgements

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List of abbreviations and acronyms

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences (within the Australian Government Department of Agriculture)
COTS	crown of thorns starfish
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIN	dissolved inorganic nitrogen
GBR	Great Barrier Reef
MCA	Multiple Criteria Analysis
MCAS–S	Multi-Criteria Analysis Shell for Spatial Decision Support
NRM	natural resource management
PN	particulate nitrogen
PP	particulate phosphorus
PSII	Photosystem II inhibiting (herbicide)
QDAFF	Queensland Department of Agriculture, Fisheries and Forestry
TSS	total suspended solids

Key findings

- Land used for agriculture occupies about 82 per cent of the GBR catchment. Land used for cropping, dairy, grazing, horticulture (including bananas) and sugar cane contributes an estimated 56, 69 and 66 per cent respectively to the estimated anthropogenic loads of TSS, PN and PP, plus an estimated 87 per cent of the anthropogenic DIN and 100 per cent of the PSII delivered to the GBR lagoon.

- Grazing (75 per cent of the area of the GBR catchment) contributes an estimated 45, 43 and 45 per cent respectively (Figure 5, p. 30) to the estimated anthropogenic loads of TSS, PP and PN and an estimated 21 per cent of the DIN load (Figure 6, p.30). The Burdekin and Fitzroy sub-catchments are rated as very high and high priority for investment in improving grazing management (Table 5, p. 41).

- Stream bank erosion, (which cannot be attributed to particular land uses but occurs largely on land used for grazing) contributes an estimated 39, 28 and 21 per cent respectively to the anthropogenic loads of TSS, PP and PN (Figure 5, p. 30).

- Land used for sugar cane (1.3 per cent of the GBR catchment) contributes an estimated 56 and 94 per cent respectively (Figure 6, p. 36) to anthropogenic loads of DIN and PSII delivered to the GBR lagoon. The MCAS–S process has identified the Johnstone sub-catchment as very high priority and the Burdekin (mainly East Burdekin), Haughton, Herbert, Mulgrave-Russell and Tully sub-catchments as high priority for investment in nutrient practices to reduce DIN loads. The Herbert, Pioneer and Plane sub-catchments are rated as very high priority for investing in improving herbicide management practices; the Haughton is rated as high and the Johnstone and O'Connell as moderate priority for investment in herbicide management (Table 5, p. 41).

- The impact on funding over time of changes in priorities is discussed (p. 43).

- Opportunities for improving practices for better water quality outcomes are identified (p. 47). In the grazing industry these include supporting adoption of better herd management practices to deliver ground cover improvements whilst improving profitability, and targeting investment to reduce subsoil loss through gullying and stream bank erosion. In the sugar cane industry there are significant opportunities to reduce DIN loads, particularly by moving from district yield to block or zone potential yields to calculate nitrogen fertiliser applications.

- Recommendations are made on improvements in reporting, monitoring and modelling land management practices to track investment outcomes (p. 49). Areas are identified for updating Source catchment modelling (p. 51) to reflect new understanding of sediment storage processes and to provide spatially detailed water quality outputs, especially for the Burdekin and Fitzroy sub-catchments.

- The research needed to further improve investment targeting is identified (p. 53).

Executive summary

Introduction

This report contains information that will support and inform discussion of funding priorities for future investment in the Great Barrier Reef (GBR) catchment, particularly for delivering on the Reef Water Quality Protection Plan 2013. The report focuses on the two main industries: the sugar cane industry, which makes the largest contributions to anthropogenic dissolved inorganic nitrogen (DIN) and herbicides; and grazing, which makes the largest contribution to total suspended solids (TSS) loads.

The Multi-Criteria Analysis Shell for Spatial Decision Support (MCAS–S) tool was used to support an assessment of the investment priority for each industry in the 35 sub-catchments making up the GBR catchment through data analysis and expert judgement. It combines information on (a) the risk to the GBR marine assets (corals, sea grasses) from land-based contaminants (TSS, particulate nitrogen (PN), particulate phosphorus (PP), DIN and five high-priority Photosystem II herbicides (PSII)) and (b) the potential for improvement in land management practices that would reduce contaminant loads entering the GBR (solvability).

Anthropogenic loads data are presented for the banana, dairy, grains or horticulture industries. However, no information was available on the extent of change in management practices resulting from investment for these industries, so they were not included in the MCAS–S analyses.

Declines in the coastal ecosystems of the GBR have been linked with increases in the land-based runoff of suspended sediments and nutrients and the addition of herbicides since European settlement. The 2013 Scientific Consensus Statement (State of Queensland 2013a) noted that there is strong evidence that improving catchment water quality will improve the resilience of the reef and associated ecosystems, buying some time by partially offsetting the increasing damage and stress from climate factors.

The Australian and Queensland governments established the Reef Water Quality Protection Plan in 2003 to halt and reverse the decline in the quality of the water entering the GBR lagoon. In the last five years, $158 million has been spent on improving agricultural management practices in reef catchments through grants to land managers and industry. Land managers have also invested an estimated $1.60 for each dollar provided by the Australian Government for Reef Rescue. In the first two years of the subsequent Reef Plan (2009) delivery, an estimated 34 per cent of sugar cane farmers, 25 per cent of horticulture farmers and 17 per cent of graziers adopted improved practices. Water quality modelling results from the Reef Plan Second Report Card (State of Queensland 2010) indicate that these changes could translate into a six to 15 per cent reduction in key pollutants (State of Queensland 2013b).

The Reef Plan Third Report Card (State of Queensland 2013c) noted that these programs are starting to halt and reverse the decline in reef water quality, reporting estimated reductions in the average annual anthropogenic loads of TSS, TN and PSII herbicides entering the reef. Subsequent scenario analyses undertaken to assess the feasibility of meeting the Reef Plan 2009 water quality targets suggest that the 50 per cent target for DIN may not be achieved by the adoption of the current A (aspirational or cutting edge) class nutrient management practices.

While there is considerable funding for the protection of the Great Barrier Reef, it is modest relative to the size of the water quality problem, and careful targeting of expenditure is needed to achieve desired outcomes.

In developing the Reef Water Quality Protection Plan 2013 (State of Queensland 2013b), it was agreed that actions under the plan would include prioritising investment and knowledge. These included ‘prioritise and align investments based on risk assessments of key pollutants, source areas and the risk they pose to Great Barrier Reef ecosystems, as well as information on priority areas for rehabilitation’.

A working group comprising Australian and Queensland government, CSIRO and university scientists was established to advise on investment priorities for each of the 35 major sub-catchments in the GBR catchment. Working group members collaborated to produce this report. This report complements the relative risk assessment for the marine environment of the GBR prepared by Brodie et al. (2013b).

Methods used to rank sub-catchments for investment

The Multi-Criteria Analysis Shell for Spatial Decision Support (MCAS–S) was chosen to draw together lines of evidence from water quality monitoring and modelling, research and practice change monitoring, and expert opinion from Reef stakeholders. A Multi-Criteria Analysis spreadsheet containing the data used in the MCAS–S was provided to each GBR regional body in late 2013 to help their planning processes for the use of 2013–14 funding from the Australian Government Reef Programme.

The Paddock to Reef Integrated Monitoring, Modelling and Reporting program (Paddock to Reef program), established to estimate and report on progress towards Reef Plan goals and targets for land and catchment management and water quality, produces data on the likely long-term loads and load reductions predicted as a result of management practice change. These data have been used in this study to inform future investment priorities at the regional level through the Water Quality Grants Program and for delivery of the Reef Trust.

The MCAS–S tool enabled the ranking of scores for nine factors for the grazing industry and 10 factors for the sugar cane industry to identify priorities for funding for each of the GBR’s 35 sub-catchments (see Figures 1a and 1b on pages 14 and 15 for locations). For example, for the grazing industry, modelled annual average total loads (pre-development plus anthropogenic loads) of TSS, PN, PP and DIN were used to estimate the risk to the GBR’s corals and sea grasses posed by the quality of the water draining from each sub-catchment into the GBR lagoon.

The room for improvement (area of grazing land under C or D class management practices which has potential to move up to A or B class practices) was combined with the annual average anthropogenic loads of TSS, PN and PP to estimate solvability (the combination of factors that contribute to a possible solution – here defined as the magnitude of the anthropogenic load and the area over which management practices could be improved). Scores for risk and solvability were then combined for each sub-catchment to establish a priority for grazing investment.

Investment priorities for sub-catchments

Grazing investment priorities

For the grazing industry, modelled annual average total loads (pre-development plus anthropogenic loads) of TSS, PP and PN were combined to estimate the risk to the reef’s corals and seagrasses from sub-catchments with grazing. The room for improvement, (area of grazing land under C and D class sediment management practices) was combined with the annual average anthropogenic loads of TSS, PP and PN to estimate solvability. Scores for risk and solvability were then combined for each sub-catchment to establish relative priorities for investment in sediment management in grazing (Table 5, p. 41 summarises the results).

Grazing investment priorities for sediment management were identified for the Burdekin (very high) and the Fitzroy (high) sub-catchments (see figures 1a and 1b for locations) relative to all other sub-catchments, which were assessed as low to very low priority (Table 5, p. 41). Information is available from recent research (but could not be incorporated in the MCAS–S analysis) on the areas, erosion processes (especially sub-surface soils lost via gully erosion) and soil types within the Burdekin and Fitzroy sub-catchments likely to be major contributors of fine sediment to the GBR lagoon. This should be used at regional level to identify which practices and locations where investment should be made in improving grazing management.

Cane investment priorities

For the sugar cane industry, modelled annual average total loads (pre-development plus anthropogenic loads) of DIN, plus a crown of thorns starfish (COTS) influence index and a herbicide concentration index, were combined to estimate the risk to the reef's corals and seagrasses from sub-catchments growing sugar cane. The room for improvement, (area of cane land under B, C and D class nutrient management practices and the area under C and D class herbicide management practices), was combined with the annual average anthropogenic loads of DIN and PSII herbicides to estimate solvability. Scores for risk and solvability were then combined for each sub-catchment to establish relative priorities for investment in improving nutrient and herbicide management in cane (Table 5, p. 41 summarises the results).

For the sugar cane industry, nutrient reduction investment priorities for sub-catchments were identified as very high for the Johnstone and high for the Mulgrave-Russell, Tully and Herbert in the Wet Tropics region and the Haughton in the Burdekin region. The Daintree in the Wet Tropics was ranked as moderate priority for nutrient reduction investment. The Barron (Wet Tropics); O'Connell, Pioneer and Plane (Mackay Whitsunday region), Mary (Burnett Mary region) and Burdekin were ranked as low priority. Sub-catchments ranked as very low priority for nutrient reduction investment include the Mossman and Murray (Wet Tropics); Black and Don, (Burdekin region); Proserpine (Mackay Whitsunday region); Fitzroy; and the Baffle, Kolan, Burnett and Burrum (Burnett Mary region).

Priority areas for investment in improved herbicide application practices for the sugar industry were influenced by the herbicide concentration index. Sub-catchments in the south of the GBR tended to have lower flows and higher herbicide concentrations. Priorities for herbicide investment were very high for the Herbert (Wet Tropics) and the Pioneer and Plane (Mackay Whitsunday), high for the Haughton and moderate for the Johnstone and O'Connell. Sub-catchments ranked as low priority for investment for herbicide management were the Mulgrave-Russell, Tully, Murray and Proserpine. Priorities for herbicide investment in the Daintree, Mosman and Barron, Black, Burdekin, Don, Fitzroy, Baffle, Kolan, Burnett, Burrum and Mary were ranked as very low.

Future improvements

Other opportunities for improving returns on investment through programs aiming to improve the quality of runoff from agricultural land are outlined. They include improving land management practices in the grazing and cane industries; better methods for monitoring, modelling and reporting land management practice change; improvements to spatial data sets required as input to the Source catchments modelling; and research to improve understanding of catchment processes affecting GBR water quality.

Chapter 1

Introduction

Declines in the coastal ecosystems of the GBR have been linked with increases in the land-based runoff of suspended sediments and nutrients and the addition of herbicides which have occurred since European settlement (De'Ath and Fabricius 2010, Brodie et al. 2012, Schaffelke et al. 2013). Recent estimates of the increases in mean annual loads delivered by rivers draining the Great Barrier Reef range from 5.5 times for total suspended solids and 5.7 times for total nitrogen to 8.9 times for total phosphorus (Kroon et al. 2012).

The recent Scientific Consensus Statement (Brodie et al. 2013a) noted that there is strong evidence that improving catchment water quality will improve the resilience of the reef and associated ecosystems. Reducing the land-based losses of nutrients, sediments and herbicides may buy the reef some time by partially offsetting the increasing damage and stress from climate factors, including temperature increases and ocean acidification. It suggested that the most significant effect could come from removing the water quality effects that are thought to trigger more frequent COTS outbreaks (State of Queensland 2013a).

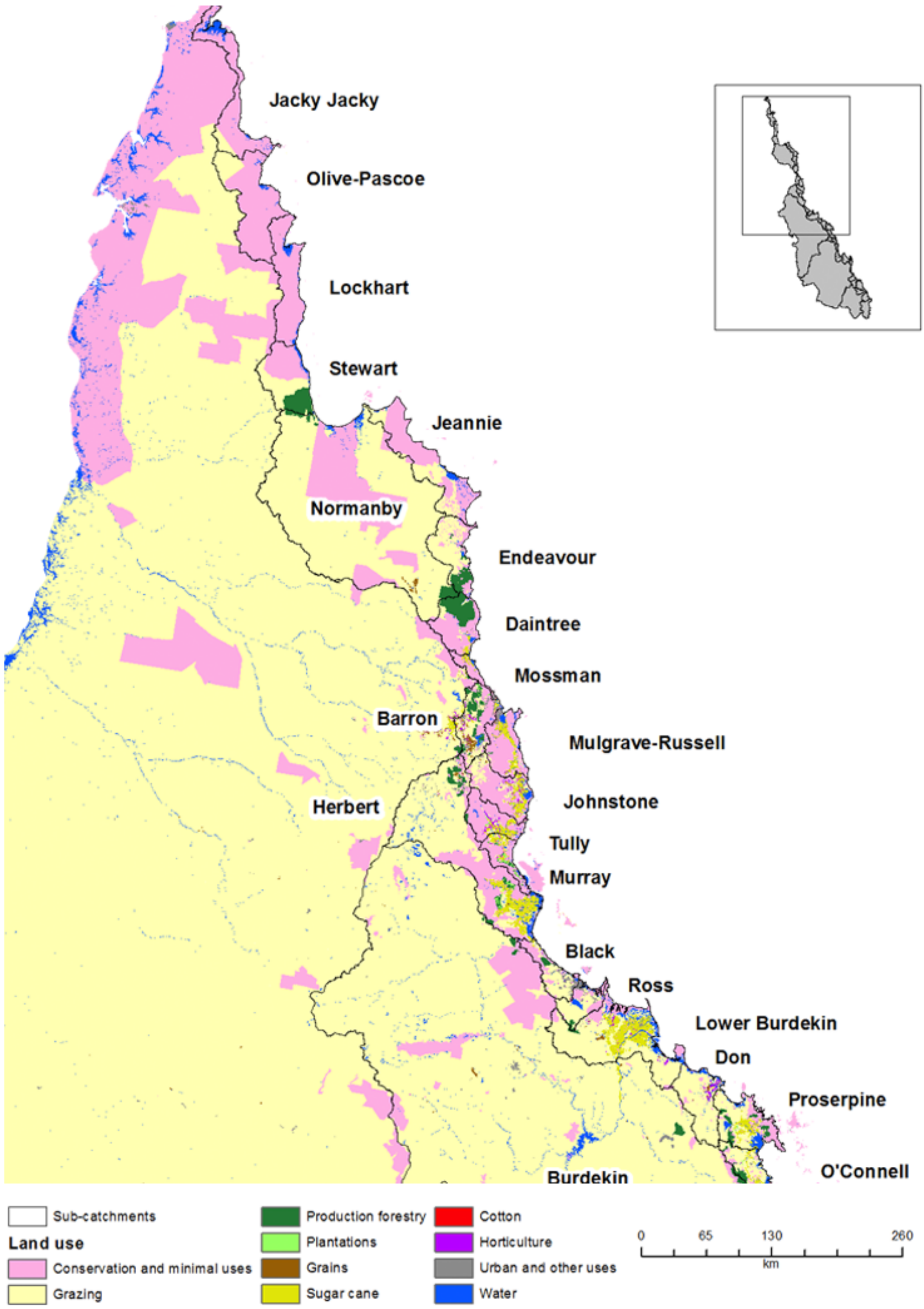
The catchments of the GBR comprise an area of almost 42.16 million hectares; about 82 per cent of this land is used for agricultural production (Figures 1a and 1b). In 2010–11 the gross value of agricultural production, principally from the broadacre cropping, dairy, horticulture, grazing and sugar cane industries, totalled $4.25 billion (Table 1). As noted in the Scientific Consensus Statement (State of Queensland 2013a), research has identified that the majority of sediment and nutrient loads delivered to the GBR lagoon are derived from diffuse agricultural sources (e.g. Kroon et al. 2012 and 2013), with point sources such as sewage treatment plants and urban lands making relatively small contributions (see e.g. Drewry 2008, Kroon 2008, Lewis et al. 2008, Waters and Carroll 2013).

TABLE 1 Gross value of agricultural production for major agricultural industries in the Great Barrier Reef natural resource management regions

NRM Region	Total gross value of agricultural production ($m)	Meat cattle ($m)	Dairy ($m)	Broadacre cropping (excluding sugar cane) ($m)	Sugar cane ($m)	Horticulture excluding bananas ($m)	Bananas ($m)
Cape York	51.9	48.2	–	1	–	2.4	–
Wet Tropics	802.8	55.9	35.2	15.8	296.4	103.7	276
Burdekin	983.8	396	2.2	46.9	237.6	290.1	–
Mackay Whitsunday	306.1	41.6	–	3.1	232.7	27.1	0.1
Fitzroy	1 003.5	671.9	5.4	254.4	5.3	51.6	–
Burnett Mary	1 102.5	265	66.8	37.7	116.8	547.3	0.8
Total	4 250.6	1 478.6	109.6	358.9	888.8	1 022.2	276.9

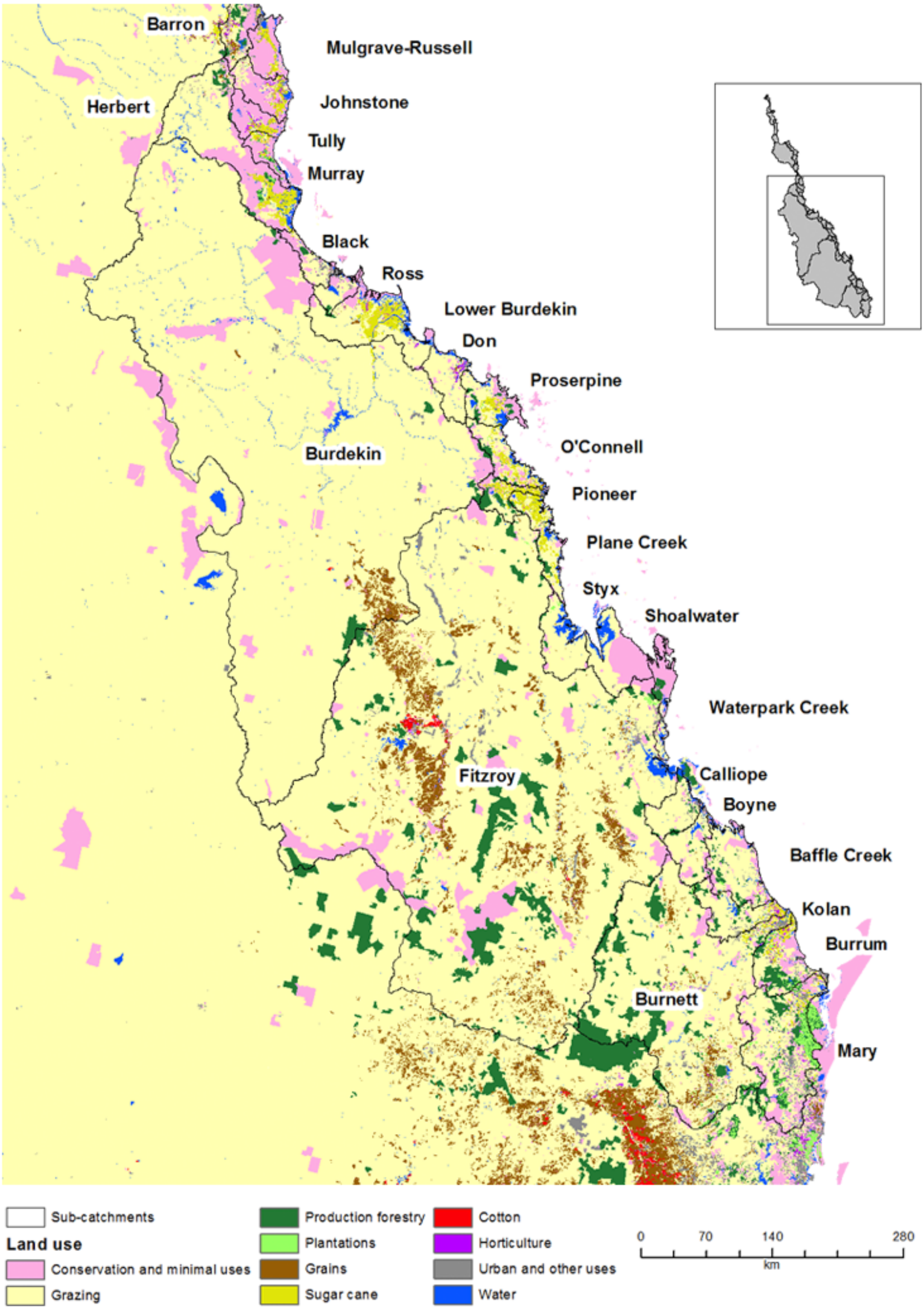
Source: Australian Bureau of Statistics agricultural census 2010–11

FIGURE 1a Land use in the northern sub-catchments of the Great Barrier Reef



Source: Queensland Land Use Mapping Program 2009

FIGURE 1b Land use in the southern sub-catchments of the Great Barrier Reef



Source: Queensland Land Use Mapping Program 2009

In response to concerns about the health of the reef, the Australian and Queensland governments established the Reef Plan in 2003 to halt and reverse the decline in the quality of the water entering the GBR lagoon. The Reef Plan was updated in 2009, and again in 2013 (State of Queensland 2013b). Reef Rescue (2008–09 to 2013–14) and the Reef Programme (2014–15 to 2017–18) are the Australian Government's contributions to this plan.

In the five years of Reef Rescue, $158 million was spent on improving the management practices of farmers and pastoralists in the Reef catchments through grants to land managers and support for industry engagement, extension and communication activities under the Water Quality Grants and Partnerships Program. This investment has been complemented by land manager investment in cash and in kind (more than an estimated $1.60 for each Reef Rescue dollar invested) (Australian Government 2014). Progress towards Reef Plan targets has been monitored through the Paddock to Reef program (Carroll et al. 2012) and published in a series of report cards (State of Queensland 2012, 2013c). Water quality modelling is indicating that these changes could translate into a six to 15 per cent reduction in key pollutants (State of Queensland 2013b).

Investments in research made over the last five years, plus modelling and monitoring results from the Paddock to Reef program have improved our understanding of the GBR marine ecosystems and their associated catchments. A working group (membership at Appendix 1) was established to provide advice on the relative investment priority for each of the 35 major sub-catchments, based on the potential for further improvement in on-farm management. Priorities were determined for major industries and for sediment, nutrient and herbicide management. This work provides the basis for this report.

Terms of reference for study

The working group's terms of reference were:

- Analyse and report on the extent of practice change at river basin level by the broadacre cropping, cane, dairy, grazing and horticulture industries, and estimate the cost per hectare of these changes. This will use the relevant 'ABCD' management practice frameworks for sediment, nutrient and herbicide management.
- Review the modelled water quality changes (nutrient, sediment and herbicide reductions) expected as a result of practice changes, and estimate the likely costs of these improvements to establish costs and benefits of water quality improvements for each river basin.
- If resources permit, undertake scenario analyses using water quality modelling to identify the types and locations of future investments predicted to provide the greatest water quality improvements.
- Synthesise the results of these analyses to inform relative priorities for further investments.
- Consult with stakeholders and the broader reef water quality science community to ensure their input into the analyses and communicate the outcomes of the process to them.

The Reef Plan Third Report Card (State of Queensland 2013c) noted that the programs delivered under Reef Plan are starting to halt and reverse the decline in reef water quality. While there is considerable funding available for the protection of the Great Barrier Reef, this is modest relative to the size of the water quality problem, and expenditure needs to be carefully targeted to achieve the desired outcomes.

Previous studies have suggested that there is substantial geographic variability in the loads delivered to the GBR lagoon, indicating the potential for opportunities to target investment. For example, Kroon et al. (2012) and Greiner et al. (2005) have shown that the increases in pollutant loads vary across the 35 sub-catchments draining into the GBR lagoon as a result of differences in extent and type of agricultural land use and practices, the extent of deforestation, mining, retention by reservoirs, surface runoff (reflecting differences in climate, topography and soils) and urbanisation. The assessment of relative risk of degraded water quality to the GBR (Brodie et al. 2013b) also identified that risk to the major reef assets, coral reefs and seagrasses differs between the pollutant classes and the source catchments, and varies with the distance of the assets from the river mouths. These studies indicate the substantial geographic variation in risk to the reef at and below sub-catchment level.

This study seeks to identify the opportunities to sharpen the focus of future investment in practice change to reduce anthropogenic pollutant loads to the GBR lagoon by identifying the:

1. relative contribution of each of the 35 sub-catchments flowing to the reef lagoon to pollutant loads (TSS, PP, DIN, PN, and herbicides – PSII)
2. relative contribution of major agricultural industries in each sub-catchment to pollutant loads generated
3. room for improvement in agricultural industries' nutrient, herbicide and sediment management practices
4. management practices expected to deliver the biggest load reductions.

Chapter 2

Methods

Multi-Criteria Analysis Shell for Spatial Decision Support analysis

For this study, we chose the Multi-Criteria Analysis Shell for Spatial Decision Support (MCAS–S) approach (ABARES 2011) to draw the lines of evidence from water quality monitoring and modelling, research and practice change monitoring together in a transparent way. It also enables input from Reef stakeholders including governments, industry, the science community and regional natural resource management (NRM) bodies, as well as exploration of the data inputs and potential solutions.

Reef stakeholders had previously contributed to a Multiple Criteria Analysis (MCA) (Hajkowicz 2007, Bureau of Rural Sciences 2010) undertaken to advise on the allocation of Reef Rescue funding for years two to five of the program. This process informed allocation of Reef Rescue funds to regions in 2008. The MCA process and its results were well received. It facilitated the sharing of up-to-date information, and structured interactions between Reef Rescue implementers, scientists and stakeholders (Cotsell et al. 2009). The main result of the MCA work was to increase the priority given to the management of extensive grazing lands, in recognition of the extremely large pollutant loads delivered from the Burdekin and Fitzroy sub-catchments during periodic flood events (Cotsell et al. 2009).

As part of the current analysis, an MCA spreadsheet was prepared for each region to enable them to use initial results of the analysis for prioritising on-ground investment in 2013–14, and to familiarise them with the MCA process and the data for the estimated total and anthropogenic water quality loads, land use and the areas in different management practice classes (the ABCD frameworks) for sub-catchments available from the Paddock to Reef program.

MCAS–S is a spatial decision support software tool developed by ABARES (ABARES 2011). It is available free from daff.gov.au/abares/data/MCAS–S. This software facilitates spatial multi-criteria analysis – a process designed to improve decision-making by organising factual information, opinion, and policy and management goals in a transparent and logical framework. MCAS–S is particularly useful in participatory processes. MCAS–S enables users to view and classify map layers, and adapt and combine map layers to provide insight into key relationships and questions. Stakeholders can see the potential impact of decisions, look at alternatives using live-update mapping options, and produce statistical reports for areas of interest quickly and simply. MCAS–S has been used to inform the design of risk-based general surveillance systems for animal disease in Australia (East et al. 2013), decision making by the Murray Darling Basin Authority (ABARE–BRS 2010), examining trade-offs between agriculture, energy production, and biodiversity conservation (Hill and Olsen 2013) and assessing the risks of degraded water quality to GBR ecosystems (Brodie et al. 2013b).

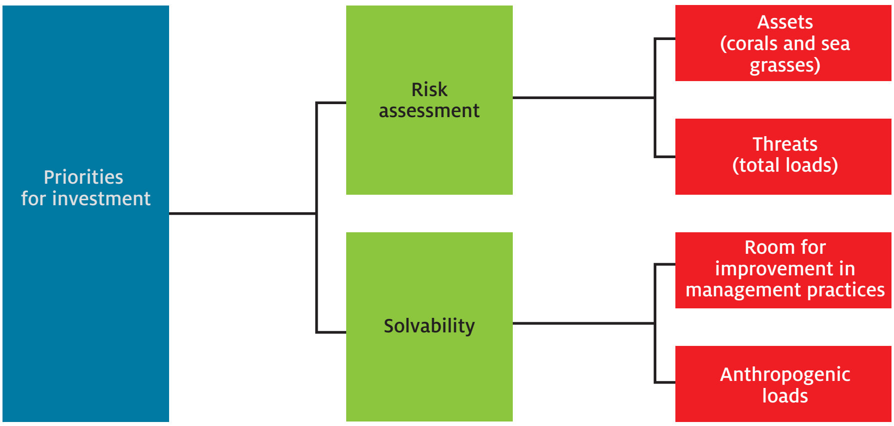
MCAS–S uses raster spatial layers with a common extent and projection, and allows their combination according to user-defined simple algebraic formula (such as addition). Weightings can be assigned to each layer based on expert judgement. There are a number of options (equal interval, equal area, logarithmic or user defined) for classifying the mapped data. The software enables the production of statistical reports such as maximum and minimum values, ranges and counts of grid cells in various ranges. The MCAS–S analysis undertaken for this study only included data sets that were available in a similar format so that comparisons between the 35 GBR sub-catchments examined could be made.

MCAS–S analysis for the Reef Water Quality Protection Plan 2013

The Reef Plan 2013 MCAS–S analysis follows the 'assets, threats and solvability' model for priority setting (Hajkowicz and McDonald 2006). Figure 2 shows the conceptual diagram or means-to-an-end pathway prepared to help visualise the relationships between policy alternatives (means) and objectives (ends) for this study. The 'solvability' criterion within the ATS model is a proxy measure of the likely cost (Stefan Hajkowicz, pers. comm.). A highly solvable problem may be considered to have lower cost. For example, in this study the area (hectares) of sugar cane land being managed using B, C, and D nutrient management practices (room for improvement) is one of the solvability criteria. This is because there are known actions to reduce nutrient losses from sugar cane land. More room for improvement within the investment region creates an increased likelihood of cost-effective options being identified to reduce marginal nutrient loads to the reef.

Three workshops were held with members of the working group to review the available data and agree on the information describing the assets, threats and solvability components of the MCAS–S analysis, the number of classes, and the class intervals and weightings for each data input.

FIGURE 2 Reef Water Quality Protection Plan 2013 – generalised means-to-an-end



The assets referred to in this study were defined by Brodie et al. (2013b) as the areas (km^2) of coral reef and seagrass meadows within the marine boundaries of each GBR NRM region, and were the key GBR ecosystems they used to assess the relative risk of pollutants to GBR ecosystem health. The pollutants assessed included the TSS, DIN and PSII delivered by the six NRM regions draining to the GBR lagoon, plus chlorophyll a – an indicator of nutrient enrichment in aquatic environments. High chlorophyll concentrations enhance the survival of COTS larvae.

The results of this marine assessment are summarised in Appendix 2 (Brodie et al. 2013b). These are reported at the NRM region level, and thus could not be used in the current MCAS–S analyses which use data at the more detailed 35 sub-catchment scale (see Figures 1a and 1b for locations). As a result, the total (anthropogenic plus pre-development) annual nutrient and sediment loads from each sub-catchment were used as a measure of the threats to coral reef and seagrass meadows. An index for herbicide concentrations was added to represent the herbicide threat to marine assets, and a COTS index to represent additional threats from some sub-catchments due to the likely influence of their DIN loads on the initiation of COTS outbreaks. The end-of-catchment loads for TSS, DIN and herbicides influence the ecologically relevant marine water quality variables of TSS, chlorophyll and herbicide concentrations which pose a risk to the GBR corals and seagrasses (Brodie et al. 2013b).

Solvability (the combination of factors that contribute to a possible solution) is defined as the score for size of the anthropogenic pollutant loads from agricultural lands, plus the score for room for improvement (the area over which land management practices affecting sediment, nutrient and/or herbicide loads could be improved). Sub-catchments with high solvability scores will deliver large pollutant loads to the GBR lagoon, and have large areas over which management practices could be improved.

The hypothesis underlying the Australian Government's Reef Rescue and Reef Programme is that improvements in agricultural land management practices will result in improvements in water quality at the end of the catchments discharging to the GBR lagoon. Seventy-nine per cent – $158 million – of the Australian Government's investment in Reef Rescue (2008-09 to 2013-14), was provided for Water Quality Grants and Partnerships to deliver on the following targets by 2013:

- 10 per cent reduction in anthropogenic sediment and particulate nutrient loads
- 25 per cent reduction in dissolved anthropogenic nutrients and herbicide loads
- 1300 farmers and 650 pastoralists adopting improved management practices.

ABCD management systems frameworks were developed by industry and regional NRM organisations for Reef Rescue to categorise farming practices for the cane, grazing, cropping and horticulture industries according to recognised water quality improvements at paddock scale (Rolfe et al. 2008. Drewry et al. 2008). Detailed definitions for A (cutting-edge practices), B (currently promoted), C (common) and D (unacceptable) classes are available at reefplan.qld.gov.au/measuring-success/methods/management-practices.aspx. The grazing and cane frameworks used for Reef Rescue are shown in Appendices 5 and 6. Management system benchmarks were developed by the Paddock to Reef program through direct surveying of landholders, with surveys designed to align with the management practice frameworks. The benchmarks broadly describe how the landscape is managed (the proportion in an A, B, C, or D system state). As changes in management are identified (for example, through a Reef Rescue incentive grant to a farmer to move from C to B) these are represented in the reporting and modelling as areas moving from one system state to another (e.g. from 'C' management, to 'B' management class).

Under the Paddock to Reef program, sub-catchment scale industry benchmarks for the adoption of improved management practices were established for cane and grazing against regional ABCD management practice frameworks. (See reefplan.qld.gov.au/measuring-success/methods/assets/gbr-report-card-2011-management-practices-methods.pdf). Face-to-face surveys using questions based on key management practices (e.g. stock management, ground cover monitoring, tillage) were conducted by field officers, and sample results extrapolated to establish industry-wide benchmarks. Annual management practice change was tracked through detailed project information on Reef Rescue on-ground water quality improvement projects supplied by regional NRM bodies and other sources of practice change such as accredited and evaluated training undertaken through FarmReady, a Department of Agriculture Program providing training for primary producers to develop strategies to adapt and respond to the impacts of climate change.

The program utilises the values for the input data (red boxes in Figure 2) for each criterion, scoring the data for each sub-catchment; the sub-catchments with the lowest and highest loads (e.g. anthropogenic DIN loads) are scored as zero and one respectively. The remaining sub-catchments are ranked in relation to these smallest and largest contributors. The input data are then classified for mapping; in this study five equal interval classes are used. For interpretation purposes these classes are labelled as very low, low, medium, high and very high. Each sub-catchment's score is added to provide a combined score.

In the example shown in Appendix 3, the input layers for C and D sediment management practices in the grazing industry are added to produce a combined room for improvement score (shown in the histogram) for each sub-catchment. The room for improvement scores are then classified into 5 classes to produce the room for improvement map. Scores for each of the anthropogenic loads are prepared in the same way, and added to produce a combined anthropogenic load score for each sub-catchment. Combining (adding) the room for improvement scores and the anthropogenic loads scores produces a solvability score for each sub-catchment. Adding sub-catchments' risk assessment and solvability scores produces an overall priority score for investment in each sub-catchment. The results are presented as a series of maps (e.g. Figure 9).

The costs per unit of pollutant reduction across different industries and sub-catchments would be useful information to include in any future prioritisation process. The approximate cost per unit of modelled pollutant load reduction reported in the Reef Plan Second Report Card (State of Queensland 2010) for each NRM region was estimated using the costs of cane and grazing projects delivered under Reef Rescue.

The estimated abatement cost per tonne of sediment from grazing varied between $42 and $2600. Similarly the estimated cost of DIN abatement for cane varied from $22,000 to $117,000 per tonne across regions. The estimated cost of herbicide abatement for cane ranged from $2000 to $5900 per kilogram of active ingredient across regions (Kevin Gale, Department of Environment, pers. comm.). These differences were much larger than expected, and it was decided not to include this information in the MCAS–S analysis.

A number of factors may contribute to significant differences in abatement costs between regions, including average farm size, production differences (e.g. rain-fed v. irrigated cane, rangelands v. coastal grazing), climate, soil type and topography. However, further investigation also revealed differences that may be the source of significant errors in estimates of costs of practice change and associated pollutant abatement between regions, including:

- Large differences in the pollution reduction levels attributed to management practice system changes between regions. Regional abatement estimates for system changes were estimated independently by regional industry groups.
- Differences in how the areas of practice change were reported by regional NRM bodies for projects – ranging from whole properties to relatively small project areas within properties. For example, for grazing in some regions, the impact of attendance at accredited training courses was reported and subsequently modelled as practice improvement (e.g. C to B class system change) over entire properties. In other regions, the areas directly affected by much smaller on-ground project activities, such as mechanical treatment of scalds, were reported and modelled.
- Large investments (up to $300,000) by some regions went into foundation projects, such as region-wide GPS base station networks, and improved mill mud distribution systems for which direct water quality outcomes could not be modelled, although these projects may have significant water quality benefits in the long term.

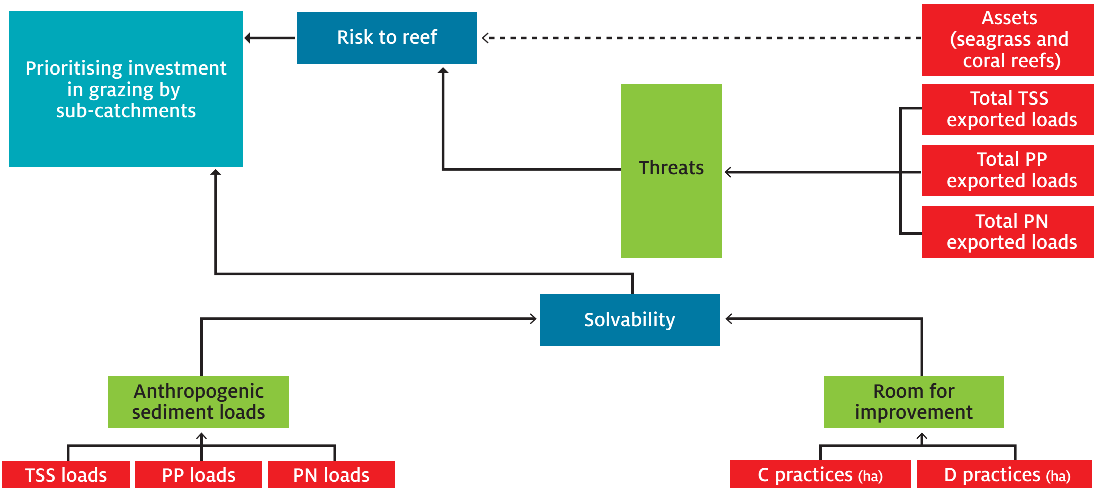
These uncertainties in the reporting of project areas and pollutant abatement costs will be reduced over time as project reporting and modelling systems are improved. In addition, future load reductions will be estimated and modelled for individual practice changes rather than management practice system changes, which should greatly reduce inter-regional differences due to variations in ABCD class management practice frameworks.

A preliminary analysis of the modelled water quality loads data at the regional level, and the results of the assessment of the risk of key pollutants to GBR ecosystems (Brodie et al. 2013b) had been undertaken to provide advice to applicants for Water Quality Grants and Partnerships (Caring for our Country 2013). This work identified that the sugar cane industry made the largest contributions to anthropogenic DIN and herbicides, and that grazing made the largest contribution to TSS loads. Applicants were asked to give priority to funding for improvements in the cane and grazing industries in their applications. Data were also available for the cane and grazing industries on the extent of change in management practices resulting from investment. It was agreed to focus the MCAS–S analysis on these industries, with a view to including the other industries when sufficient information on their management practices and pollution generation rates is available.

Grazing industry analysis

Figure 3 shows the means-to-an-end diagram developed by the working group for grazing. The marine assets are the coral reefs and seagrass beds as described in Brodie et al. (2013). Note that data for these assets are not entered into the MCAS–S analysis but are used to define the threats. The threats to these assets are represented as the total (pre-development and anthropogenic) TSS, PP and PN loads from each sub-catchment. PP and PN loads were not included in the Brodie et al. risk assessment but are incorporated here due to increasing concerns about the possible role of phosphorus as an influence on reef health, and the bioavailability of particulate nutrients in the marine environment.

FIGURE 3 Grazing means-to-an-end diagram



Solvability scores are calculated by adding the scores for each sub-catchment's anthropogenic loads for TSS, PN and PP from grazed land, plus the sub-catchment's scores for room for improvement in grazing land management practices (descriptions in Appendix 5, data in Appendix 7a).

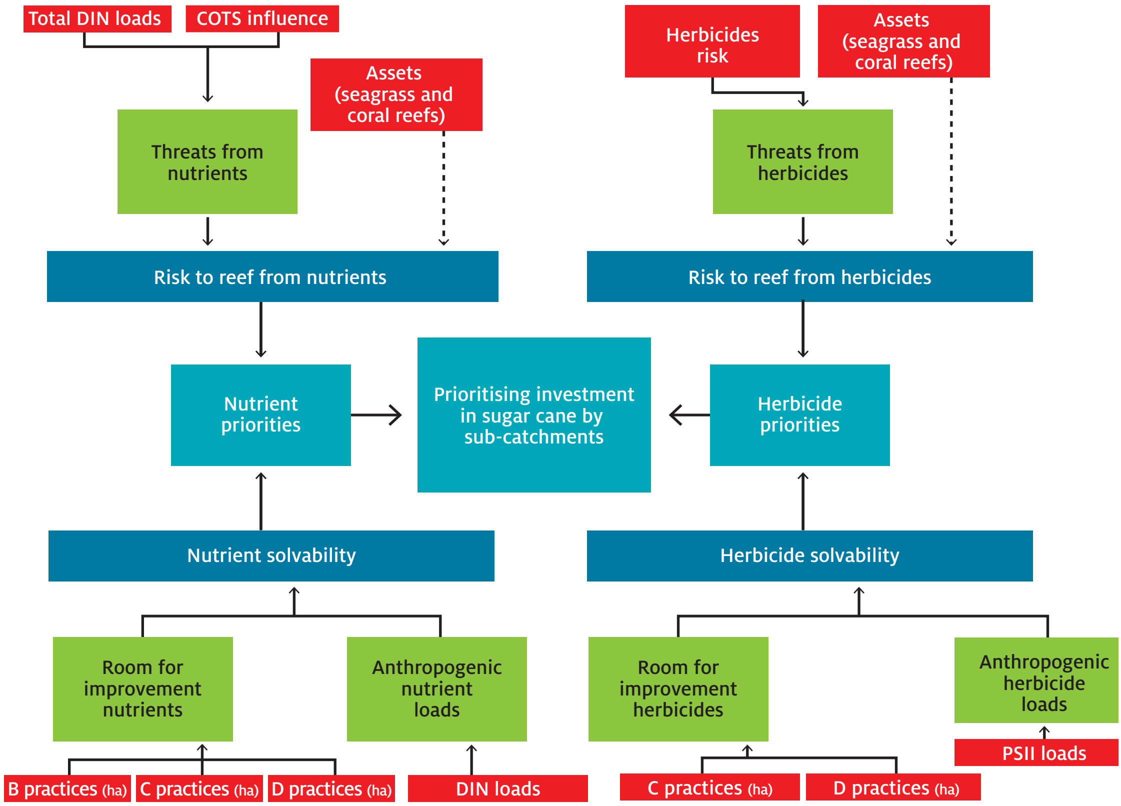
Cane industry analysis

Figure 4 shows the means-to-an-end diagram for sugar cane. The marine assets are the coral reefs and seagrass beds as described in Brodie et al. (2013b). Again the data for these assets are not entered into the MCAS–S analyses but are used to define the threats. The nutrient threats to these are represented as the total (pre-development and anthropogenic) DIN loads, plus a COTS index of the relative differences between sub-catchment discharges to the COTS initiation zone (Furnas et al. 2013a). This zone is the area of the GBR lagoon between latitude 14.5°S (Cairns) and 17°S (Lizard Island) where primary COTS outbreaks have been observed. COTS outbreaks are a major cause of coral loss (De'Ath et al. 2012) and appear to be a response to excess nutrient runoff from certain catchments that impact this initiation zone.

Nutrient solvability for the cane industry is defined as the scores for room for improvement in nutrient management practices plus the scores for anthropogenic DIN loads in each sub-catchment. The room for improvement in each sub-catchment is the modelled area of cane grown using B, C or D nutrient management practices (see Appendix 6 for descriptions). B class practices (currently promoted practices, often referred to as 'Best Management Practices'), were included in the room for improvement because recent work has suggested that the adoption of these B class practices may not result in the reduced nitrogen application rates needed for DIN load reduction (State of Queensland 2013a).

The herbicide threats are the annual mean concentrations for herbicides delivered to the GBR lagoon by each sub-catchment. The figures are derived from Lewis et al. (2011) and prepared by Stephen Lewis, James Cook University). Herbicide solvability is the scores for room for improvement in herbicide management practices (C and D class practices, Appendix 7b) plus the scores for herbicide loads. The working group decided not to include sediment loads in the sugar cane analysis because TSS loads from sugar for most sub-catchments are a minor risk to the reef and sediment losses are reduced through improved nutrient management practices.

FIGURE 4 Sugar cane means-to-an-end diagram



MCAS–S data inputs

Modelled water quality data

Modelled water quality results for the Reef Report Card 2010 (State of Queensland 2012), including the average annual (1986–2009) modelled anthropogenic and total (pre-development plus anthropogenic) loads and loads per hectare for each sub-catchment, were supplied by the Paddock to Reef program (Carroll et al. 2012). This program uses the eWater Cooperative Research Centre (2010) Source catchments modelling framework to generate estimates for sediment, nutrient and herbicide loads entering the Great Barrier Reef lagoon from the 35 major Reef sub-catchments. SedNet modelling functionality has been incorporated in the Source catchments modelling to include estimates of sediments and particulate nutrients being delivered through gully and stream bank erosion.

The model is run for each scenario using a fixed climate period (1986–2009) to remove the effects of climate variability to estimate the annual average pre-development (100 per cent native vegetation) and baseline (2009 land use and land management) pollutant loads. Changes in land management (e.g. ground cover) relative to the baseline year are then modelled for the same long-term climate signal to produce the long-term annual average load reductions by NRM region for each pollutant. Land use changes are not modelled, as these are not detectable over the short timeframes of the reporting period. Delays between improved land management practice and attainment of improved land condition are not considered – load reductions are modelled for the expected final state of the land condition.

Whilst subject to significant uncertainty, regional and sub-catchment pollutant load estimates are validated through comparison with monitored loads where available. The Great Barrier Reef Catchment Loads Monitoring Program monitors TSS, nutrients (nitrogen and phosphorus) and herbicides as part of the Paddock to Reef program. TSS and nutrients are monitored at 25 sites covering 11 high priority catchments and 14 sub-catchments. Herbicides are monitored at 11 sites in nine high priority catchments and two sub-catchments. Samples are collected on a monthly basis during ambient (low flow, dry season) conditions and every few hours to daily during high flow events in the wet season. The concentrations of contaminants are determined, and the volume of water flowing in the rivers is then used to estimate the total amount of each contaminant (i.e. the load) that flows past the sampling sites. The loads for all measured contaminants are released in an annual technical report. (See reefplan.qld.gov.au/measuring-success/paddock-to-reef/catchment-loads-monitoring.aspx.)

Modelling load reductions

Regional and catchment load reductions arising from improved land management practices in cane and grazing are modelled based on plot and paddock scale monitoring and modelling, and rainfall simulation experiments (Shaw et al. 2013). Information and methods used for monitoring and modelling are continuously improved, with the aim of decreasing uncertainties and increasing the range of industries and practices that may be modelled. Current model predictions of load reductions arising from the adoption of improved management practices are considered conservative.

A range of models were used to generate the daily pollutant loads for current and improved practices for Source catchments. For cane, APSIM (Thorburn et al. 2007) was used to model crop growth and DIN losses, with 'Howleaky?' used to model phosphorus and herbicides. 'Howleaky?' was used to model grains cropping (Rattray et al. 2004). The Revised Universal Soil Loss Equation (Renard et al. 1997) was used to model sediment loss from grazing lands with management effects on cover modelled using GRASP (Grass Production Model) (McKeon et al., 2000). Pollutant loads were generated using typical scenarios of A, B, C and D management practices which were defined through expert opinion in each region. The relative improvements in water quality outputs between the levels of management change (e.g. C to B) are therefore not equivalent across regions.

The modelling framework enables the synthesis of management practice, paddock monitoring and modelling, and catchment monitoring and modelling data. The modelled output is used to report end of catchment pollutant loads for each of the 35 major sub-catchments flowing to the GBR lagoon for a baseline year, and changes relative to the baseline year for each subsequent year of reported changes in management practices.

GBR sub-catchments range in size from the Mossman (48,000 hectares) to the Fitzroy (14,250,000 hectares). The larger of these sub-catchments, the Burdekin and the Fitzroy, contain a wide range of climates, soil types, underlying geologies and vegetation types. As a result, significant spatial heterogeneity in soil erosion rates is expected. Understanding these differences is important for prioritising investment and management options. Pollutant loads data for management units (so called to distinguish them from the sub-catchments which flow into the GBR lagoon) – the Belyando, Bowen Bogie, Cape Campaspe, East Burdekin, Upper Burdekin and Suttor in the Burdekin sub-catchment, and the Comet, Dawson, Fitzroy, Isaac, Mackenzie, Nogoa and Theresa Creek in the Fitzroy sub-catchment – were supplied from the Paddock to Reef program to investigate differences in soil loss at this scale.

Water quality data used in the MCAS–S analysis

Data for sediments (TSS), dissolved inorganic nitrogen (DIN) and herbicides (PSII) were chosen for the MCAS–S analysis from the suite of pollutants modelled because they had been identified as posing the greatest ecological risk to the GBR corals and seagrasses by Brodie et al. (2013). (Ecological risk in the GBR is defined by Brodie et al. 2013 as the area of coral reefs and sea grass meadows within a range of assessment classes – from very low to very high relative risk – for several water quality variables in each NRM region). Particulate nitrogen (PN) and phosphorus (PP) were also included due to concerns that these pollutants may be more readily bioavailable (available for uptake by living organisms) than previously thought, and could have significant impacts on reef corals and seagrasses.

Spreadsheets containing the modelled water quality loads for pre-development and 2008–09 scenarios were provided for the sub-catchments in each NRM region by the Paddock to Reef program to use in the MCAS–S analysis. The DIN, PP, PN, TSS and PSII herbicide data (atrazine, diuron, hexazinone and tebuthiuron) were extracted from the five spreadsheets. Anthropogenic loads for each land use were calculated by subtracting the pre-development loads from the 2008–09 loads; if the calculated anthropogenic loads were negative, these were set to zero. Anthropogenic loads were then divided by the area for each land use to calculate loads per hectare. The 14 land use classes were aggregated into seven land uses (bananas, dairy, grains, grazing, horticulture, sugar cane and other uses).

Other data supplied by Paddock to Reef included:

- total loads to the GBR lagoon, which uses the 2008–09 scenario data for all land uses,
- room for improvement data, which uses the area (hectares) under C and D practices in the grazing and B, C and D practices in the sugar cane industries, (Appendices 7a and 7b respectively).

The crown of thorns starfish index

COTS outbreaks are an important cause of coral loss on the GBR and appear to be a response to excess nutrient runoff from certain catchments that impact this COTS initiation zone. In recognition of the importance of the influence of catchment discharges in driving COTS outbreaks, an index of regional contributions of river discharges to the COTS initiation zone has been included. The COTS index (Furnas et al. 2013a) (Table 2) is based on the relative freshwater volumetric contributions of individual rivers to the COTS outbreak initiation zone between Cairns (17°S) and Lizard Island (14.5°S) and sub-regions north and south of Undine Reef (16°S) from 1 (lowest) to 8 (highest).

TABLE 2 The crown of thorns starfish (COTS) index for Great Barrier Reef sub-catchments (after Furnas et al. 2013a). # Re-ranking to provide scores for the MCAS–S analysis (which is programmed to identify larger numbers with increased risk) is based on magnitude of contribution, from 1 (lowest) to 8 (highest).

	Freshwater Exposure Index normalised against the Daintree			Ranking	
River	Total	Northern	Southern	Total	MCAS–S ranking#
Normanby	0	0	0	8	1
Daintree	100	45	55	1	8
Barron	52	1	51	4	5
Russell-Mulgrave	59	18	41	2	7
Johnstone	29	7	22	6	3
Tully	57	16	41	3	6
Herbert	7	1	6	7	2
Burdekin	49	4	45	5	4

These contributions were normalized against the Daintree River, the largest river discharging directly into the outbreak initiation region. The flow based rankings were used rather than those based on DIN loads, to avoid double counting the DIN loads which are used to estimate the risk to reef from nutrients. Re-ranking to provide scores for the MCAS–S analysis (which is programmed to identify larger numbers with increased risk) is based on magnitude of contribution, from 1 (lowest) to 8 (highest).

Calculation of herbicide concentrations

To avoid double counting of the modelled herbicide loads, herbicide concentrations were calculated and used to represent the threat to seagrass and coral reefs posed by these pollutants coming from sub-catchments. Herbicide concentrations are also a better way representing toxicity. The PSII inhibitor 'toxic loads' were calculated (Appendix 9) using a three-step process comprising (1) the calculation of herbicide load data for diuron, atrazine, hexazinone, ametryn and tebuthiuron for the individual sub-catchments of the GBR (see Lewis et al. 2011); (2) the conversion of these data to a combined 'toxic' PSII load and; (3) the calculation of an annual mean concentration for the individual sub-catchments of the GBR.

The calculation of the herbicide load data involved reanalysis of the Lewis et al. (2011) model to include the monitored load data from the 2010–11 water year, from Turner et al. (2013). A combination of monitored load data and land use data were used to model herbicide loads across sub-catchments using the approach outlined in Lewis et al. (2011). The load data for the individual herbicides were then converted to a toxic PSII inhibitor load, using the ecotoxicological EC_{50} data from Flores et al. (2013), for diuron, atrazine, hexazinone and tebuthiuron. The relative toxicity of ametryn was taken from Kennedy et al. (2010), which provides a summary of several previous studies.

The data were normalised relative to the toxicity of the herbicide diuron, and so the PSII inhibitor load represents a 'diuron equivalent' load (Table 3). Hence the PSII inhibitor loads represent a normalised toxicity for each of the herbicides, recognising that some have greater PSII inhibition potential. The calculation of PSII equivalence has previously been used in the GBR in the Paddock to Reef program (e.g. Kennedy et al. 2012, Smith et al. 2012). Finally, the sub-catchments' 'toxic loads' were divided by their respective mean annual flows to calculate an annual mean concentration. Since the toxicity of herbicides is related to concentration rather than load, this step is designed to help account for the influence of dilution on the herbicide toxicity between the different basins.

To prepare the data for use in MCAS–S, the resulting spreadsheets were joined to the sub-catchment boundaries' shape file and rasterised to produce the primary data layers. Each data input was displayed as a map. Scaling for the classes to be represented on the map and weightings for each input were discussed by the Working Group. Appendix 8 contains the list of data layers used in the study and the scaling and weights applied to each layer. The Working Group agreed to weight the cane nutrients room for improvement scores (C was multiplied by 2 and D by 3) to reflect the increase in effort and cost needed to move from C or D practices to B practices. Similarly with herbicide room for improvement, D was multiplied by 2 to reflect the significantly larger water quality benefit of moving from D to C class herbicide management practices.

TABLE 3 Normalised PSII inhibitor values used to calculate PSII herbicide equivalent loads

Herbicide	Mean EC_{50} across GBR-relevant species	Normalised PSII value	Reference
Diuron	5.2	1	Flores et al. (2013)
Atrazine	54	0.1	Flores et al. (2013)
Hexazinone	23	0.23	Flores et al. (2013)
Tebuthiuron	67	0.08	Flores et al. (2013)
Ametryn	4.7	1.11	Kennedy et al. (2010)

Land management practices

For the MCAS–S analysis, 2010–11 areas (hectares) under each of the ABCD systems for sediment management in the grazing industry and nutrient and herbicide management in the cane industry were supplied for each sub-catchment by the Paddock to Reef program.

Management system benchmarks for grazing developed by the Paddock to Reef program provide an estimate of the amount of land managed with the A, B, C and D management practices shown in Appendix 5. Grazing industry benchmarks had been developed through representative sampling of graziers in each catchment; these were weighted to reflect the potential impact of the management practices on water quality. The output used in the water quality modelling is a metric that attempts to approximate the likely impact of management on land condition, runoff and soil loss. The scores for room for improvement in practices were calculated for the grazing industry by adding together the area (hectares) under C and D class practices for each sub-catchment – i.e. the areas that could be available for adoption of B class practices. Future funding will be used to encourage pastoralists using C or D practices to adopt B grazing management practices.

For the cane industry, scores for room for improvement in nutrient management were calculated by summing the areas under B, C and D nutrient management practices, recognising that funding from the Reef Programme will focus on encouraging the adoption of revised practices for nutrient management. Recent work has shown that the B class practices for nutrient management shown in Appendix 6 may not deliver the DIN reductions needed to meet current Reef Plan targets (State of Queensland 2013a), and revised B class practices for nutrient management, which focus on matching nitrogen inputs to block or within block zone, have been developed for the cane industry.

Scores for room for improvement in herbicide management were estimated for each sub-catchment by summing the areas under C and D herbicide management practices. Management system benchmarks for sugar cane had been developed by the Paddock to Reef program following an industry-wide survey utilising a common suite of key indicator questions. Responses to these questions were analysed to develop a metric (A, B, C or D class) which attempts to approximate the impacts of management on the potential loss of sediment, nutrients, and herbicides from sugar cane farming systems.

The data on land management practice change provided to the Paddock to Reef program was not spatially explicit; areas subject to management change were described at the sub-catchment level rather than for the land parcels where the investments took place. The potentially large benefit of spatial targeting for maximum return on investment may be diluted by this approach.

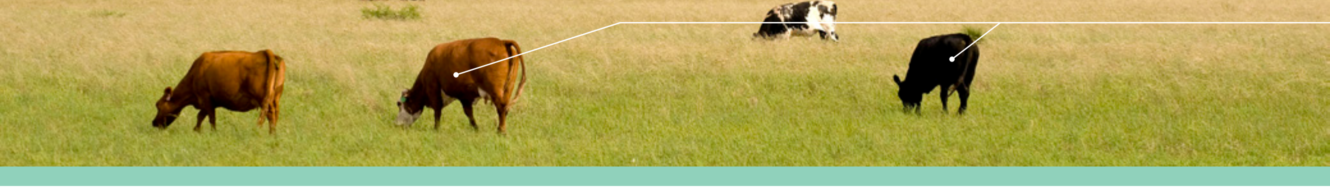
Multi Criteria Analysis spreadsheets for NRM regions

In addition to preparing the Paddock to Reef water quality and land management practices data for use in MCAS–S, an Excel spreadsheet-based Multi – Criteria Analysis, was prepared for each of the six regional NRM bodies. These spreadsheets included:

- the average annual modelled total loads (anthropogenic plus pre-development) for the 1986–2009 climate period for sub-catchments used to characterise the threats to the coral and seagrass assets in the MCAS–S analysis
- the average annual modelled anthropogenic loads and loads per hectare (1986–2009 climate period) for sub-catchments for the banana, grains, grazing, horticulture and sugar cane industries and other uses – the anthropogenic loads used as input to solvability in the MCAS–S analysis
- the room for improvement in management practices in the sugar cane and grazing industries, also used as an input to solvability
- data from the Australian Bureau of Statistics agricultural census for 2010–11 showing the numbers of agricultural businesses in the banana, dairy, grains, grazing, horticulture and sugar cane industries and the areas (hectares) used by these industries to help characterise each sub-catchment.

The spreadsheets provided regional NRM bodies with access to the above data and the capacity to use the Multi – Criteria Analysis to compare data for sub-catchments within their region. The spreadsheet also included tools to adjust the weightings given to data sets, exclude data sets or add local data sets (such as information on the extent of gullying) to the analysis. These changes automatically updated the scores assigned to criteria, the overall scores and the spider diagram and bar charts used to display the results.

Presentations demonstrating the use of the MCA spreadsheet were made at four well attended regional science forums sponsored by the Australian Government Reef Programme to assist regional NRM bodies with their investment prioritisation in late 2013. Support was provided to regional staff interested in using the MCA tool in their prioritisation processes.



Chapter 3

Investment priorities for sub-catchments

Agricultural industry contributions to sub-catchment anthropogenic loads

Results showing the average annual modelled loads (1986–2009 climate period) for the 35 GBR sub-catchments for the banana, dairy, grains, grazing, horticulture and sugar cane industries and other land uses (comprising conservation, forestry and urban) are presented in Figures 16 to 20, Appendix 10. The loads per hectare data are shown in Figures 21 to 25, Appendix 11. The pollutants reported are sediments (TSS), dissolved inorganic nitrogen (DIN), particulate phosphorus (PP), particulate nitrogen (PN) and herbicides (PSII). Modelled loads reported in this section are based on Reef Plan Second Report Card results, as industry contributions to the report card were the only data available at the time of writing. In summary, land used for cropping, dairy, grazing, horticulture (including bananas) and sugar cane contributes an estimated 55, 69 and 66 per cent respectively to the estimated anthropogenic loads of TSS, PN and PP, plus an estimated 87 per cent of the anthropogenic DIN and 100 per cent of the PSII delivered to the GBR lagoon.

Figure 5 shows the estimated sources of anthropogenic TSS, PN and PP loads for the GBR catchment by land use. TSS loads were estimated to come predominantly from hillslope and gully erosion in grazing lands (45 per cent), followed by stream bank erosion (39 per cent), cane lands (6 per cent) and land cropped for grains (3 per cent). Non-agricultural land uses, including conservation, forestry and urban land, which occupy 13, 5 and less than 1 per cent of the GBR catchment respectively, contribute 3, 1 and 1 per cent to the GBR's annual average anthropogenic load of TSS. While most of the PP and PN comes from hillslope and gully erosion in grazing land (43 and 45 per cent respectively), stream bank erosion contributes 28 and 21 per cent of the PP and PN respectively. Cane lands contribute 18 per cent to the annual average anthropogenic PP and 18 per cent to PN loads delivered to the GBR lagoon. The contributions from lands cropped for grain are 4 per cent (PP) and 3 per cent (PN).

Figure 6 shows the predicted sources of DIN and PSII loads for the GBR catchment. The largest contributions of DIN to anthropogenic loads come from sugar cane (56 per cent), followed by grazing (21 per cent) and grains (3 per cent). Most of the herbicides come from cane lands (94 per cent), with small contributions from land cropped for grains (4 per cent) and grazed lands, predominantly in the Fitzroy sub-catchment (2 per cent).

Grazing industry contributions to anthropogenic loads

The grazing industry, which occupies 75 per cent of the area of the GBR catchments, contributes around 45 per cent of the average annual anthropogenic loads of TSS, and 43 and 45 per cent of the PP and PN respectively (Figure 6) delivered to the GBR lagoon from hillslope and gully erosion. Much of the total anthropogenic TSS, PP and PN exported to the GBR from grazing lands comes from the Burdekin (50, 45 and 46 per cent respectively) and Fitzroy (30, 25 and 15 per cent respectively) NRM regions. Within the Burdekin NRM region, the Burdekin sub-catchment is the largest contributor from grazing lands, with 85 per cent of the TSS, 85 per cent of the PP and 83 per cent of the PN loads.

FIGURE 5 Percentage contributions from hillslope and gully erosion by land uses to GBR predicted annual anthropogenic TSS, PP and PN loads

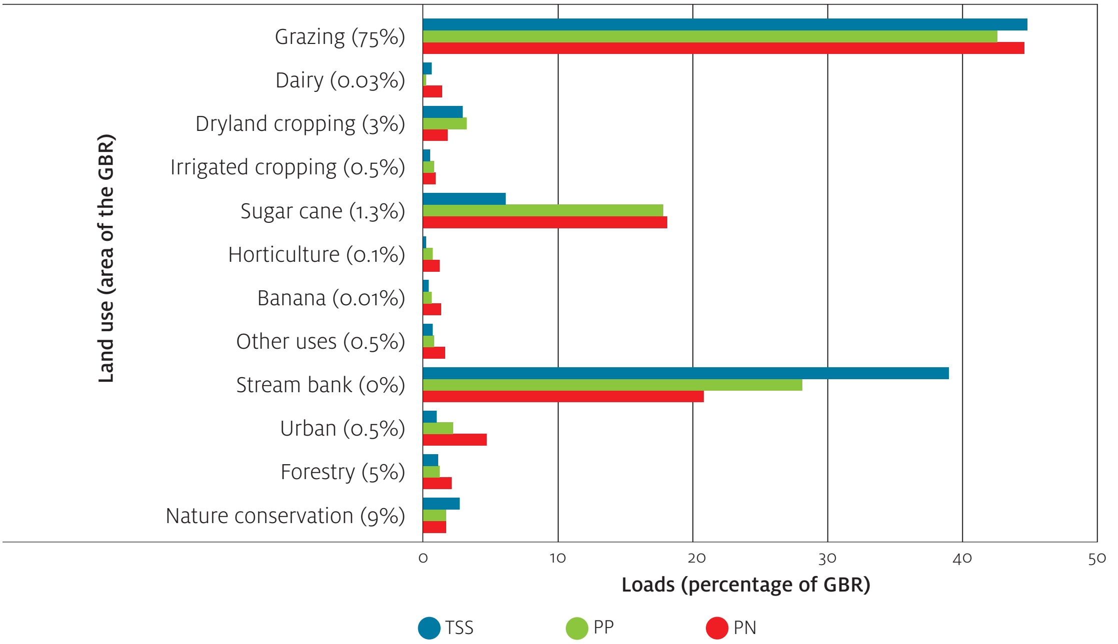
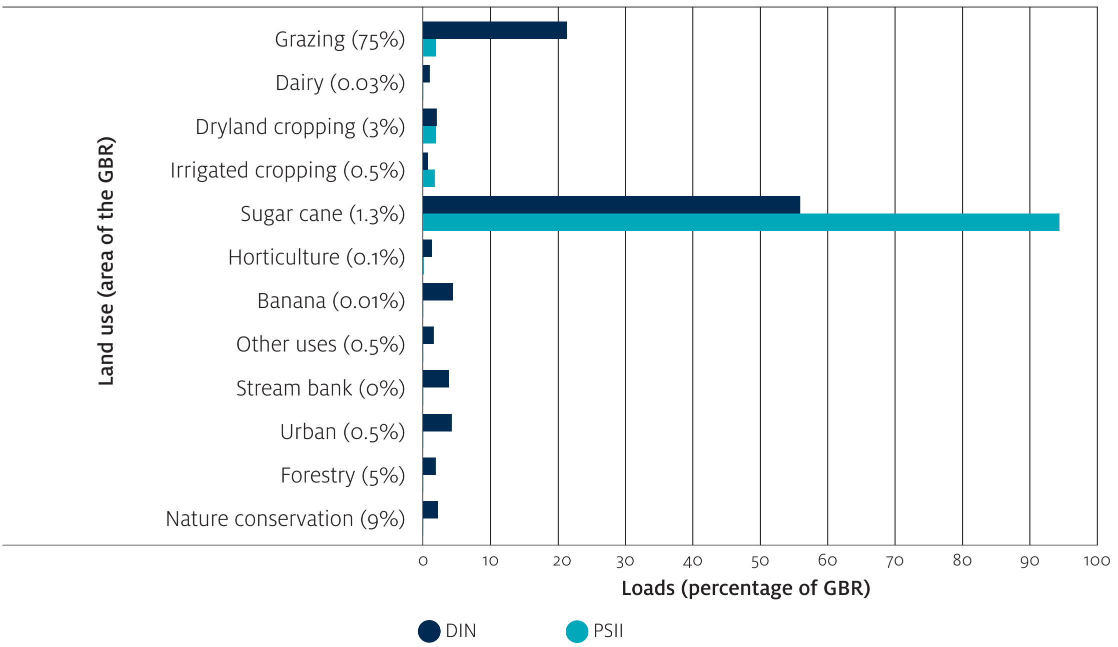


FIGURE 6 Percentage contributions by land uses to GBR predicted annual anthropogenic DIN and PSII herbicide loads



Within the Fitzroy NRM region, the biggest anthropogenic load contributions from hillslope and gully erosion in grazing lands come from the Fitzroy sub-catchment (90, 90 and 88 per cent of the TSS, PP and PN loads respectively). The grazing industry also makes a significant contribution to the GBR catchment's DIN load; 22 per cent came from grazing. Grazing in the Burdekin and Fitzroy sub-catchments contributed 50 and 35 per cent respectively to this DIN load.

Stream bank erosion losses in the current model cannot be attributed to specific land uses. However, given the extent of grazing in the GBR catchment, it is likely that substantial components of the modelled TSS, PP and PN loads from stream bank erosion (39, 28 and 21 per cent respectively) come from land managed for grazing.

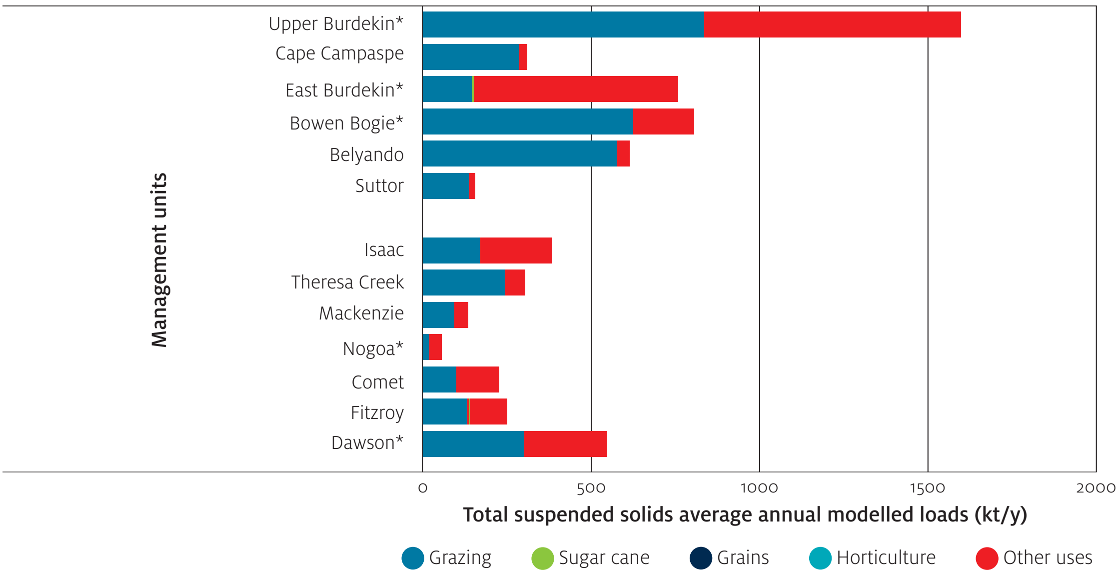
To examine the geographic variability in soil loss across the Burdekin and Fitzroy sub-catchments and the potential for better spatial targeting of investment, TSS data for end-of-system loads produced by the Paddock to Reef program were examined for management units (smaller catchment areas within the Burdekin and Fitzroy). The high variability shown in Figure 7 reflects the combination of catchment size and soil properties. For example, the TSS loads generated from grazing land range from 19 tonnes/year in the Nogoa (Fitzroy sub-catchment) to 835 tonnes/year in the Upper Burdekin (Burdekin sub-catchment). The tonnes/hectare/year generated from grazing land is also quite variable, ranging from 0.01 tonnes/hectare/year in the Nogoa, to nearly 0.6 tonnes/hectare/year in the Bowen Bogie (Figure 8). It should be noted that the loads presented for these management units represent loads generated from within the specific management unit only, and not those that necessarily contributed to the end-of-sub-catchment load. These load generation data account for sediment trapping from major dams within management units but cannot be directly compared with loads exported to the GBR lagoon. They should be used as a guide to the relative amounts of sediment generated in each management unit.

Terrestrial cosmogenic nuclide studies are a method of estimating natural background rates of erosion. Recent work in the Burdekin NRM region sub-catchments has further demonstrated the geographic variability in soil loss. This research (Croke et al. in review) has suggested that the Bowen (part of the Bowen Bogie management unit) and the Upper Burdekin and Suttor management units had high erosion rates prior to agricultural development (due to geology, slope and rainfall) and, with the introduction of agriculture, are delivering substantially more sediment. Croke et al. suggest that there is a much greater chance of reducing sediment yields delivered to the GBR if priority is given to investing in these areas.

Sugar cane industry contributions to anthropogenic loads

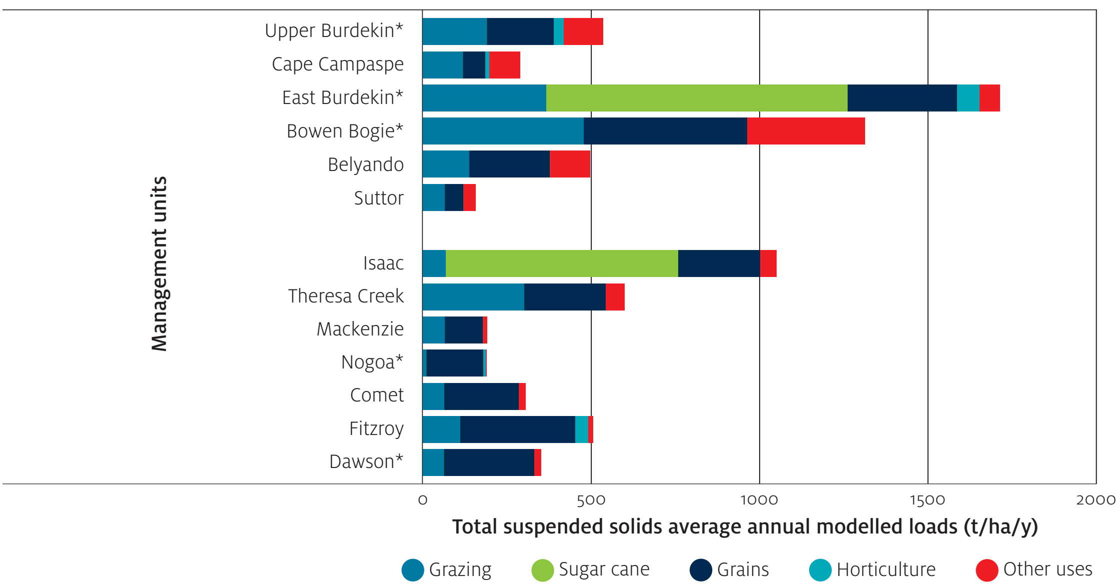
The cane industry, which occupies 1.3 per cent of the area of the GBR catchments, contributes an estimated 6, 18 and 18 per cent of the average annual anthropogenic loads of TSS, PP and PN delivered to the GBR lagoon (Figure 5). It also contributes an estimated 56 per cent of the anthropogenic DIN load and 94 per cent of the herbicides (Figure 6). The largest DIN contributions from cane growing come from the Wet Tropics (50 per cent) and Burdekin (21 per cent) NRM regions. The Mackay Whitsunday and Burnett Mary regions contribute 16 and 12 per cent respectively. At the sub-catchment level, the largest contributors to total GBR DIN load from cane areas are the Johnstone (23 per cent), followed by the Haughton (14 per cent), the Herbert (10 per cent) and the Tully (8 per cent). At the sub-catchment level, the largest contributors to PSII load from cane areas are the Herbert (17 per cent), Johnstone (15 per cent), Mulgrave-Russell (11 per cent), Tully (11 per cent) and Haughton (9 per cent) sub-catchments.

FIGURE 7 Total suspended solids loads by land use (kilotonnes/year) generated from the management units within the Burdekin and Fitzroy sub-catchments



* = management units with instream dams
Note: Other uses includes contributions from stream bank erosion, nature conservation, forestry and urban land uses.

FIGURE 8 Total suspended solids loads by land use (tonnes/hectare/year) generated from the management units within the Burdekin and Fitzroy sub-catchments

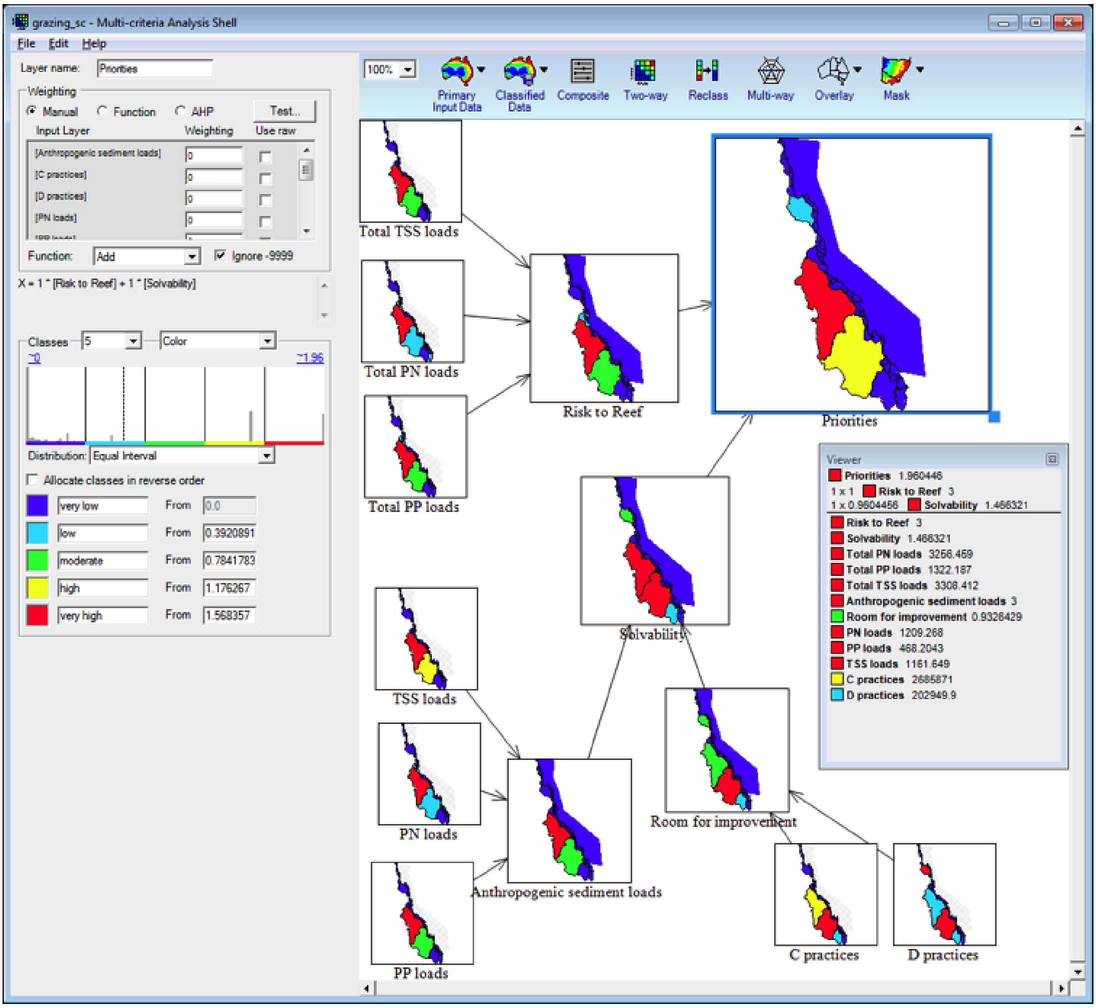


* = management units with instream dams
Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land uses.

MCAS–S results – grazing industry

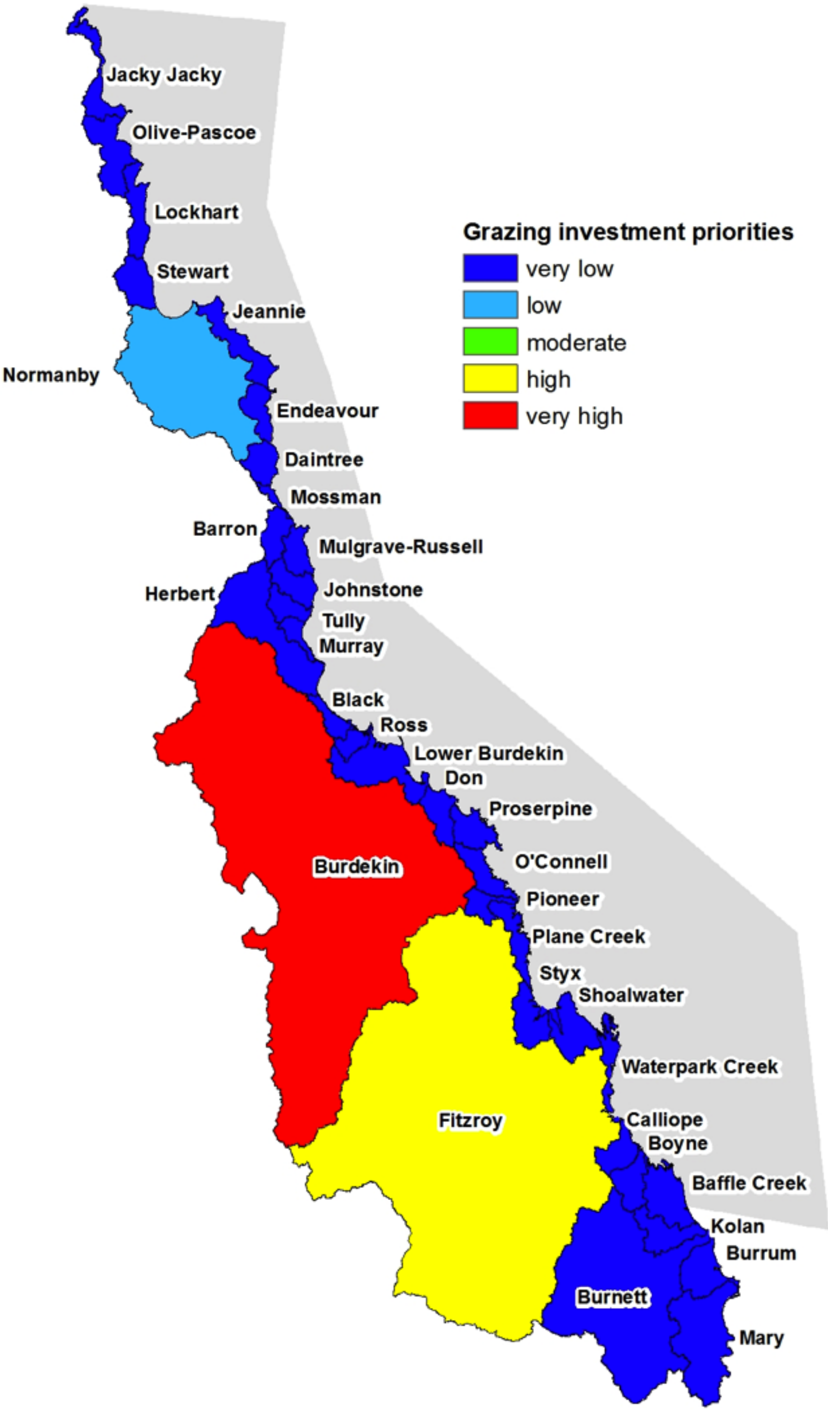
Figure 9 is an overview of the MCAS–S results for grazing, displaying the classified scores for each data set for each sub-catchment, and how these scores are combined to identify priorities for investment at sub-catchment level. To simplify comparisons, these classes have been labelled very low, low, moderate, high and very high in terms of their priority for investment.

FIGURE 9 Grazing MCAS–S results overview



The results of the grazing analysis are shown in Figure 10. The Burdekin sub-catchment is identified as a very high priority for investment in improving grazing management. Figure 9 shows that the Burdekin sub-catchment's risk to the reef has been classified as very high on the basis of the total loads of TSS, PP and PN delivered to the GBR lagoon. The Burdekin sub-catchment's anthropogenic TSS, PP and PN loads from grazing land (Appendix 10, Figures 16 to 18) are also classified as very high, and the room for improvement (the almost 2.89 million hectares managed under C and D class practices – see Appendix 7a) is moderate.

FIGURE 10 Sub-catchment investment prioritisation for grazing – MCAS–S results



Combining very high anthropogenic loads with moderate room for improvement has resulted in an assessment of very high solvability – that is, there are very high estimated anthropogenic loads coming from grazing land and there is a large area of grazing land – an estimated 22 per cent of the Burdekin sub-catchment – over which management practices could be improved to help reduce this load. Combining very high solvability with very high risk has identified the Burdekin sub-catchment as very high priority for investment in improving grazing management practices.

The Fitzroy sub-catchment's total TSS, PP and PN loads present a moderate risk to the reef. Solvability is rated as very high on the basis of moderate anthropogenic sediment loads and very high room for improvement (a significant area of grazing is operated with C and/or D class practices). Combining moderate risks to the reef from sediment loads and very high solvability has identified the Fitzroy sub-catchment as a high priority for investment in improving grazing management practices. The remaining (principally coastal) sub-catchments are rated as very low priority for investment in improving grazing management practices; they all have very low scores for risk to the reef, anthropogenic sediment loads and room for improvement.

To summarise, the Burdekin and Fitzroy sub-catchments are rated as very high and high priority for investment in improving grazing management by virtue of their large area, very high total and anthropogenic loads and large scope for room for improvement (areas managed using C and D class practices).

MCAS–S results – sugar cane industry: nutrients

The relative priorities between sub-catchments for reducing nutrient inputs from sugar cane are shown in Figure 11. The Johnstone sub-catchment is a very high priority for investment in improving nutrient management practices in the cane industry. Its score for risk to the reef from nutrients (total DIN loads plus COTS influence) is rated as very high. Estimated anthropogenic loads for DIN from cane lands are very high (Appendix 10, Figure 19). Scores for very high anthropogenic loads combined with high room for improvement in nutrient management (an estimated 26,580 hectares – see Appendix 7b – are managed using B, C or D nutrient management practices) produce a high nutrient solvability score. A combination of a high score for solvability and a very high anthropogenic loads score produces a very high priority score for investment in improving nutrient management.

The Burdekin (cane is mainly grown in the East Burdekin), Haughton, Herbert, Mulgrave-Russell and Tully sub-catchments are rated as high priority for investment. They have either very high risk to reef (a combination of estimated total DIN load and COTS influence) or very high solvability, a combination of estimated anthropogenic DIN loads and room for improvement. The Daintree is rated as moderate; it has a very high risk to the reef due to its COTS influence but is rated as very low for all other inputs.

Sub-catchments rated as low priority include the Barron, Fitzroy, Mary, O'Connell, Pioneer and Plane. Risk to the reef was rated as very low for most of these sub-catchments. The 23 remaining GBR sub-catchments were rated as very low priority for investment in improved nutrient management on cane lands. These include the Baffle, Black, Burnett, Burrum, Don, Kolan, Mossman, Murray and Proserpine sub-catchments, which had very low scores for the factors contributing to risk to reef and solvability (except for Burrum, where solvability was rated as low).

There is no sugar grown in the other 14 sub-catchments (see Appendix 4) which rated as very low priority for improving cane nutrient management. The sensitivity of the cane nutrients' priorities results to the COTS influence (for the eight sub-catchments contributing to the COTS index) was tested by rerunning the MCAS–S analysis with the COTS data excluded. Priorities for the Wet Tropics sub-catchments, the Daintree and Mulgrave-Russell, changed significantly, while those for the Pioneer, Plane and Fitzroy increased from low to moderate (Table 4).

In the Burdekin sub-catchment, cane (approximately 5000 hectares – see Appendix 4) is mainly grown in the East Burdekin management unit (the Burdekin Irrigation Area). The Burdekin sub-catchment's nutrient management priority is ranked as high in the MCAS–S analysis because of the very high risk to reef rating. This rating is very high because the total DIN loads (to which grazing makes a significant contribution) for the sub-catchment are large (see Figure 19, Appendix 10) and the COTS influence moderate. End-of-catchment load analysis at the management unit level might result in a lower priority for investment in improving cane nutrient management in the East Burdekin.

TABLE 4 Sensitivity of sub-catchment priorities for investing in improved nutrient management in sugar cane to the crown of thorns starfish influence index

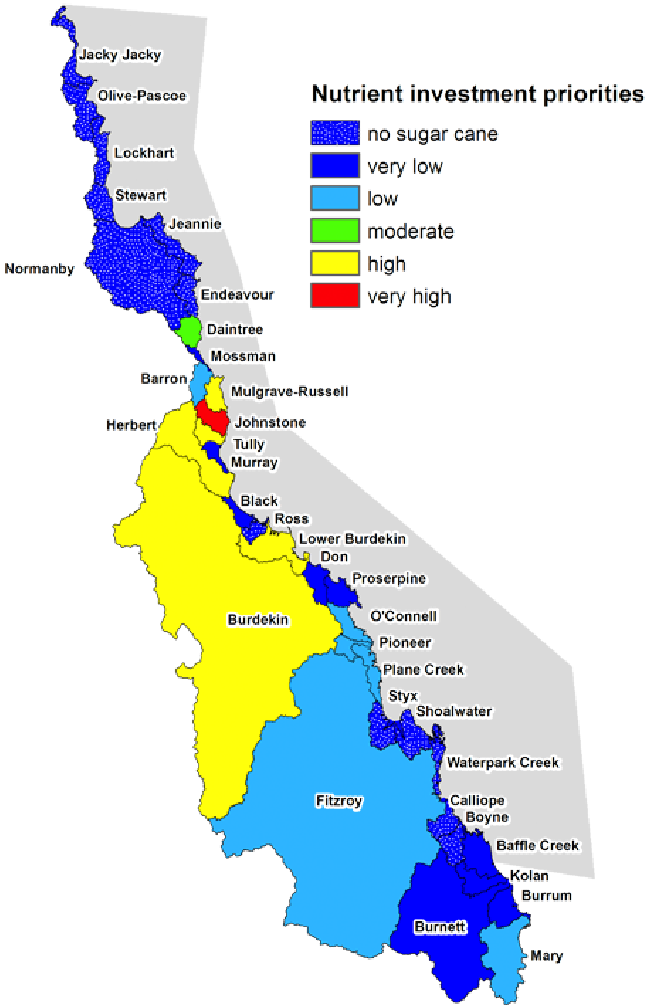
Sub-catchment	Priority rating with COTS influence index	Priority rating without COTS influence index
Daintree	Moderate	Very low
Barron	Low	Very low
Mulgrave-Russell	High	Low
Tully	High	Moderate
Pioneer	Low	Moderate
Plane	Low	Moderate
Fitzroy	Low	Moderate

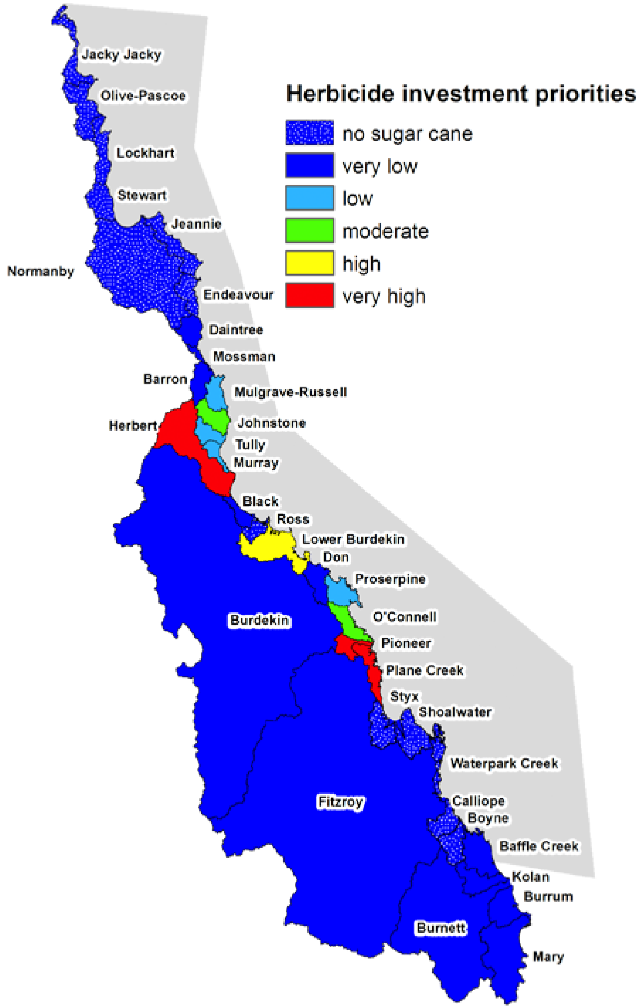
In the Fitzroy sub-catchment only a small area of cane (in the Isaac management unit – see Appendix 4) is grown. Improving nutrient management in the Isaac is rated as very low priority.

MCAS–S results – sugar cane industry: herbicides

The relative priorities between sub-catchments for reducing herbicide inputs from sugar cane lands are shown in Figure 11. The Herbert, Pioneer and Plane sub-catchments have been rated as very high priority for improving herbicide management practices; these have high to very high scores for risk to the reef (estimated PSII concentrations) or for estimated PSII loads, plus high scores for room for improvement (the areas managed using C or D herbicide management practices in these three sub-catchments range from 25,650 to 59,300 hectares – see Appendix 7b). The Haughton is rated as a high priority for improving herbicide management. While this sub-catchment's risk to the reef is rated as low, solvability (anthropogenic loads plus room for improvement) is very high.

FIGURE 11 Sub-catchment investment prioritisation in improving nutrient and herbicide management for sugar cane – MCAS–S results adjusted to reflect locations where sugar cane is grown



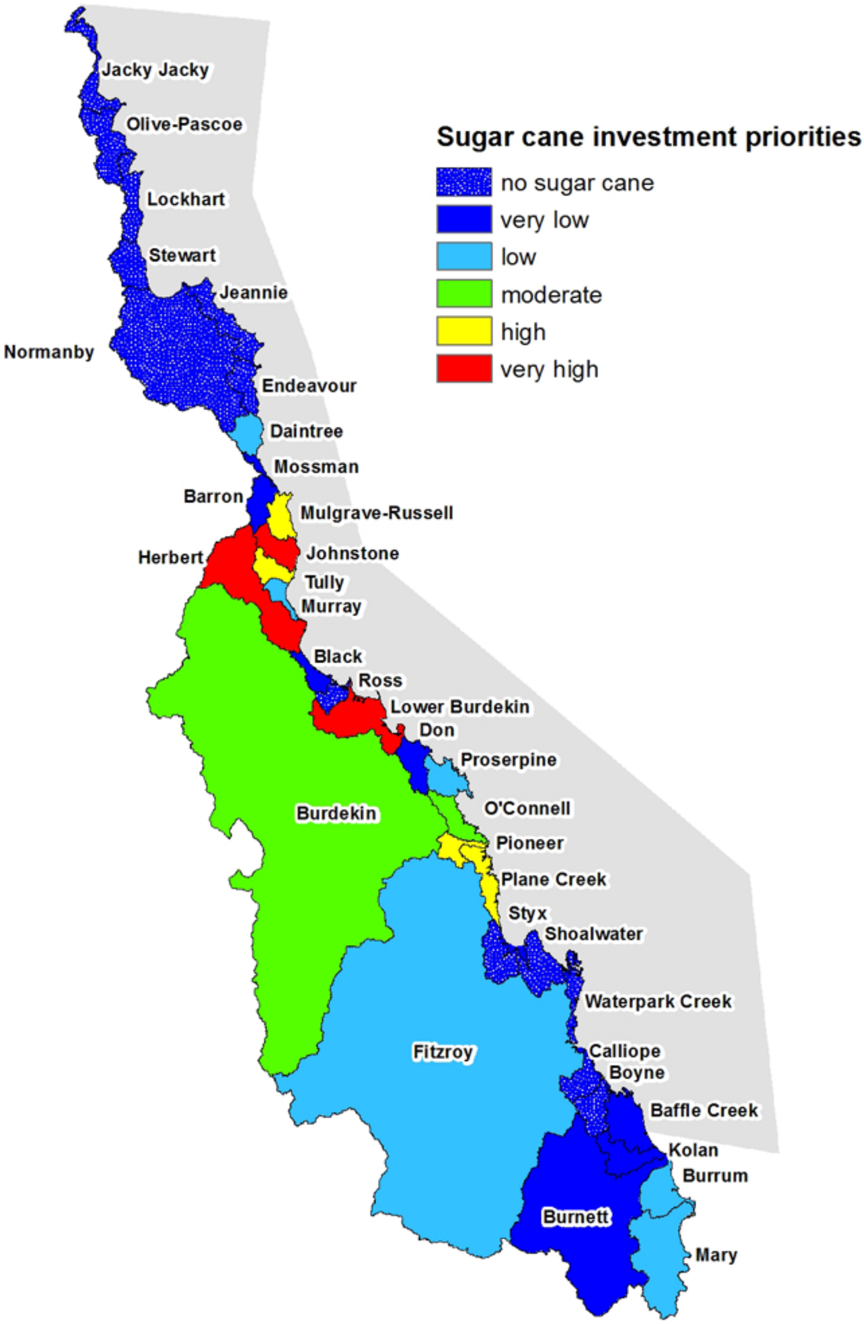


The Johnstone and O'Connell catchments are rated as moderate priority; herbicide concentrations from the O'Connell present a moderate risk to the reef, although solvability is rated as very low; anthropogenic loads for the Johnstone are very high, resulting in a high solvability score.

Figure 12 shows the combined nutrient and herbicide MCAS–S results for sugar cane. Combining the priority scores for nutrients and herbicides results in very high priority for investment ratings for the Herbert and Johnstone; with the Mulgrave-Russell, Pioneer, Plane and Tully sub-catchments as high priority. Comparison of the nutrient and herbicide results at Figure 11 shows that only the Haughton, Herbert and the Johnstone are rated as moderate, high or very high priority for investment in both nutrient and herbicide management practice improvement. The Pioneer and Plane, rated as high priority in the combined assessment, have low ratings for nutrient investment; the Mulgrave-Russell and Tully are high priority for nutrients but low priority for herbicides.

Rankings for the Burdekin sub-catchment (moderate) and the Fitzroy sub-catchment (low) in the combined nutrient and herbicide results appear higher than they should be because the nutrient prioritisations incorporate very high (Burdekin sub-catchment) and high (Fitzroy sub-catchment) ratings for the total DIN loads, much of which is coming from grazing (Appendix 10, Figure 19). Compared with the Haughton for example, the number of growers and area of cane grown in the Burdekin and Fitzroy sub-catchments is quite small (Appendix 4).

FIGURE 12 Combined nutrient and herbicide sub-catchment investment prioritisation for sugar cane – MCAS–S results adjusted to reflect locations where sugar cane is grown



Grazing – relative investment priorities for sub-catchments

Grazing priority rankings reflect the relative risk to the reef posed by estimated total TSS, PP and PN loads, the size of the estimated anthropogenic loads of TSS, PP and PN, the area grazed and the estimated area under C and D class practices (the extent of the area where practices could be improved). These rankings are largest for the Burdekin and Fitzroy, rated as very high and high priority respectively for investment in improving land management (Table 5). These sub-catchments drain very large areas; the Burdekin, followed by the Fitzroy, makes the largest contribution to annual average anthropogenic loads of TSS. Their dominant role in sediment export has been reported previously by Greiner et al. 2005, McKergow et al. 2005, Kroon et al. 2012 and the Scientific Consensus statement (State of Queensland 2013a).

Data on the loads per hectare per year of pollutants delivered to the GBR lagoon by sub-catchments were not included in the MCAS–S analyses but are briefly examined to see if sub-catchments identified as very high or high priority for investment in improved grazing management also deliver high loads per hectare of pollutants to the GBR lagoon. Estimated TSS loads per hectare from grazing land range from almost 0 in the Lockhart to 0.61 in the Johnstone sub-catchment, and are relatively low compared with loads per hectare from grains and horticulture (see Figure 16, Appendix 10). Grazing lands in most of the Wet Tropics sub-catchments, which are all rated as very low priority for investment in improving grazing practices, have TSS loads per hectare at the higher end of the range (more than 0.3 tonnes/hectare/year) as do several of the Mackay Whitsunday sub-catchments (O'Connell and Plane). The Burdekin and Fitzroy sub-catchments, identified as very high and high priority for investment in improved grazing management (Figure 10), deliver quite low TSS loads per hectare (0.1 and 0.07 tonnes respectively).

The modelled water quality loads by land use shown in Figure 7 indicate that there is substantial variability in erosion losses across the Burdekin and Fitzroy sub-catchments. Work by Croke et al. (in review) and the data in Figure 8 suggest that some management units within the Burdekin and Fitzroy sub-catchments may have substantially higher losses of sediment per hectare.

Locally available information should also be considered in allocating funds for improving grazing management practices. For example, Wilkinson et al. (2013a) has shown that sub-surface soils are the most likely sources of fine sediment in the Upper Burdekin and Bowen (part of the Bowen-Bogie management unit); this is probably derived from erosion of existing gully networks in proximity to rivers. Bartley et al. (2014) have noted that within the Burdekin sub-catchment the Bowen and the Upper and Lower Burdekin management units appear to be the dominant source of the fine silts and clays which are thought to pose the greatest risk to coral reefs. Within these sub-catchments, remotely sensed data showing areas of persistent low ground cover, gully density maps and soil maps showing the distribution of very fine-textured basaltic and sedimentary soils, which deliver a higher proportion of fine sediment per tonne lost to the reef (Bartley et al. 2014a), should be used to pinpoint locations for investment. By combining the sub-catchment-scale priority maps (e.g. Figure 10) with these high-resolution tools, users have highly prescriptive tools to address TSS concerns.

TABLE 5 Investment rankings for NRM region sub-catchments for sugar cane and grazing

NRM region	Sub-catchment	Area (ha)	Cane nutrients	Cane PSII	Cane nutrients and PSII	Grazing sediments
Cape York	Jacky Jacky	292 976	NA	NA	NA	VL
	Olive-Pascoe	412 922	NA	NA	NA	VL
	Lockhart	284 735	NA	NA	NA	VL
	Stewart	277 234	NA	NA	NA	VL
	Normanby	2 439 585	NA	NA	NA	L
	Jeannie	362 236	NA	NA	NA	VL
	Endeavour	209 580	NA	NA	NA	VL
		4 279 268				
Wet Tropics	Daintree	210 656	M	VL	L	VL
	Mossman	47 887	VL	VL	VL	VL
	Barron	218 889	L	VL	VL	VL
	Mulgrave-Russell	197 882	H	L	H	VL
	Johnstone	232 607	VH	M	VH	VL
	Tully	168 527	H	L	H	VL
	Murray	111 544	VL	L	L	VL
	Herbert	984 200	H	VH	VH	VL
		2 172 192				
Burdekin	Black	112 780	VL	VL	VL	VL
	Ross	172 250	NA	NA	NA	VL
	Haughton	495 286	H	H	VH	VL
	Burdekin	12 830 249	L	VL	L	VH
	Don	335 607	VL	VL	VL	VL
		13 946 172				
Mackay Whitsunday	Proserpine	250 055	VL	L	L	VL
	O'Connell	233 211	L	M	M	VL
	Pioneer	168 382	L	VH	H	VL
	Plane	254 483	L	VH	H	VL
		906 131				
Fitzroy	Styx	301 454	NA	NA	NA	VL
	Shoalwater	360 807	NA	NA	NA	VL
	Waterpark	184 489	NA	NA	NA	VL
	Fitzroy	14 249 672	VL	VL	VL	H
	Calliope	224 386	NA	NA	NA	VL
	Boyne	250 154	NA	NA	NA	VL
		15 570 962				
Burnett Mary	Baffle	403 543	VL	VL	VL	VL
	Kolan	295 470	VL	VL	VL	VL
	Burnett	3 303 802	VL	VL	VL	VL
	Burrum	345 040	VL	VL	L	VL
	Mary	933 976	L	VL	L	VL

Note: VL = very low, L = low, M = medium, H = high, VH = very high, NA = not applicable.

Sugar cane – relative investment priorities for sub-catchments

Sugar cane nutrient management priorities (Table 5) for sub-catchments generally reflect the relative risk to the reef posed by total DIN loads and herbicide concentrations, the size of the anthropogenic loads of DIN from sugar cane, the area of cane grown and the area under B, C and D class practices. The Burdekin sub-catchment is an exception; it is rated as high, largely on the basis of the large total DIN load (pre-development and anthropogenic loads from all sources, including a significant input from grazing) and COTS influence (Table 2). However, the anthropogenic DIN load from cane is scored as low in the MCAS–S analyses and the room for improvement is scored as very low, leading to a low solvability score. Within the Burdekin sub-catchment, only a comparatively small area of cane is grown, mostly in the East Burdekin (5000 hectares and about 30 cane farmers). It is recommended that the Burdekin sub-catchment nutrient management priorities be re-rated as low to reflect these factors, with overall cane investment priorities re-rated as low. Similarly, the Fitzroy sub-catchment, with a smaller area of cane (in Isaac) and 17 farmers, should be re-rated as very low for nutrient management priorities, resulting in an overall rating for cane and nutrient investment of very low.

Greiner et al. (2005) identified the Johnstone (here rated as very high priority for cane investment) and Plane (high priority) as having high ecological impact in their MCA comparison of GBR river basins (sub-catchments) due to their potential discharge of diffuse source pollutants into the GBR lagoon, the potential impact of that discharge and the ability to control discharge. The Mulgrave-Russell (high) and O'Connell (medium) were rated by Greiner et al. as having a high hazard to fishing and marine tourism on the basis of the likely economic impact of pollution.

The ranking of the relative risk of degraded marine water quality to the GBR coral reef and seagrass ecosystems between the GBR regions (Brodie et al. 2013b, see Appendix 2) was Wet Tropics (very high), Fitzroy (high), Burdekin (high), Mackay Whitsunday (moderate), Burnett Mary (uncertain), Cape York (low). Brodie et al. (2013b) identified The Wet Tropics region as the priority area for nitrogen management (on land used for sugar cane and bananas), Mackay Whitsunday and the Lower Burdekin (Haughton sub-catchment) for PSII management (on coastal cane lands). MCAS–S regional level results presented for this study (the cane nutrients and PSII data from Table 5) broadly suggest that investment priority rankings for the Wet Tropics (very high) and the Burnett Mary (very low) are similar to those from the marine study. In the MCAS–S analysis, Mackay Whitsunday is ranked ahead of the Fitzroy, largely due to the impact of the high rankings for herbicide concentrations for all four sub-catchments. In the marine risk assessment (Appendix 2) the nutrient-related variables of chlorophyll threshold exceedence and DIN plume loading were ranked highest in the Fitzroy region, contributing to its high relative marine risk.

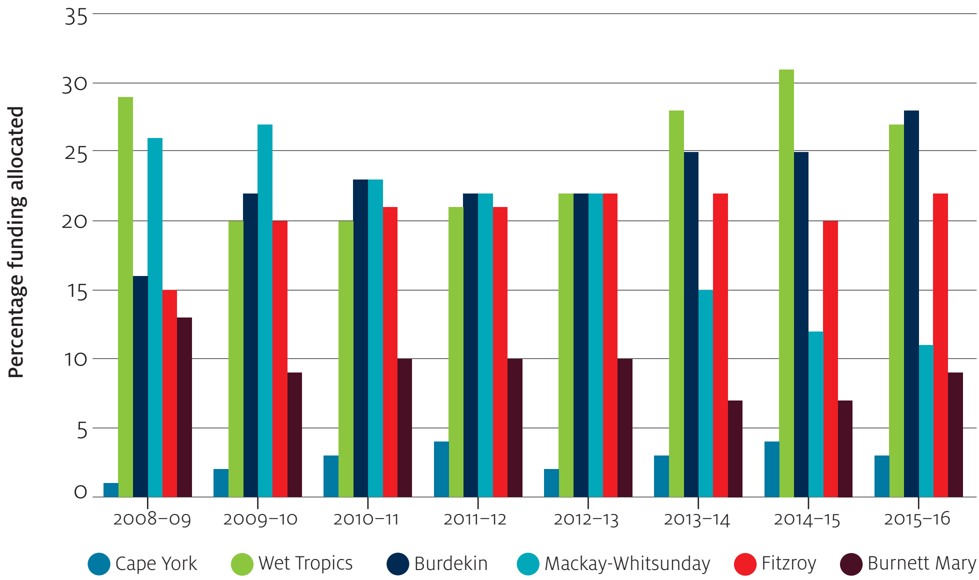
Pollutant loads per hectare were not included in the sugar MCAS–S analysis, but are examined to see if sub-catchments rated as high priority for investment also had high loads per hectare. In the sugar cane industry anthropogenic DIN loads (kg/ha/y) range from a low of 0.17 in the Fitzroy to 24.19 kg/ha/y in the Johnstone (Figure 24, Appendix 11). The larger losses of DIN per hectare are mostly associated with sub-catchments rated as very high (Johnstone) or high (Tully, Haughton, Burdekin) priority for investment in improving nutrient management. The Baffle, Mary and Mossman sub-catchments were rated as very low priority for investment in sugar cane nutrient management improvement, but had higher losses per hectare than the Burdekin and Haughton. A two-way analysis of the MCAS–S data identified only the Johnstone sub-catchment as having both very high loads and very high loads per hectare of DIN from cane lands.

Herbicide loads (kilograms/hectare/year) from cane lands ranged from 0 in the Fitzroy (the percentage area of this sub-catchment under sugar is very small) to 0.085 kg/hectare/year in the Tully (Figure 25, Appendix 11). Larger losses per hectare were associated with sub-catchments in the Wet Tropics (except the Barron); most except the Herbert (very high) and Johnstone (moderate) were rated as low to very low priority for investment. The Pioneer, Plane and Haughton, rated as very high priority for investment in herbicide management (due to very high or high herbicide concentrations or very high anthropogenic loads, combined with very high or high room for improvement), tended to have lower herbicide losses per hectare (Figure 25, Appendix 11). The higher rainfall in the Wet Tropics sub-catchments is a likely factor driving the high losses per hectare. A two-way analysis of the MCAS–S data scored only the Johnstone sub-catchment as having both very high loads and very high loads per hectare of herbicides.

Investment priorities over time

Investment priorities for Reef programs have changed over time in response to new science and better information. Figure 13 shows the impacts of these changes on Australian Government funds provided to regional NRM bodies in the GBR catchment. From 2009–10, funding for the Burdekin and Fitzroy regions increased, reflecting increased emphasis on rangelands grazing as a result of the MCA conducted in 2008–09 (Cotsell et al. 2009), which recognised the importance of grazed land as a source of sediment. Other changes included decreased funding for dairy (which occupies small areas in the Wet Tropics and Burnett Mary NRM regions) and increased funding for Cape York for research to define investment priorities and actions for this region. The funding for the Burnett Mary region decreased marginally due to recognition of the greater distance between the point of river discharge and the location of sensitive reef ecosystems in this region.

FIGURE 13 Percentage of Australian Government Reef Programme funds allocated to NRM regions 2008–09 to 2015–16



The investment prioritisation process conducted in 2012–13 by the authors of this report for the Australian Government Reef Programme 2013–14 to 2015–16 (Caring for our Country 2013) used the results of the Brodie el al. (2013) marine risk assessment, room-for-improvement data (GBR-wide ABCD framework benchmarking for cane and grazing) and the anthropogenic loads by land use data from the Paddock to Reef program to identify relative funding priorities at the NRM region level. This resulted in significantly increased funding priority for the Wet Tropics region, due largely to the influence of DIN discharge from this region (primarily from cane, with an additional contribution from bananas) on COTS outbreak initiation frequency. Funding priority for the Mackay Whitsunday region decreased, as the relative risk of anthropogenic loads of pollutants from agricultural sources from this region to seagrass and coral reefs was assessed by Brodie et al. as moderate, compared to the Wet Tropics (very high), Burdekin (high) and Fitzroy (high) (Appendix 2). It should be noted that quality of funding proposals received from delivery partners and the fit of these with Australian Government priorities also influenced the funding provided to regions.

Using the MCAS–S investment priorities information

Table 5 shows the MCAS–S rankings for investment in the 35 GRB sub-catchments in improving nutrient and herbicide management in sugar cane, and in the management of sediments on grazed lands. This information is intended to encourage discussion of priorities in developing projects and allocating funds by regional NRM bodies and by the Australian and Queensland governments.

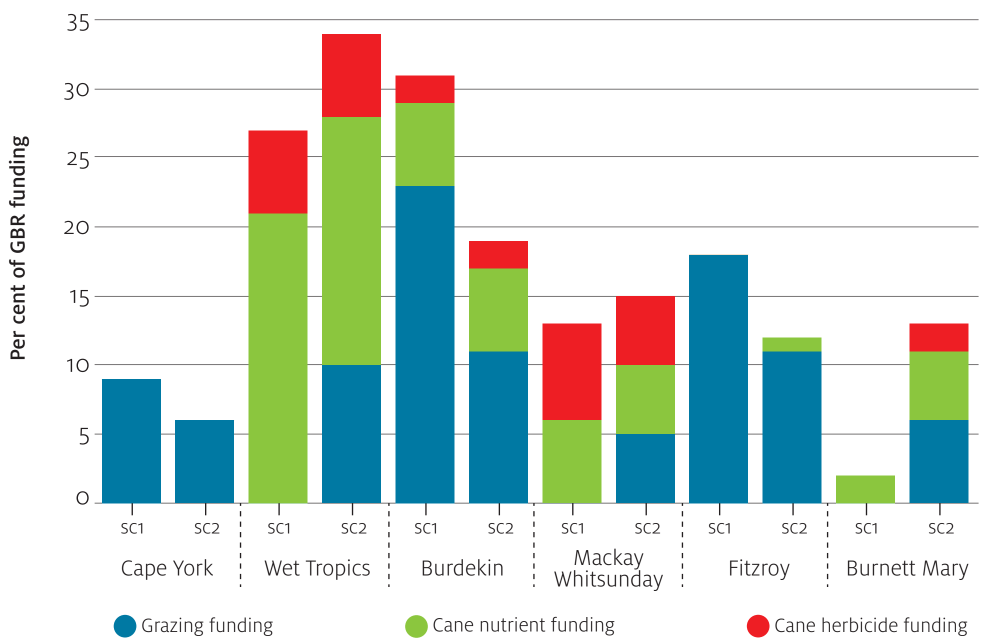
The information can be used to explore funding allocation scenarios across the GBR sub-catchments or within individual regions. In the example below, a notional budget is established, then the MCAS–S derived priority rankings for sub-catchments from Table 5 are entered into a spreadsheet, and numbers allocated to the rankings – for example, very high = 5, high = 4, medium = 3, low = 2, very low = 1. The sub-catchment numbers for each of cane nutrients, cane herbicide and grazing sediment management are then summed; each sub-catchment number is divided by the sum. The result is multiplied by the total annual funding available, and in turn by the percentage allocated for investment in a particular issue, such as cane nutrients.

The scenario results for regional budgets displayed in Figure 14 use the following assumptions which could also be varied:

- future annual funding is assumed to be the average of funds available to Water Quality Grants during the period 2013–14 to 2015–16
- 50 per cent of funds are available for improving grazing management practices, 35 per cent for improving cane nutrient management and 15 per cent for improving herbicide management (in the absence of MCAS–S results for the banana, dairy and horticulture industries).

Two scenarios were chosen to illustrate this approach; in Scenario 1 funds were not provided for very low priority rankings, whereas in Scenario 2 very low priority rankings were funded (Figure 14). In these scenario analyses, the Jacky Jacky, Olive-Pascoe and Lockhart (Cape York) were excluded, as these sub-catchments have little or no agricultural land use (Figure 1a).

FIGURE 14 Scenario analyses for allocation of funds at NRM region level on the basis of MCAS–S investment rankings in Table 5



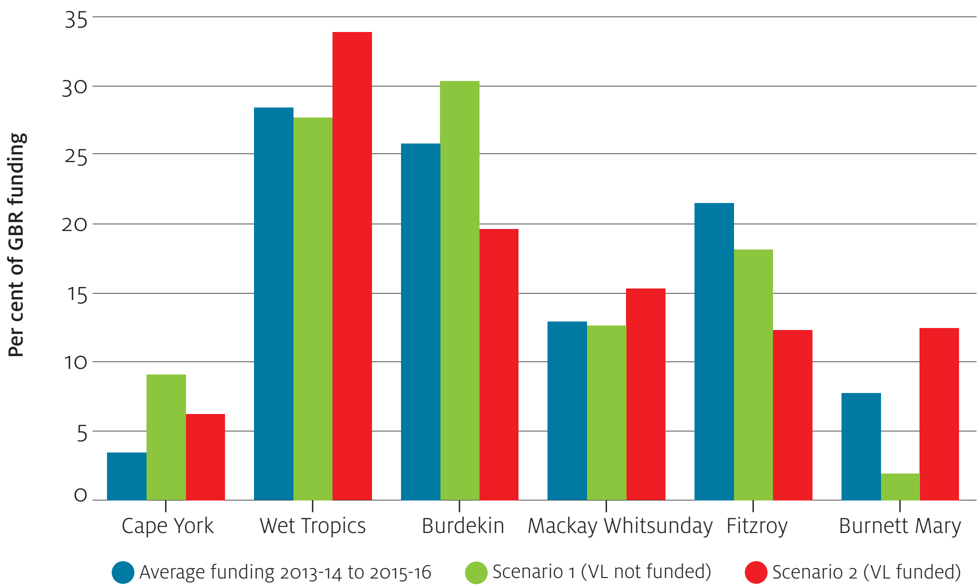
Note: sc1 = very low-ranking sub-catchments not funded, sc2 = funding provided for very low rankings.

Figure 14 shows the impact of removing funding for the very low priority rankings. Under this scenario no funds are allocated to Wet Tropics, Mackay Whitsunday or Burnett Mary for grazing improvements, and no funding is provided to the Burnett Mary for herbicide management improvement. It should be noted that the Fitzroy NRM region currently receives no funding for improving the management of cane nutrients or herbicides; the number of cane farmers and the area under cane in this region (in the Isaacs sub-catchment) is quite small (see Appendix 4).

Figure 15 shows the potential impact of these scenarios on regional NRM funding compared with the average of funds provided in 2013–14 to 2015–16. Changes in funding under scenario 1 (where very low priorities are not funded) range from a decrease of 5.8 per cent for Burnett Mary to an increase of 5.6 per cent more than the average for Cape York. For scenario 2, changes range from a decrease of 9.2 per cent for Fitzroy, to an increase of 5.5 per cent for Wet Tropics.

For Cape York there is an increase in funding under both scenarios. Under scenario 1 funds for grazing improvements are only allocated to the Normanby, which was ranked third for grazing investment in Table 5. In scenario 2 some funds are also allocated to the Jeannie and Endeavour sub-catchments. For Wet Tropics there is little difference between average funding 2013–14 to 2015–16 and scenario 1 results. In scenario 2, allocation of funds to the 13 Wet Tropics sub-catchments rated as very low priority for grazing, cane nutrients or herbicide investment increases Wet Tropics funding by about 5.5 per cent.

FIGURE 15 Comparison of the scenario analyses with the average funds received by regions from the Australian Government Reef Programme 2013–14 to 2015–16

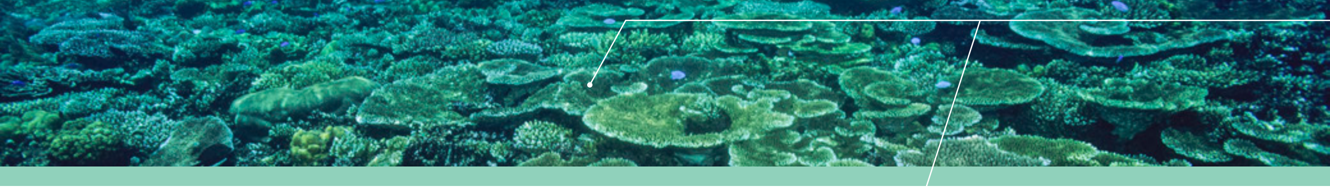


In the Burdekin, scenario 1 results in an increase in funding of 4.5 per cent, receiving a higher proportion of the funds available for grazing investment. In scenario 2, funds (compared with the average 2013–14 to 2015–16 allocation) decrease by about 6.2 per cent as funds are spread across sub-catchments ranked as very low priority for funding. In the Mackay Whitsunday region there is little difference between the average 2013–14 to 2015–16 allocation and scenario 1 results; scenario 2 increases funds by 2.4 per cent when resources are allocated to five very low priority sub-catchments.

In the Fitzroy NRM region all sub-catchments are ranked as very low priority for funding, except the Fitzroy sub-catchment (see Table 5), which is high priority for grazing investment. Funding for this region decreases under scenario 1 (by 3.4 per cent), where only the Fitzroy sub-catchment is funded for grazing improvement, and in scenario 2 (by 9.2 per cent). In scenario 2 a small amount of funding is allocated for improvements in cane management (Figure 2) as the very small area of cane in the Fitzroy sub-catchment, which is encompassed by the Mackay Whitsunday cane program, had not been excluded prior to the analysis; but funding for grazing is reduced, as this is shared across many more mostly very low priority sub-catchments. For the Burnett Mary, scenario 1 results in a reduced (by 5.8 per cent) allocation, with funding to be focused on cane nutrients in the Mary sub-catchment (Figure 2). In scenario 2 funds increase by 4.7 per cent as resources are allocated to other sub-catchments ranked as very low priority for grazing, cane nutrient and herbicide management improvements.

Summary of key points

- Land used for agriculture occupies about 82 per cent of the GBR catchment. Land used for cropping, dairy, grazing, horticulture (including bananas) and sugar cane, contributes an estimated 55, 69 and 66 per cent to the estimated anthropogenic loads of TSS, PN and PP, plus an estimated 87 per cent of the anthropogenic DIN and 100 per cent of the PSII delivered to the GBR lagoon.
- Grazing (75 per cent of the area of the GBR catchment) contributes an estimated 45, 43 and 45 per cent to the estimated anthropogenic loads of TSS, PN and PP and an estimated 21 per cent of the DIN load. Grazing is likely to be a major contributor to the anthropogenic loads of TSS, PN and PP coming from stream bank erosion (which cannot be attributed to a particular land use). Stream bank erosion contributes an estimated; 39, 28 and 21 per cent of the of TSS, PN and PP loads respectively.
- The Burdekin and Fitzroy sub-catchments are rated as very high and high priority for investment in improving grazing management by virtue of their large area, very high total and anthropogenic loads and large room for improvement (areas managed using C and D class practices). Research suggests that some management units within these sub-catchments may deliver disproportionately larger amounts of sediment to the lagoon; this information could be used to improve prioritisation within these sub-catchments.
- Land used for sugar cane (1.3 per cent of the GBR catchment) contributes an estimated 56 and 94 per cent to the estimated anthropogenic loads of DIN and PSII delivered to the GBR lagoon.
- The Johnstone sub-catchment is a very high priority for investment in improving nutrient management practices to reduce DIN loads. The Burdekin (cane is mainly grown in the East Burdekin), Haughton, Herbert, Mulgrave-Russell and Tully sub-catchments are rated as high priority; the Daintree is rated as moderate priority for investment.
- The Herbert, Pioneer and Plane sub-catchments have been rated as very high priority for investing in improving herbicide management practices; the Haughton is rated as a high priority and the Johnstone and O'Connell catchments are rated as moderate priority for investment.



Chapter 4

Future improvements

The catchments flowing to the GBR lagoon and its associated marine ecosystems are part of a dynamic, complex and interconnected system. Much of the research, monitoring and modelling being undertaken to improve the quality of water delivered to the lagoon from land used for agriculture is at the leading edge of such activities. Water quality science is continually improving and, as understanding changes, the Reef Water Quality Protection Plan activities will be refined to take this into account.

This MCAS–S analysis has been undertaken to provide policy makers, industry and NRM regions with information to improve the allocation of resources to achieve maximum pollutant reductions with the limited resources available. The sub-catchments within NRM regions, industries and pollutants have been identified where the likely biggest returns on investment in improving management practices for better water quality outcomes could be expected on the basis of currently available information and the most recent research.

In the following sections, further opportunities for improving returns on investment through the Water Quality Grants and other programs aiming to improve the quality of runoff from agricultural land are outlined. These include:

- improving land management practices for better water quality outcomes
- better methods for monitoring, modelling and reporting land management practice change
- improvements to Source catchments modelling for the Paddock to Reef program
- research to improve understanding of catchment-based processes affecting GBR water quality.

Improving land management practices for better water quality outcomes

Opportunities in the grazing industry

The 2013 Scientific Consensus Statement (State of Queensland 2013a) noted that water quality modelling indicates that early adopters of best practice land management have reduced pollutant loads, making a significant step towards the goal of halting and reversing the decline in the quality of the water delivered to the reef. Continuous improvement in management practices plus transformational changes in some farming technologies may be necessary to reach some targets.

With 45 per cent of the annual average anthropogenic sediment load, plus a significant component of the stream bank erosion load delivered to the GBR coming from grazing land, future load reductions depend on the capacity of pastoralists to improve management practices. However, in 2009 the Northern Beef industry (which includes Queensland pastoral areas draining to the reef) was reported to be in its worst state since the 1970s and generally unprofitable and unsustainable (McCosker et al. 2010). These results are consistent with QDAFF financial benchmarking projects in the Fitzroy and Burdekin in 2006–10, and the production aspects were supported by QDAFF surveys for the Reef Plan in 2011–13. Anecdotal information suggests that, although grazing management workshops are quite well attended, most participants do not have the resources to implement the management changes needed to reduce soil loss through hillslope, gully and stream bank erosion.

‘The extremely poor performance of the extensive breeder herd is an alarming contributor to poor business performance’ (McCosker et al. 2010). Herd management skills seem to be closely linked with environmental outcomes. Breeder performance (conception rates, weaning rates etc.) is just as important for environmental performance as it is for business profit; good breeder productivity contributes to increased profitability, enabling more conservative stocking rates. Reducing stocking rates over parts of properties (in turn) will enable ground cover to improve and potentially allow for the return of some perennial species, as well as reduce soil losses. O’Reagain et al. (2011) have demonstrated that sustainable management with lower stocking rates can be profitable in climatically variable environments.

It is recommended that the Reef Plan Water Quality Risk Framework for Grazing be revised to recognise the important role that herd management improvements play in improving profitability and providing opportunities for reductions in stocking rates, with better outcomes for water quality, soil condition and long-term sustainability. This revision should be underpinned by a review which examines how a staged framework for property investment that supports pastoralists improving herd management and infrastructure to reduce stocking rates while improving ground cover management and pasture productivity could be developed. The review should also identify further research needs and how best to communicate the longer term strategies that need to be adopted step wise by graziers to improve profitability and longer term sustainability.

Stream bank erosion across the GBR catchment is estimated to contribute 39 per cent of TSS loads and 28 and 21 per cent of PP and PN respectively delivered to the reef (Figure 5). A significant component of these loads will come from grazed lands, which occupy 75 per cent of the GBR catchments. Stream bank erosion is included in the ‘Other uses’ category shown in Appendices 10 and 11 (Figures 16–25) because it cannot be attributed to specific land uses in the current Source catchments modelling. Water quality improvements arising from investments in stream bank fencing and revegetation have not been modelled as the data were not available at the time of writing this report. Therefore it is difficult to assess the impact of practices used to date. However, given the size of the stream bank contribution to loads, it is recommended that further work is undertaken to identify how and where to direct investment to reduce these loads in the most cost effective manner.

Subsoil erosion (including gullying) is now known to be a very significant source of the sediment delivered to the GBR (Croke et al. 2009, Tims et al. 2010, Hancock et al. 2013, Olley et al. 2013 and Wilkinson et al. 2013a). Effective gully management includes reducing grazing pressure to increase levels of ground cover in vulnerable eroding parts of the landscape and to reduce runoff volumes from these areas. Targeted remediation works in unstable gullies, and other erosion features can also assist reducing sediment yield (Thorburn and Wilkinson 2013).

Informal check dams constructed from fallen timber and positioned in the base of existing gully networks have been used in the Burdekin and Normanby sub-catchments. Results from the Burdekin showed that a combination of check dams and grazing management in adjacent paddocks gave a large reduction in sediment leaving the gullies in the second year following treatment (Wilkinson and Thorburn 2013b). These check dams need to be placed in locations with stable (non-incising) bed levels; disturbance of sodic subsoils needs to be avoided. They have been shown to be an effective way to trap this fine sediment on the gully bed, reduce gully sediment yield, and initiate revegetation of the gully bed, provided they are appropriately sized to the runoff volumes. Production of local gully control manuals to encourage adoption of this approach should be considered, together with access to technically competent support to ensure that works provide optimal benefits.

Opportunities in the sugar cane industry

Scenario analyses (modelling) have been undertaken to assess the feasibility of meeting the Reef Plan 2009 water quality targets, a minimum 50 per cent reduction in nitrogen, phosphorus and herbicide loads at the end of catchments by 2013 and a minimum 20 per cent reduction in total suspended sediment (TSS) loads at the end of catchments by 2020 (Waters et al. 2013). These estimates suggest that the 20 per cent TSS reduction target can be achieved with a 50/50 adoption of A and B class practices across all cane and grazing land. For DIN, the modelling suggests that the 50 per cent target may not be met by the complete adoption of A class nutrient management practices.

The 2013 Scientific Consensus Statement (State of Queensland 2013a) noted that the universal adoption of B class practices is unlikely to meet water quality improvement targets for fine sediments, total nitrogen or total phosphorus, but may for PSII herbicides. Management of agricultural lands will need to move beyond current industry accepted practices to more 'aspirational' practices to meet water quality targets. A revised Paddock to Reef Water Quality Risk Framework has been developed for the sugar cane industry, and is being used to respond to these concerns (Kevin McCosker, Queensland Department of Agriculture, Fisheries and Forestry, pers. comm.). The new framework includes weightings to identify the practices which will deliver the largest improvements in water quality.

The Scientific Consensus Statement (State of Queensland 2013a) noted that nitrogen surpluses (the difference between nitrogen inputs and nitrogen in crop offtake) are high in many intensively managed crops, and that loads could be reduced by reducing inputs. Current cane industry nutrient recommendations aim to supply nutrients to meet the district yield potential, which is defined as 120 per cent of the estimated highest annual average district yield. These recommendations result in the majority of fields being over-fertilised to ensure that the minority are not nutrient limited. Alternative management systems have been identified (Thorburn et al. 2011), but further work will be needed to help growers improve fertiliser use efficiency. Discussions are being held with researchers and industry to identify the additional work needed to support improved nitrogen use efficiency whilst maintaining profitability and productivity.

Good progress has been made in reducing annual average PSII loads, principally in the sugar cane industry. Paddock to Reef water quality modelling estimates indicate that 70 per cent of modelled load reduction is due to management improvements in the Wet Tropics and Mackay Whitsunday regions (Waters et al. 2013). These regions encompass a number of the sub-catchments rated as high priority for investment in improved herbicide management in this study (Table 5). Existing A and B class herbicide and soil management practices for sugar cane (Appendix 6) are contributing to this load reduction.

These include controlled traffic and banded application (particularly in combination) which has been shown to give significant reductions in herbicide runoff under simulated storm rainfall, especially for furrow irrigated cane (Silburn et al. 2013). Oliver et al. (2014) found that banded application of diuron and atrazine using a shielded sprayer onto raised beds decreased the average total load of both herbicides moving off-site by 90 per cent compared with the conventional broadcast treatment in a furrow irrigated farming system. Further reductions may also be expected with regulatory changes; for example, the Australian Herbicides and Veterinary Medicines Authority has recently (November 2013) amended the usage of the PSII herbicide diuron in the Wet Tropics to reduce the maximum applicable annual volume applied by 75 per cent. However, a wide range of new and emerging herbicides are being used in cropping systems, and there is a need to expand monitoring to incorporate these and to better understand their behaviour and fate.

Better methods for reporting, monitoring and modelling land management practice change

The 2012 review of the Paddock to Reef program (Chinn and Gongora, unpublished) noted the need to improve the management practice adoption component of the program. Changes which would improve confidence in the modelled load reductions, enable tracking of change at investment sites over time and ensure that the most cost effective investments are chosen include:

- reporting of the spatial locations of investments (property-level GIS data)
- quality checking of the data set by regional bodies
- monitoring of individual practices rather than system change
- reporting on practice change for all industries funded
- reporting on the costs of practice change in a way that they can be meaningfully compared across regions.

Currently most regional NRM bodies do not provide land management practice change information as spatially explicit shape files that enable modellers to locate the area of change. A tool is used to 'accumulate' the outputs from each of the model land management practices into a single time-series. This is done at a sub-catchment scale by weighting, based on the proportion of the sub-catchment represented by each ABCD management practice class. This avoids the need to make assumptions around the spatial distribution of the management practices, and instead assumes an even distribution across the climate/soil/sub-catchment (Carroll et al. 2012).

The result is sub-optimal reporting of investment benefits and an inability to report ongoing change (and the cumulative impact of those investments) over time for investment sites. The provision of higher spatial resolution data will enable all regional modelling outputs to be of similar resolution and more useful for regional and sub-regional prioritisation processes. In the future, project data will include spatial information for each investment for collation in the same database. This will provide greater accuracy in modelling of water quality outcomes, and assist with the targeting of further investments to specific localities according to room for improvement.

For Reef Rescue, the land management practice change outputs provided to modellers were metrics representing system changes that tried to approximate the likely impact of changed management on land condition, runoff and soil loss. Recently revised Water Quality Risk Assessment Frameworks for grazing and sugar cane will enable estimation and modelling of future load reductions for individual practice changes, which should greatly improve the rigour of estimates around the impact of practice change investments. It will also significantly reduce inter-regional differences due to variations in ABCD class management practice frameworks.

Current modelling of sub-catchment reductions in pollutant loads is based on the assumption that practice changes have been implemented by landholders who have received funding for this purpose through Reef Rescue 2007–09 to 2013–14 and/or extension services provided by the Queensland Government, regional NRM bodies or private sector consultants. To improve confidence in the modelled reductions related to grants for equipment or farm infrastructure, it is recommended that a follow-up audit of a proportion of land holder grant recipients is undertaken. Further targeted evaluation should be incorporated in the design phase of extension programs and projects, utilising the Paddock to Reef Water Quality Risk Frameworks. It is also recommended that multiple lines of evidence for practice change (such as annual fertiliser sales) be collated and published.

While the sugar cane and grazing industries were identified as major priorities for future investment (Caring for our Country 2013), nutrient management in banana crops was also a high priority (for the Wet Tropics), as were management actions to reduce sediment, nitrogen and herbicide loads from broadacre cropping in the Fitzroy. Surveys of cropping management practices in the Fitzroy region (Barson 2013) indicate that there is room for improvement in cultivation techniques, crop residue retention and soil nutrient testing that reduce sediment and nitrogen loads. Collection of data on management practice change for the GBR's broadacre cropping areas is needed to track investment outcomes and model water improvements due to practice change in this industry. A paddock based model and a management practice framework are being developed to report on water quality improvements due to practice change in the banana industry.

The cost of implementing practice change should be an important consideration in any prioritisation process. The limited information available on costs of pollutant abatement indicated substantial variation between industries and pollutants and was considered not suitable for incorporation in the current MCAS–S analysis. There is a need to further explore how water quality targets can be achieved at least-cost (Roebeling et al. 2009).

The following cost estimates (Kevin Gale, Department of Environment, pers. comm.) are for ongoing annual average load reductions based on two years of Reef Rescue investments and the results of the Reef Plan Second Report Card (2010):

- For grazing, the cost of sediment reduction averaged $137 per tonne, with most reduction and most cost effective reduction achieved in large projects in the extensive grazing areas of the Burdekin, Cape York and Fitzroy regions. The total investment was $13.75 million for 100 kilotonnes/year ongoing sediment reduction at end of catchments.
- For sugar cane, the cost of DIN reduction averaged $38,500 per tonne across all regions (nominally allocating 70 per cent of cane funding against DIN reduction). Total investment was $16.8 million for 434 tonnes/year ongoing DIN reduction at end of catchments.
- For herbicide reduction in sugar cane, the cost averaged $3,844 per kilogram of active constituent across all regions (nominally allocating 20 per cent of cane funding against herbicide reduction). The total investment was $4.8 million for 1254 kilograms/year ongoing reduction at the end of catchments.

- For sediment reduction in sugar cane, the cost averaged $125 per tonne across all regions (nominally allocating 10 per cent of cane funding against sediment reduction). The total investment was $2.37 million for 19 kilotonnes/year ongoing reduction at the end of catchments. Most of the reduction occurred in the rain-fed cane production systems of the Wet Tropics and Mackay Whitsunday regions. It should be noted that many of the herbicide and nutrient management projects implemented by the sugar cane industry would also have reduced sediment losses.

As noted in Chapter 2, the very large differences between regions in abatement costs are thought to be influenced by differences between regions in how changes were estimated and reported in addition to differences in farming systems. Additional factors influencing regional differences in abatement costs include the extent to which investments were targeted spatially to reduce pollutant loads and the competitiveness of the regional funding process. It will be important for future investment evaluation to ensure that consistent measurement and reporting approaches are adopted and included in future discussion of priorities.

Improving Source catchments modelling outputs

Refining the spatial scale of the reporting unit for water quality modelling results

While the main land use in the Burdekin and Fitzroy sub-catchments is grazing (92 and 80 per cent of their areas respectively), it is clear from the water quality modelling results showing loads generated from grazing land (Figure 7) that erosion losses vary substantially across these NRM regions. Research has also identified significant differences in rates of erosion, sources of erosion (hillslope, gully and stream bank) and in the likely impact on the reef of finer sediments derived from specific sub-catchments (Bartley et al. 2014a). Regional NRM bodies have asked for modelled water quality results to be made available for spatial units smaller than sub-catchments. The catchment modelling operates at a very detailed scale (5150 spatial units are modelled across the GBR catchment). The models use verification data from 25 water quality monitoring stations in 14 sub-catchments (TSS and nutrients), 14 sites in 14 priority sub-catchments for herbicides, and 201 river gauging stations recording water flows. There is a trade-off between the reliability and spatial scale of the modelled water quality outputs. Further investigation and discussion with regional NRM bodies is recommended to optimise the spatial scale of water quality reporting, especially for the Burdekin and Fitzroy sub-catchments.

Improving data on the sources of sediment loss

Recent research has led to substantial improvements in understanding the likely sources of sediment eroded from GBR catchments; subsoil sources, especially gullies, are thought to be contributing a much larger component. As noted by Chinn and Gongora (unpublished) the availability of better data for rock cover (a component of ground cover), and information from sediment tracer studies identifying the relative proportions of sediment delivered from hillslope, gully and stream bank erosion will enable improved modelling of sediment losses. Reef Rescue efforts have focused on improving ground cover management on grazed lands to reduce TSS loads. Ground cover management will continue to be a major component of good grazing management, as ground cover management is a component of managing these sub-surface sources. Increased ground cover (and an increase in the proportion of deep rooted native perennial grasses) has a major role in reducing the runoff that is fuelling gully and stream bank erosion, as well as protecting hillslopes (Bartley et al. 2014b).

Having up-to-date spatial layers of the spatial location and rate of change of gully and stream bank erosion processes will enable the models to better reflect the relative importance of gullies, hillslopes and stream banks in delivering sediments for each sub-catchment. This will improve the allocation of funds between erosion control activities and lead to improved water quality outcomes for the GBR.

Improving the estimates of sediment delivered to the GBR lagoon

The use of models such as Source catchments requires a number of assumptions to be made about the processes underway in catchments and how these are influenced by human activities and climate. Recent research using sediment tracing and dating techniques has indicated that predicted anthropogenic end-of-GBR catchment loads delivered to the GBR lagoon could be overestimated, as more sediment may be stored in floodplains and in channel benches than currently accounted for in modelling.

Results of sediment tracing studies in Theresa Creek, a catchment within the Fitzroy River basin, suggest that the high rates of sediment storage in channel benches may mean that catchment disturbance related increases in erosion (due to agricultural land use post European settlement) may not have translated to commensurately large increases in catchment sediment yields (Hughes et al. 2010). Further work is required to quantify the role of sediment sinks in the downstream low-lying parts of the Fitzroy River basin and other large dry-tropical catchments that drain to the GBR.

Thompson et al. (2011) have shown (in the Nogoa, part of the Fitzroy basin) that topographic features such as floodplain constrictions and tributary junctions can reduce catchment connectivity and the transfer of sediment, which is subsequently stored on floodplains rather than transported to the coast. More than 46 such major valley constriction sites have been reported for the Fitzroy (Amos et al. 2008). Information on the spatial location of these constrictions across the GBR sub-catchments and the rate of deposition and re-entrainment of these sediments could be collected from digital elevation models to provide information about sediment storage at nodes.

Improving ground cover data

Ground cover (the percentage of the soil surface covered by plant matter and other biological crusts and rock) data derived from satellite remote sensing is a fundamental input to Source catchments modelling, and for reporting on the Reef Plan's ground cover catchment target for grazed lands. Ground cover data are used in the catchment modelling to represent the effect of cover on soil erosion rates, and hence sediment loss into streams.

Recent advances in ground cover monitoring from remote sensing have increased the spatial and temporal resolution of the data available for catchment modelling. Fractional cover data are now used to represent the green and non-green ground cover components as well as the bare ground. This information will improve estimates of cover and runoff relationships. The combination of freely available Landsat and MODIS satellite data has also significantly improved the temporal resolution of the ground cover data; monthly and seasonal data could be used to capture the inter- and intra-annual dynamics of ground cover. This will enable ground cover changes to be represented more accurately in the catchment models, and it is also improving the information available for pastoral land management decision making.

Advances have also been made in estimating ground cover in areas of the GBR catchment with significant tree cover (tree cover tends to obscure ground cover monitoring by satellites). These advances have the potential to significantly increase the extent of the monitoring and reporting area for the GBR ground cover target (to more than 90 per cent of the GBR catchment area) and to improve modelling of ground cover and runoff relationships in these areas. Some field checking is still needed to ensure the reliability of ground cover estimates for these tree covered areas. Validation of modelled water quality against measured water quality will be needed where cover factor adjustments have been made based on the improved ground cover data. It may be necessary to develop adjustment factors for different levels and types of cover, and for different land types or regions. This should include experiments to validate ground cover estimates under trees and the impacts this cover has on runoff and erosion.

Research to improve understanding of catchment-based processes affecting GBR water quality

Bioavailability of PN

In the last five years a substantial proportion of funding from Reef Rescue Water Quality Grants has been used to improve nitrogen management practices to reduce DIN loads from cane lands. Comparing modelled average annual modelled anthropogenic DIN and PN loads from all land uses suggests that PN loads are about 30 per cent higher than DIN loads. Dissolved inorganic and particulate forms of nutrients discharged into the GBR are both important in driving ecological effects (Furnas et al. 2013b). Dissolved inorganic forms of nitrogen (and phosphorus) are considered to be of greatest concern compared with dissolved organic and particulate forms of nutrients, as they are immediately and completely bioavailable for algal growth. However, most PN and PP (eroded principally from grazed lands) is mineralised from fine sediment following delivery to the GBR and could be readily available for uptake in marine systems (Brodie et al. 2013b). A review recently funded by the Australian Government Reef Programme is expected to provide a better understanding of PN dynamics and the time to bioavailability. This understanding could lead to a change in priorities for funding.

Establishing the sources of anthropogenic DIN from grazed land

Water quality modelling results indicate that 66 per cent of the anthropogenic DIN delivered to the GBR is associated with sugar cane (56 per cent), dryland cropping (3 per cent) and irrigated cropping (1 per cent) or horticulture, including bananas (4 per cent) or other horticultural land uses (2 per cent). Grazing is estimated to contribute 21 per cent to the overall GBR anthropogenic DIN load, predominantly from the Burdekin and Fitzroy sub-catchments wvw. The processes and sources of the DIN coming from grazed lands, or how amenable this might be to management, are not understood.

Research needed to support further land management practice change

The 2013 Scientific Consensus Statement notes the need for transformational changes in some farming technologies to reach some targets (State of Queensland 2013a). For the grazing industry, opportunities for delivering on Reef Plan 2013 targets would be strengthened by a better understanding of the water quality effectiveness and costs of specific grazing practices (i.e. the public and private benefit associated with investments), including riparian grazing management, reducing grazing pressure on gullied lands, and gully remediation approaches that could be applied cost effectively over large areas.

The commercial feasibility of the lowest water quality risk nutrient management practices identified in the draft Paddock to Reef water quality Risk Framework for sugar cane have yet to be proven. Field trials are needed to support widespread adoption of the cane nitrogen budgeting practices, which are based on yield expectations for specific blocks and ratoon numbers (a ratoon crop is the new cane which grows from the stubble after harvesting), and for yield zones within blocks. Ideally this issue would be addressed along with other site-based constraints, such as waterlogging and soil sodicity, to improving profitability and productivity for the sugar industry. The Australian Government Reef Programme has recently funded a compilation of sugar cane nutrient use field trial results; this review will identify further work needed to support the adoption of nutrient practices that pose the lowest risk to water quality.

Attributing risk to the reef to sub-catchments

The Brodie et al. (2013b) study (see Appendix 2) identified the relative risk to the GBR's marine assets such as seagrasses and coral reefs from the quality of the water (TSS, DIN and PSII loads) delivered from the six NRM regions in the GBR catchment. The results of this project informed regional funding levels for 2013. A marine risk assessment conducted to define the zones of influence for each of the GBR's 35 sub-catchments would provide better information on the risk to the reef posed by each sub-catchment and replace the total loads data currently used to represent threats in future MCAS–S assessments. With further outputs from the eReefs hydrodynamic model and recent improvements in remote sensing capability (e.g. Devlin et al. 2012), it would be possible to define zones of influence for each sub-catchment and conduct the risk assessment on those assessment units.

Summary of key points

- Opportunities for improving water quality outcomes on land used for grazing include supporting the adoption of better herd management practices to deliver ground cover improvements whilst improving profitability, and targeting investment to reduce subsoil loss through gullying and stream bank erosion.
- In the sugar cane industry, there are significant opportunities to reduce DIN loads by moving from district to block or zone potential yields to calculate nitrogen applications. Extension activity will be needed to support industry in this process.
- Current modelling of estimated reductions in pollutant loads is based on the assumption that practice change has been implemented by landholders who have been funded for this purpose. Spatially explicit data on the location of management practice change is needed to model the impact of individual practices on loads; a follow-up audit of a proportion of land holders should be undertaken, and multiple lines of evidence for practice change (such as fertiliser sales) be published.
- Better information on the cost of practice change needs to be collected so that this can be considered in designing and prioritising future investments.
- Provision of new spatial data layers to enable updating of the Source catchment modelling science to reflect new understanding of sediment storage processes, and to provide spatially detailed water quality outputs, especially for the Burdekin and Fitzroy sub-catchments, is recommended.
- Research recommended to improve understanding of catchment-based processes affecting water quality includes:
  - the bioavailability of PN
  - the sources of DIN from grazed lands
  - grazing management for riparian zones and gullied landscapes
  - field trials to support moving to block or zone yield as the basis for cane nutrient needs
  - the risks to reef ecosystems posed by sub-catchment pollutant loads.

A better understanding of these issues will inform targeting of future funding and may change priorities.

Chapter 5

Conclusions

Using the information on priorities

Developing a targeted approach to reducing pollutant loads, particularly by targeting water quality improvement to the highest risk pollutants to the highest risk regions, is one of the guiding principles of the 2013 Reef Water Quality Protection Plan (State of Queensland 2013b). The results of the MCAS–S analysis provide structured, transparent information to inform discussion of future investment priorities for the cane and grazing industries in the GBR sub-catchments. Sub-catchments have been ranked for investment in improving land management practices by considering the risk presented to reef water quality, and the potential for each industry to reduce the anthropogenic loads delivered from sub-catchments to the reef lagoon by improving management practices.

Table 5 provides a guide to where, on the basis of the best currently available information, investments in improving practices in the sugar cane and grazing industries could be expected to give the biggest water quality improvements. In the Wet Tropics NRM region this is in improving the management of nutrients in the Johnston, Mulgrave-Russell, Tully, Herbert and Daintree, and in improving herbicide management in the Herbert and Johnstone sub-catchments. In the Burdekin NRM region, investments in improved cane nutrient and herbicide management are expected to give the biggest returns in the Haughton sub-catchment. In the Mackay Whitsunday NRM region, investment in improving cane herbicide management practices is likely to deliver the biggest water quality improvements.

For the grazing industry, the biggest returns on investment in practices reducing sediment loss will come from the Burdekin and Fitzroy sub-catchments in the Burdekin and Fitzroy regions respectively. Data on the anthropogenic loads delivered to the GBR lagoon from smaller units such as management units (so this could be compared with the loads delivered to the lagoon from other sub-catchments) were not available to inform this study. Information on erosion rates and sources of sediment from studies such as Bartley et al. (2014), Turner et al. (2013) and Wilkinson et al. (2013a and b), plus gully mapping, could be added to the MCA spreadsheets provided to the Burdekin and Fitzroy NRM regions to help identify which management units might deliver the biggest reductions in sediment loads for the available investment. For an example of this approach, see Wilkinson et al. (2014).

It is recommended that government agencies, NRM regional bodies, rural research and development organisations and industry bodies use the priority rankings in this report to inform discussion of future investment arrangements. Opportunities to do this include:

- Refining annual regional priorities for on-ground funding. GBR NRM regions have received Australian Government Reef Programme funding for three financial years, from 2013–14.
- Developing and updating Water Quality Improvement Plans; plans are currently being prepared for Cape York, the Wet Tropics, the Burdekin, Mackay Whitsunday and Burnett Mary.
- Improving the targeting and delivery of extension through the Queensland Government funded cane and grazing best management practice programs.
- Future funding under the Reef Trust (see environment.gov.au/reef-trust).

- The development of strategic plans prepared by rural research and development corporations, particularly Meat and Livestock Australia and Sugar Research Australia. Funding of research development and extension activities directed at improving the quality of water leaving land used for cane growing and grazing in the GBR catchments will contribute to these organisations meeting government expectations that their investment programs will deliver public good outcomes for the broader community.

It is recommended that the MCAS–S data sets and software used in this study be available to interested stakeholders, together with the report, to assist them to interrogate the results.

Changes in priorities over time

The priorities identified in this report are based on the likely annual average water quality loads estimated by Source catchments modelling for the 1986–2009 period, the management practice change data for the sugar cane and grazing industries reported for 2010–11, and the 2013 marine assessment of the relative risk of regional water quality to reef and seagrass ecosystems (Brodie et al.). Data sets used in the MCAS–S analysis were necessarily those that were available and comparable across the 35 sub-catchments examined.

It is recommended that the analysis be rerun when new data sets become available – for example, to include a relative marine risk assessment undertaken for the 35 sub-catchments, or to incorporate improved outputs from the Source catchment modelling. The results of the research recommended in Chapter 4 may also require a revision of the priorities identified in this study.

To assist regional NRM planning, it is recommended that regular updates of the water quality data, the management practice change data and the ancillary information on industries be provided to NRM regions as an Excel spreadsheet based Multi-Criteria Analysis. The spreadsheet provides access to these data sets in an easily used format. It would include the capacity to add local data sets, including expert judgements (for example a ranking of the extent of gullies in sub-catchments could be produced using available maps supplemented by expert advice) and would encourage the use of new information as it becomes available from regionally conducted research or mapping.

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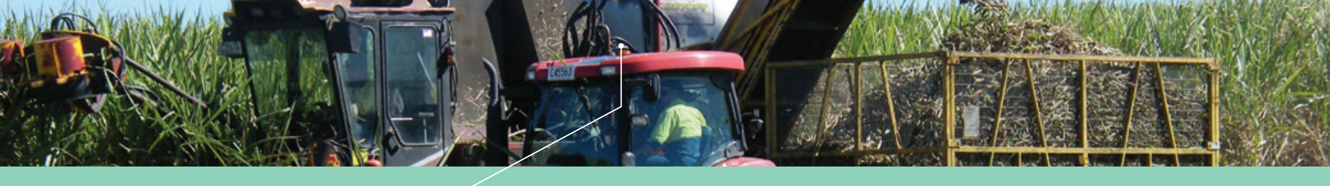


Appendices

APPENDIX 1 Working Group on Reef Rescue 2 Prioritisation project – membership

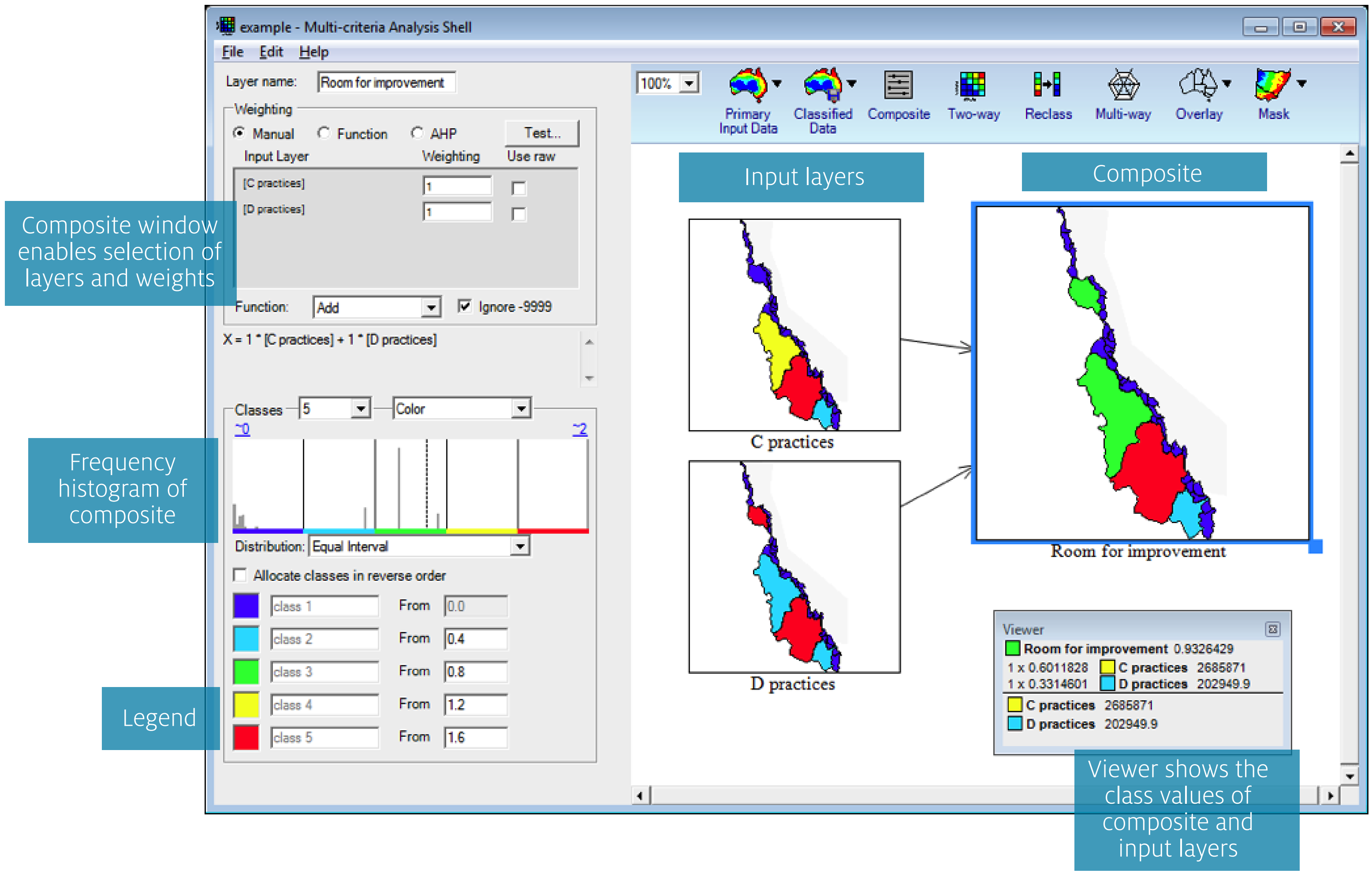
Dr Michele Barson	Department of Agriculture
Dr Jon Brodie	James Cook University
Dr Chris Carroll, Mr Dave Waters	Queensland Department of Natural Resources and Mines
Mr Colin Creighton	Reef and Rainforest Research Centre
Dr Kevin Gale	Department of Environment
Dr Peter Hairsine	CSIRO Land and Water
Dr Rob Lesslie, Dr Lucy Randall	ABARES, Department of Agriculture
Mr Kevin McCosker	Queensland Department of Agriculture, Fisheries and Forestry
Dr Mike Ronan	Queensland Department of Environment and Heritage Protection
Dr Britta Schaffelke	Australian Institute of Marine Science
Dr Jane Waterhouse	C_2O Consulting
Dr Stuart Whitten	CSIRO Ecosystem Sciences
Dr Hugh Yorkston	Great Barrier Reef Marine Park Authority

APPENDIX 2 Summary of the outcomes of the overall assessment of the relative risk of water quality in the GBR

Region	Dominant variables in marine assessment *Variables where max area is in Region*	Marine Risk Index		Regional Anthropogenic Load as a proportion of the Total GBR Load (%)			Loads Index	Relative Risk Index	Management Issues	Associated land uses	Overall Ranking of Relative Risk
	CR = Coral Reef SG = Seagrass	**Coral Reef**	**Seagrass**	**TSS**	**DIN**	**PSII Herb**					
Cape York	COTS Initiation Zone (CR)	12	4	3	<1	<1	0	9	The data in this Region are highly uncertain due to limited validation of marine datasets.		**LOW**
Wet Tropics		100	83	9	20	61	100	100	Nutrients Pesticides	Sugarcane Bananas	**VERY HIGH**
Burdekin	TSS 2mg/L (SG, CR) TSS 7mg/L (SG) TSS Plume loading (CR, SG) Chl 0.45µg/L (SG) DIN Plume loading (SG)	40	100	32	11	13	62	76	Sediments Pesticides Nutrients	Grazing Sugarcane (coastal)	**HIGH**
Mackay Whitsunday	Pesticide exposure (CR, SG)	54	37	4	6	12	25	50	Pesticides Nutrients	Sugarcane	**MODERATE**
Fitzroy	TSS 7mg/L (CR) Chl 0.45µg/L (CR) DIN Plume loading (CR)	86	59	17	5	4	28	80	Sediments Pesticides Nutrients	Grazing Cropping	**HIGH**
Burnett Mary	All variables rank relatively low	11	23	4	4	9	20	19	Sediments	Grazing	**UNCERTAIN**

Source: Brodie et al. (2013b)

APPENDIX 3 Example of MCAS–S composite – estimation of room for improvement in sediment management practices in the grazing industry



APPENDIX 4 Area and number of agricultural businesses for grazing and sugar cane in the GBR

NRM region	Sub-catchment	Management unit	Area (ha)	Paddock to Reef data*: Area of grazing (ha)	Paddock to Reef data*: Area of sugar cane (ha)	ABS Agricultural Census 2010–11: Number of grazing businesses	ABS Agricultural Census 2010–11: Number of sugar cane businesses	ABS Agricultural Census 2010–11: Gross value of sugar cane production ($)
Cape York	Jacky Jacky		292 976	25 003	–	–	–	–
	Olive-Pascoe		412 922	63 314	–	–	–	–
	Lockhart		284 735	11	–	6	–	–
	Stewart		277 234	96 679	–	1	–	–
	Normanby		2 439 585	1 721 689	–	25	–	–
	Jeannie		362 236	113 022	–	–	–	–
	Endeavour		209 580	130 316	–	17	–	–
Wet Tropics	Daintree		210 656	14 814	4 354	21	22	4 263 604
	Mossman		47 887	1 651	4 844	11	40	11 969 657
	Barron		218 889	67 233	5 618	226	62	19 461 232
	Mulgrave-Russell		197 882	6 594	24 934	64	207	49 945 297
	Johnstone		232 607	37 880	28 005	328	226	45 466 763
	Tully		168 527	8 121	20 264	43	97	39 923 272
	Murray		111 544	6 909	15 789	27	45	15 979 034
	Herbert		984 200	551 806	75 862	154	476	109 118 722
Burdekin	Black		112 780	51 523	1 412	25	9	2 123 235
	Ross		172 250	87 890	–	32	–	–
	Haughton	Lower Burdekin	495 286	291 620	98 548	128	488	219 583 909
	Burdekin	Upper Burdekin	4 004 962	3 515 498	–	190	3	306 514
		Cape Campaspe	1 993 987	1 926 292	–	51	–	–
		East Burdekin	328 856	316 590	4 953	13	30	12 915 183
		Bowen Bogie	1 162 865	1 047 127	–	80	9	2 936 244
		Belyando	3 506 225	3 357 993	–	151	–	–
		Suttor	1 833 354	1 675 435	–	55	–	–

APPENDIX 4 Area and number of agricultural businesses for grazing and sugar cane in the GBR

NRM region	Sub-catchment	Management unit	Area (ha)	Paddock to Reef data*: Area of grazing (ha)	Paddock to Reef data*: Area of sugar cane (ha)	ABS Agricultural Census 2010–11: Number of grazing businesses	ABS Agricultural Census 2010–11: Number of sugar cane businesses	ABS Agricultural Census 2010–11: Gross value of sugar cane production ($)
Burdekin		Sub-catchment total	12 830 249	11 838 935	4 953	540	42	16 157 941
	Don		335 607	273 669	54	45	1	–
Mackay Whitsunday	Proserpine		250 055	112 782	24 780	79	149	36 861 246
	O'Connell		233 211	111 918	35 701	195	212	42 500 976
	Pioneer		168 382	53 786	39 181	127	308	60 989 813
	Plane		254 483	117 786	68 059	253	382	92 301 938
Fitzroy	Styx		301 454	241 327	–	29	–	–
	Shoalwater		360 807	146 438	–	36	–	–
	Waterpark		184 489	29 313	–	25	–	–
	Fitzroy	Isaac	2 222 052	2 001 191	332	174	17	4 202 420
		Theresa Creek	846 631	645 216	–	233	–	–
		Mackenzie	1 313 643	1 151 226	–	131	1	256
		Nogoa	1 920 777	1 503 649	–	173	1	–
		Comet	1 729 030	1 255 334	–	202	–	–
		Fitzroy	1 142 325	940 013	–	605	2	1 052 605
		Dawson	5 075 214	3 857 909	–	1 291	–	–
		Sub-catchment total	14 249 672	11 354 538	332	2 809	21	5 255 281
	Calliope		224 386	183 048	–	106	–	–
	Boyne		250 154	185 188	–	78	–	–
Burnett Mary	Baffle		403 543	271 460	842	168	6	1 613 026
	Kolan		295 470	203 501	14 940	160	90	33 189 515
	Burnett		3 303 802	2 550 452	19 852	2 103	163	20 590 860
	Burrum		345 040	128 790	31 727	128	174	41 532 823
	Mary		933 976	472 326	19 047	1 091	95	15 444 631
Total			42 156 556	31 551 332	539 098	9 083	3 316	884 272 776

APPENDIX 5 ABCD land management practice framework for the grazing industry

Principle	Framework A practices	Framework B practices	Framework C practices	Framework D practices
	Maintaining A condition land and/or improving B & C condition land towards A	*Maintaining A/B condition land and/or improving B & C condition land towards A/B*	*Maintaining land in AB condition and gradual improvement of C condition land*	*ABC condition land declining*
1. Achieving optimum carrying capacity				
1.1 Managing Land types	Land types documented on property map. Property fencing enables all paddocks and land types to be managed to achieve ground cover targets.	Land types defined and managed to prevent overgrazing of preferred land types. Property map includes plans for future improvements. Appropriate internal fencing.	Paddocks managed for dominant soil type with some overgrazing of preferred land types. Land types not marked on property map. Basic internal fencing.	Overgrazing on preferred land types and around watering points. No property plan in place. Inadequate internal fencing to manage grazing pressure.
1.2 Managing Land Condition	Grazing Land Management Plan implemented and land condition monitored in accordance with plan.	Paddocks monitored for land condition. Grazing Land Management Plan is being developed.	Casual observation of land condition with basic pasture management.	No management to arrest or improve declining land condition.
1.3 Water distribution	Watering points located to prevent uneven patch grazing across all land types and paddocks. Watering point location and design prevents localised land degradation.	Adequate watering points for paddock size, and carrying capacity. Watering points are located to minimise occurrence of uneven grazing.	Limited watering infrastructure resulting in some uneven grazing pressure.	Large paddocks under-watered resulting in overgrazing in proximity to available water. No plan for development of further watering points.
1.4 Riparian and frontage management	All major water courses fenced to enable effective management of riparian area. Off stream watering points used to protect and manage frontage paddocks. Action taken to rehabilitate degraded riparian areas.	Major watercourses and riparian zones managed through fencing and off-stream watering points.	A few strategically placed off-stream watering points at pressure areas.	No off-stream watering points. Waterways not fenced. Frontage country frequently overgrazed.
1.5 Pasture Spelling	Spelling of all paddocks at appropriate intervals according to pasture species and land type to ensure as a deliberate means of improving ground cover and land condition.	Spelling of paddocks at appropriate intervals according to pasture species and land type to ensure adequate end of growing season ground cover.	Occasional spelling only of paddocks of concern or for husbandry reasons (e.g. weaner paddock).	No plan for spelling pasture and limited management frequently resulting in low ground cover at end of growing season, regardless of seasonal conditions.

APPENDIX 5 ABCD land management practice framework for the grazing industry

Principle	Framework A practices	Framework B practices	Framework C practices	Framework D practices
	Maintaining A condition land and/or improving B & C condition land towards A	*Maintaining A/B condition land and/or improving B & C condition land towards A/B*	*Maintaining land in AB condition and gradual improvement of C condition land*	*ABC condition land declining*
2. Matching stocking rate to forage availability				
2.1 Stocking rate	Forage budgeting and land condition monitoring used to stocking rates match forage availability across all paddocks and land types. Grazing management results in end of dry season ground cover targets being met.	Stocking rate adjusted to forage availability in response to seasonal conditions and land condition. Pasture spelling used periodically to manage all land types	Some flexibility in stocking rate. Prepared to reduce stock numbers in dry conditions.	High stocking rates that frequently exceed forage availability regardless of seasonal conditions.
2.2 Ground cover	Paddocks have more than 40% cover and appropriate pasture yield at end of dry season. Forage budgeting utilised and supported by photo monitoring at end of dry season.	Ground cover doesn't fall below 40% at end of season regardless of seasonal conditions.	In most years 40% end of dry season ground cover maintained. Cover may fall below 40% in dry years on some land types and paddocks.	Less than 40% groundcover in most years regardless of seasonal conditions.
3. Strategic use of fire to achieve management and ecological outcomes				
3. Strategic use of fire	Strategic fire management is part of the grazing management plan. Including: pre-fire planning and preparation, post-fire management, consideration of intensity of burn and impacts upon biodiversity.	Documented fire management strategy which includes targeting woody weeds and timber thickening. Appropriate (wet season) spelling of paddocks post burn.	Opportunity burning. No fire prevention strategy. Limited pre- and post-fire planning. Not linked to grazing management plan.	Inappropriate use of fire - no fire prevention strategy, excessive burning frequency. Grazing of burnt areas occurs without sufficient time to recover. No documented fire management strategy.

APPENDIX 5 ABCD land management practice framework for the grazing industry

Principle	Framework A practices	Framework B practices	Framework C practices	Framework D practices
	Maintaining A condition land and/or improving B & C condition land towards A	*Maintaining A/B condition land and/or improving B & C condition land towards A/B*	*Maintaining land in AB condition and gradual improvement of C condition land*	*ABC condition land declining*
4. Strategic management of weeds and feral animals to achieve productivity and ecological outcomes				
4. Strategic pest management	Strategic pest management plan implemented to control terrestrial and/or water weeds and pest animals. Pest source areas and outbreaks marked on property map and linked to grazing land management plan.	Implementation of a documented pest and weed management plan based on regular monitoring. Accounts for pest impacts when documenting forage budget.	Reactive management of terrestrial and water weeds and pest animals, including declared species. No pest management plan.	No pest management.
	Promote regeneration of riparian zones to prevent degradation and weed infestation.			
5. Strategic use of sown pastures to achieve productivity and resource condition outcomes				
5. Strategic use of sown pastures	Assessment of the need for sown pasture (environmental and economic) incorporated into a property development plan. Pasture species, establishment methods, buffering and soil conservation practices most suited to specific land and soil types.	Where appropriate, establishment of sown pastures. Appropriate soil conservation practices adopted and buffers in place on watercourses. Establishment method is appropriate for the landscape and soil type.	Where appropriate, sown pastures established on suitable soil types.	No consideration given to the role of sown pastures within the enterprise.
6. Location and maintenance of property roads and firebreaks				
6. Property roads and firebreaks	Roads and firebreaks well planned and located in accordance with a property management plan and marked on property map. Preventative erosion control practices implemented and well maintained. All roads and tracks are designed to minimise the chance of water flows concentrating into rills. Soil erosion is minimal.	Roads and firebreaks are well maintained, marked on property map and controlled according to plan. Replacement roads and firebreaks are relocated in a planned manner to stable areas where feasible to prevent and stabilise erosion. Erosion control works are implemented in high priority areas.	Location of roads and firebreaks is not planned with maintenance and implementation of erosion control works only in areas where serious erosion has occurred.	Roads are poorly located and not maintained. As erosion expands, they are relocated to adjacent areas. Firebreaks are only installed in a wildfire emergency with no consideration for strategic location or maintenance.

APPENDIX 5 ABCD land management practice framework for the grazing industry

Principle	Framework A practices	Framework B practices	Framework C practices	Framework D practices
	Maintaining A condition land and/or improving B & C condition land towards A	*Maintaining A/B condition land and/or improving B & C condition land towards A/B*	*Maintaining land in AB condition and gradual improvement of C condition land*	*ABC condition land declining*
7. Prevention and stabilisation of erosion areas including gullies, stream banks, and hillslopes				
7. Prevention and stabilisation of erosion	Erosion control measures in place across property, with ongoing monitoring and implementation of further mitigation options. All roads and tracks are designed to minimise the chance of water flows concentrating into rills including diversion banks. Actively maintaining high levels of ground cover uphill of areas vulnerable to gullying.	Diversion banks established upslope of areas vulnerable to gullying or alternative actions where appropriate. Erosion control measures in place according to plan with (haphazard) intermittent monitoring. Stock denied access to concentrated erosion areas.	Some fencing used to exclude stock from erosion areas to promote ground cover. No erosion or land degradation management included in a management plan.	No identification of high risk areas or management for gully erosion.
8. Records Management				
8. Records management	Accurate records of stock numbers by animal class, paddock numbers and stock movements. Livestock performance data such as liveweights and pregnancy test data recorded and used in management. Land condition is monitored and used to inform property planning and land and livestock management. Costs and benefits of management strategies e.g. supplementary feeding are assessed and used in future decision making.	Accurate records of stock numbers by animal class, paddock numbers and stock movements. Livestock performance data such as liveweights and pregnancy test data recorded and used in management. Production costs are monitored. Land condition is monitored.	Basic records of brandings, weanings, stock numbers and movements. Limited recording of production data.	Limited stock records and no recording of production data.

APPENDIX 6 Reef Rescue Sugar Industry – Broad ABCD for Water Quality Land Management Practice Framework showing practices as at 2008-09 season – Differences from previous categories – DRAFT –13 May 2010

Practice Type	Practice Action	D = Superseded/ Dated	C = Code of Practice	B = Best	A = Aspirational
			(do 100% of these actions)	(do 75% of these actions)	(not proven or economically viable)
Principles		Superseded practices or not recommended	Code of Practice	Best management practice from an overall farm sustainability perspective (environment, social, economic)	Best for water quality but not from an overall farm sustainability perspective (environment, social, economic)
Nutrient	Number of application rates	Single application rate	One rate for plant, and a different rate for ratoon	Variable rates between blocks based on soil type	Variable rates within block (eg based on yield mapping, soil mapping). Amounts based on property yield potential recommendations.
	Application rate amount	Amounts based on historic rules of thumb	Amounts based on old industry recommendations	Amounts based on 6ES or equivalent (takes account of fallow history/ legumes/ by-products etc)	Specific advisor recommendations to change amounts; and/or use Near Infra Red data to change amounts
	Timing	Ad hoc	Same time each year	Time applications for crop class, irrigation and weather	As for "B"
	Placement/ method	Broadcast on surface (or in cutaway for plant cane)	Banded surface for granular	Sub-surface.	Sub-surface with auto shut off at end of row and/ or fertiliser box with rate control
				Any liquid products applied above surface prior to first irrigation/ rain	
	Accuracy/ Calibration	None	Annual	When product changes or at least once per month	Each time of use or at least once per month
	Testing	None	Some soil testing	One soil test per crop cycle	As for "B" plus Leaf sampling analysis
Chemical (herbicides for sugar)	Number of application rates (strategy and planning)	Single application rate	One rate for plant cane and one rate for ratoon cane	Herbicide strategy by block	Variable strategy within blocks
	Application rate amount	Use maximum label rate amount	Rate amount appropriate to weed pressure within label rates	Herbicide strategy by block	Variable strategy within blocks
	Timing	Ad hoc	Spray as per label recommendations	Time applications for crop class, irrigation and weather	All weeds controlled before 4 leaf stage
					Multiple weed control during fallow
	Placement/ method	Standard spray rig both high clearance and low clearance	Occasionally change nozzles	Nozzles matched to job	Variable rate controller, yield sensor

APPENDIX 6 Reef Rescue Sugar Industry – Broad ABCD for Water Quality Land Management Practice Framework showing practices as at 2008-09 season – Differences from previous categories – DRAFT –13 May 2010

Practice Type	Practice Action	D = Superseded/ Dated	C = Code of Practice	B = Best	A = Aspirational
Chemical (herbicides for sugar)				New technology e.g. hooded sprayers, shielded sprayers, dual tank set ups	
			(do 100% of these actions)	(do 75% of these actions)	(not proven or economically viable)
	Use of residuals	Residual use only	Use residuals and some knock downs	Knock down replaces residual where practical	Mainly use knock down, rarely use residual
	Accuracy/ Calibration	None	Annual	When product changes or at least once per month	Each time of use
	Storage and disposal	No storage or disposal strategy	Dispose of containers in Drum Muster and chemicals in Chemclear or equivalent	As for C	As for "B"
			Lockable storage and bunding		
Soil management	Tillage	Cultivate all of bare fallow, plant cane and ratoons	Minimum till on bare fallow and ratoons	Minimum till on all (fallow, plant and ratoon crops)	Zonal tillage on permanent beds
	Row width	Single row width	Single row width	Matched to machinery	As for "B"
	GPS	None	None	Use GPS on bed-forming and planting	GPS on all operations – bed-forming, planting, harvesting and haul out
	Paddock management	None	Protect sloping fields eg use contours, minimal tillage on sloping fields, trash on sloping fields	Use filter strips	As for "B" plus have tail water dams and/or constructed wetlands
	Trash	Burnt	Green cane trash blanket on suitable soils and blocks where practical (considering irrigation system)	As for "C"	As for "C"
Cane water management	Irrigation application	Irrigation amount unknown	Irrigation amount roughly determined by pump meter readings	Irrigation amount determined by management plan	Irrigation amount uses precision eg EM mapping
		Furrow that does not match soil type and topography (except Burdekin)	Winch	Irrigation method matches soil type and topography (i.e. can include winch or furrow depending on soil and topography)	Low Pressure Over Head or Trickle

APPENDIX 6 Reef Rescue Sugar Industry – Broad ABCD for Water Quality Land Management Practice Framework showing practices as at 2008-09 season – Differences from previous categories – DRAFT –13 May 2010

Practice Type	Practice Action	D = Superseded/ Dated	C = Code of Practice	B = Best	A = Aspirational
Cane water management		No efficiency checks	For Burdekin – furrow irrigation with correct set times and flow rate to minimise runoff and deep drainage	Irrigation system efficiency checks annually	Irrigation efficiency checks as for "B"
			Efficiency checks every few years		
	Irrigation scheduling method	Grower experience, guesswork or set cycle	Prioritise crop cycle eg plant cane and 1st ratoon over 5th ratoon	Quantitative scheduling and soil moisture monitoring	Quantitative scheduling, soil moisture monitoring, and precision water application across soil type or management zones
			Some scheduling eg mini pans	Use manual scheduling eg moisture probes	Use electronic scheduling and software
Climate forecasting			(do 100% of these actions)	(do 75% of these actions)	(not proven or economically viable)
	Drainage	Basic drainage in original farm layout	Laser levelling only	Storm water pits on suitable soil types capturing first flush	Storm water pits on suitable soil types capturing first flush and pit bypass overflow plus (if irrigation) recycling with water quality testing
			Bank end of furrows (if furrow irrigation)	Contour banks, diversion banks or constructed waterways with ground cover e.g. grass	
	Days after fertiliser application	Not considered i.e. random	Zero to two days	Two to five days depending on soil type	Two to five days depending on soil type
Record keeping and planning		No plan	Basic written record keeping/ Paddock Journal	Documented Herbicide Management Plan	As for "B" plus: GIS based plan
		Records "kept in head"	Chemcert current (within previous 5 years)	Documented Nutrient Management Plan	Documented Drainage Management Plan
		Chemcert accreditation more than five years ago		Documented Irrigation Management Plan	Computerised record keeping
				Records of use include time of spraying, type of pesticide, amount of pesticide, wind speed, wind direction	
				BSES Weed Management Strategy and/or Ask GB or equivalent	

APPENDIX 7a Room for improvement in sub-catchment sediment management practices in the grazing industry 2010-11

Region	Sub-catchment	C sediment practices (ha)	D sediment practices (ha)
Cape York	Jacky Jacky	–	–
	Olive-Pascoe	–	–
	Lockhart	–	–
	Stewart	4	240
	Normanby	843 654	591 031
	Jeannie	274	190
	Endeavour	2 431	3 837
Wet Tropics	Daintree	493	174
	Mossman	200	17
	Barron	22 404	4 652
	Mulgrave-Russell	1 011	206
	Johnstone	5 101	555
	Tully	24	–
	Murray	152	–
	Herbert	148 327	16 004
Burdekin	Black	6 451	460
	Ross	12 736	1 159
	Haughton	101 545	7 802
	Burdekin	2 685 871	202 950
	Don	41 086	11 623
Mackay Whitsunday	Proserpine	40 697	22 648
	O'Connell	68 421	13 331
	Pioneer	22 671	24 618
	Plane	43 805	27 358
Fitzroy	Styx	137 897	62 709
	Shoalwater	70 484	16 376
	Waterpark	16 770	2 282
	Fitzroy	4 467 645	612 290
	Calliope	126 907	974
	Boyne	131 959	829
Burnett Mary	Baffle	18 893	20 004
	Kolan	14 089	3 774
	Burnett	1 646 781	227 088
	Burrum	239 875	9 801
	Mary	92 891	17 750

Source: Paddock to Reef Program

APPENDIX 7b Room for improvement in sub-catchment nutrient and herbicide management practices in the sugar cane industry 2010-11

Region	Sub-catchment	B nutrient practices (ha)	C nutrient practices (ha)	D nutrient practices (ha)	C herbicide practices (ha)	D herbicide practices (ha)
Cape York	Jacky Jacky	–	–	–	–	–
	Olive-Pascoe	–	–	–	–	–
	Lockhart	–	–	–	–	–
	Stewart	–	–	–	–	–
	Normanby	–	–	–	–	–
	Jeannie	–	–	–	–	–
	Endeavour	–	–	–	–	–
Wet Tropics	Daintree	2 489	1 751	114	952	2 453
	Mossman	2 769	1 948	127	1 059	2 729
	Barron	1 578	2 368	581	415	242
	Mulgrave-Russell	18 210	2 011	1 537	16 735	2 712
	Johnstone	18 315	2 777	5 490	4 867	16 924
	Tully	13 186	5 726	323	10 421	6 911
	Murray	10 274	4 462	252	8 120	5 385
	Herbert	48 468	17 448	8 345	16 583	42 733
Burdekin	Black	902	325	155	309	795
	Ross	–	–	–	–	–
	Haughton	32 616	38 921	14 138	47 988	7 740
	Burdekin	1 497	2 020	763	2 444	378
	Don	17	22	8	27	4
Mackay Whitsunday	Proserpine	10 572	5 662	3 437	13 669	–
	O'Connell	13 331	17 295	1 731	18 039	1 978
	Pioneer	13 624	22 041	1 273	22 837	2 813
	Plane	22 343	36 524	3 050	32 046	1 424
Fitzroy	Styx	–	–	–	–	–
	Shoalwater	–	–	–	–	–
	Waterpark	–	–	–	–	–
	Fitzroy	–	–	–	–	–
	Calliope	–	–	–	–	–
	Boyne	–	–	–	–	–
Burnett Mary	Baffle	417	280	142	249	95
	Kolan	8 876	4 141	1 611	7 495	2 660
	Burnett	6 906	9 591	1 799	12 036	3 140
	Burrum	10 995	16 496	2 463	21 572	1 949
	Mary	5 708	7 984	2 581	9 300	1 495

Source: Paddock to Reef Program

APPENDIX 8 List of data sets describing the assets, threats and solvability for the grazing and sugar cane industries' means to an end, plus scaling and weightings used

Folder	Sub-folder	Name	Dataset	Units	Regions	Currency	Source	Weight
Grazing priorities								
Primary	grazing	g_tss_a	Grazing anthropogenic TSS loads	kt/y	Sub-catchments	2009-10	Paddock to reef	1
Primary	grazing	g_pp_a	Grazing anthropogenic PP loads	t/y	Sub-catchments	2009-10	Paddock to reef	1
Primary	grazing	g_pn_a	Grazing anthropogenic PN loads	t/y	Sub-catchments	2009-10	Paddock to reef	1
Primary	grazing	g_c_rfi	C sediment practices	ha	Sub-catchments	2010-11	Paddock to reef	1
Primary	grazing	g_d_rfi	D sediment practices	ha	Sub-catchments	2010-11	Paddock to reef	1
Primary	risk	risk_tss	Sediment risk Total TSS exported loads	kt/y	Sub-catchments	2009-10	Paddock to reef	1
Primary	risk	risk_pp	Sediment risk Total PP exported loads	kt/y	Sub-catchments	2009-10	Paddock to reef	1
Primary	risk	risk_pn	Sediment risk Total PN exported loads	kt/y	Sub-catchments	2009-10	Paddock to reef	1
Sugar cane priorities								
Primary	sugar cane	s_din_a	Sugar cane anthropogenic DIN loads	t/y	Sub-catchments	2009-10	Paddock to reef	1
Primary	sugar cane	sn_b_rfi	B nutrient practices	ha	Sub-catchments	2010-11	Paddock to reef	1
Primary	sugar cane	sn_c_rfi	C nutrient practices	ha	Sub-catchments	2010-11	Paddock to reef	2
Primary	sugar cane	sn_d_rfi	D nutrient practices	ha	Sub-catchments	2010-11	Paddock to reef	3
Primary	sugar cane	s_psii_a	Sugar cane anthropogenic PS II loads	kg/y	Sub-catchments	2009-10	Paddock to reef	1
Primary	sugar cane	sp_c_rfi	C herbicide practices	ha	Sub-catchments	2010-11	Paddock to reef	1
Primary	sugar cane	sp_d_rfi	D herbicide practices	ha	Sub-catchments	2010-11	Paddock to reef	2
Primary	risk	cots	COTS influence	rank	Sub-catchments	2013	Britta Schaffelke	1
Primary	risk	risk_pest	Herbicide risk	rank	Sub-catchments	2013	Stephen Lewis	1

APPENDIX 9 Estimated flows, herbicide loads, ratings, toxic loads and average concentrations for Great Barrier Reef Sub-catchments

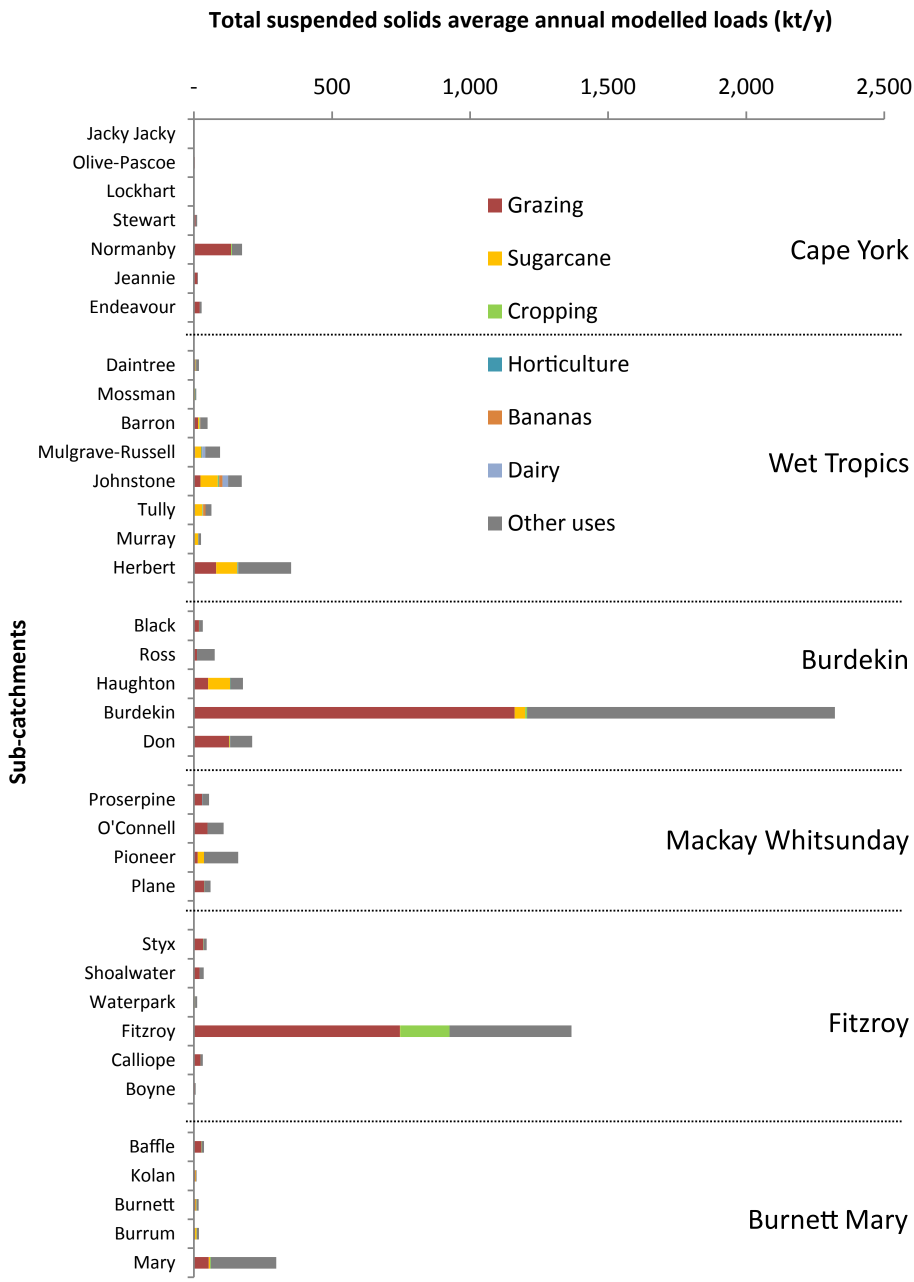
Sub-catchment	Flow (ML/y)	Ametryn (kg)	Atrazine (kg)	Diuron (kg)	Hexazinone (kg)	Tebuthiuron (kg)	Ametryn rating	Atrazine rating	Diuron rating	Hexazinone rating	Tebuthiuron rating	Total 'toxic' PSII load	Toxic EMC (µg.L⁻¹)
Pioneer River	822 186	32	530	1300	193	0	35.7	51	1300.2	43.6	0	1430.6	1.74
Plane Creek	1 264 564	39	640	1569	233	0	43.1	61.6	1568.9	52.7	0	1726.2	1.37
O'Connell River	1 475 735	24	400	980	146	0	26.9	38.5	980.4	32.9	0	1078.8	0.73
Proserpine River	1 243 837	17	286	699	104	0	19.2	27.5	698.9	23.5	0	769.2	0.62
Haughton River	1 045 169	15	512	290	8	1	16.3	49.3	290.1	1.8	0.1	357.7	0.34
Herbert River	4 273 490	0	395	478	476	2	0	38	478	107.6	0.2	623.8	0.15
Burnett River	193 141	0	96	4	38	9	0	9.3	4.3	8.7	0.7	23	0.12
Johnstone River	4 559 029	0	247	301	299	0	0	23.8	301.1	67.6	0	392.5	0.09
Mulgrave-Russell Rivers	3 684 046	0	182	225	222	0	0	17.5	224.7	50.2	0	292.5	0.08
Don River	846 600	1	32	48	12	1	1.3	3.1	48	2.7	0.1	55.2	0.07
Mossman River	507 886	0	18	23	23	0	0	1.8	22.9	5.1	0	29.8	0.06
Tully River	3 488 088	0	121	147	146	0	0	11.7	146.7	33	0	191.5	0.05
Murray River	1 290 985	0	43	53	52	0	0	4.2	52.8	11.9	0	68.8	0.05
Kolan River	74 321	0	6	3	3	1	0	0.6	2.6	0.6	0.1	3.9	0.05
Fitzroy River	4 659 346	0	586	81	27	639	0	56.4	80.6	6	49.6	192.7	0.04
Burrum River	258 813	0	14	6	6	1	0	1.4	5.5	1.3	0	8.2	0.03
Shoalwater Creek	387 422	0	3	7	1	0	0.2	0.3	6.6	0.3	0	7.3	0.02
Burdekin River	8 913 702	3	154	63	4	266	3.1	14.9	62.8	0.9	20.7	102.3	0.01
Mary River	1 400 239	0	64	2	25	1	0	6.1	2.2	5.7	0.1	14.1	0.01
Barron River	793 802	0	19	4	10	0	0	1.8	3.8	2.3	0	8	0.01
Black River	620 226	0	7	3	0	0	0.2	0.7	3.5	0.1	0	4.4	0.01
Boyne River	40 307	0	1	0	0	1	0	0.1	0	0.1	0	0.2	0.01
Daintree River	2 639 319	0	9	11	10	0	0	0.8	10.6	2.4	0	13.8	0.01

APPENDIX 9 Estimated flows, herbicide loads, ratings, toxic loads and average concentrations for Great Barrier Reef Sub-catchments

Sub-catchment	Flow (ML/y)	Ametryn (kg)	Atrazine (kg)	Diuron (kg)	Hexazinone (kg)	Tebuthiuron (kg)	Ametryn rating	Atrazine rating	Diuron rating	Hexazinone rating	Tebuthiuron rating	Total 'toxic' PSII load	Toxic EMC (μg.L^{-1})
Baffle Creek	491 201	0	3	0	1	1	0	0.3	0.3	0.3	0.1	0.9	0
Calliope River	117 034	0	0	0	0	1	0	0	0	0	0	0.1	0
Styx River	271 616	0	0	0	0	1	0	0	0	0	0.1	0.1	0
Ross River	573 747	0	1	0	0	0	0	0.1	0	0.1	0	0.2	0
Water Park Creek	391 686	0	0	0	0	0	0	0	0	0	0	0.1	0
Normanby River	4 692 715	0	1	0	1	6	0	0.1	0	0.1	0.5	0.7	0
Jacky Jacky Creek	2 830 817	0	0	0	0	0	0	0	0	0	0	0	0
Olive-Pascoe Rivers	3 575 881	0	0	0	0	0	0	0	0	0	0	0	0
Lockhart River	2 213 964	0	0	0	0	0	0	0	0	0	0	0	0
Stewart River	1 325 365	0	0	0	0	0	0	0	0	0	0	0	0
Jeannie River	1 309 193	0	0	0	0	0	0	0	0	0	0	0	0
Endeavour River	1 588 862	0	0	0	0	0	0	0	0	0	0	0	0

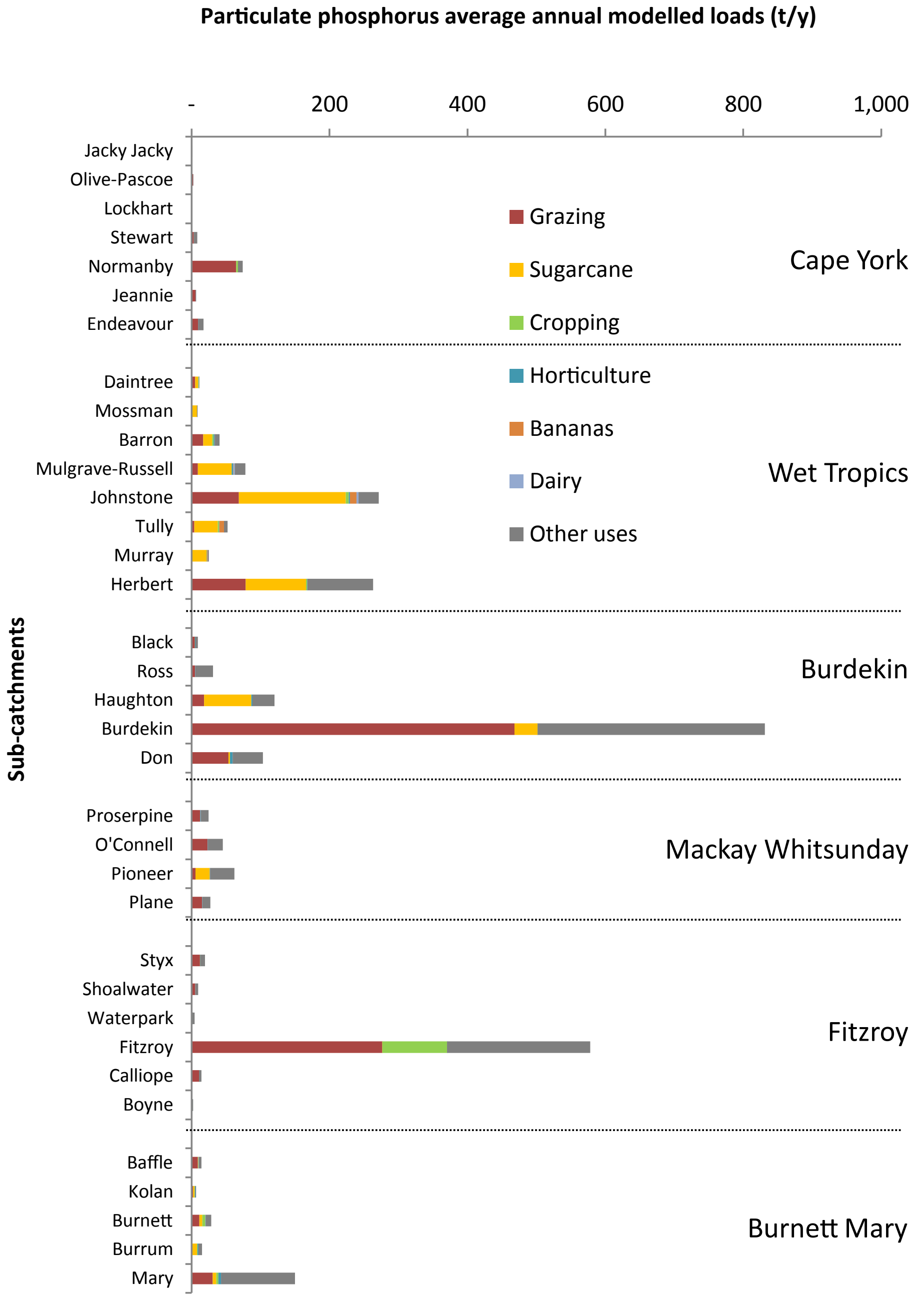
APPENDIX 10 Anthropogenic baseline – average annual modelled loads (1986–2009) exported from GBR sub-catchments by land use

FIGURE 16 Anthropogenic baseline – total suspended solids – average annual modelled loads (1986–2009) exported from sub-catchments (kilotonnes per year) by land use



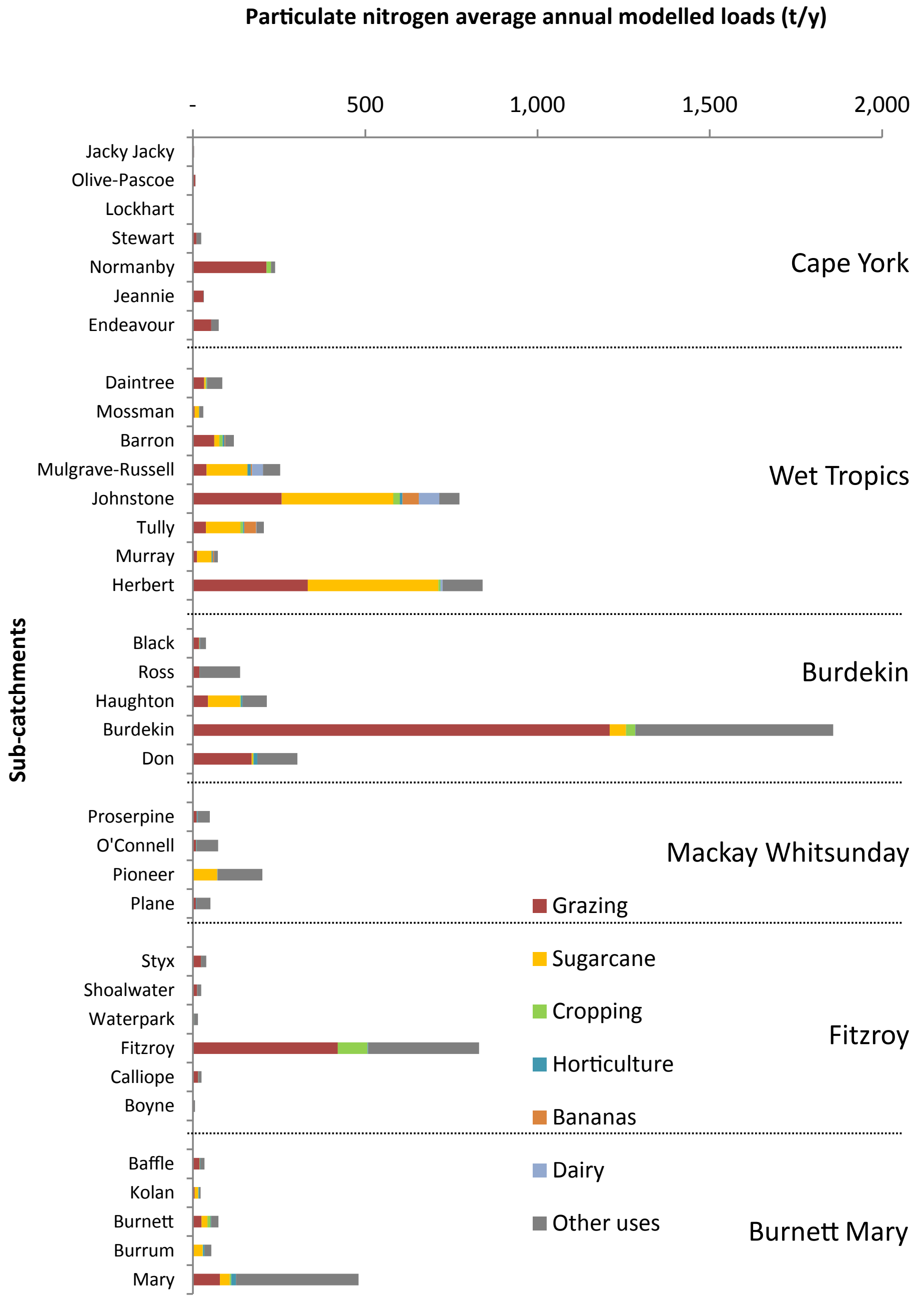
Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land.

FIGURE 17 Anthropogenic baseline – particulate phosphorus – average annual modelled loads (1986–2009) exported from sub-catchments (tonnes per year) by land use



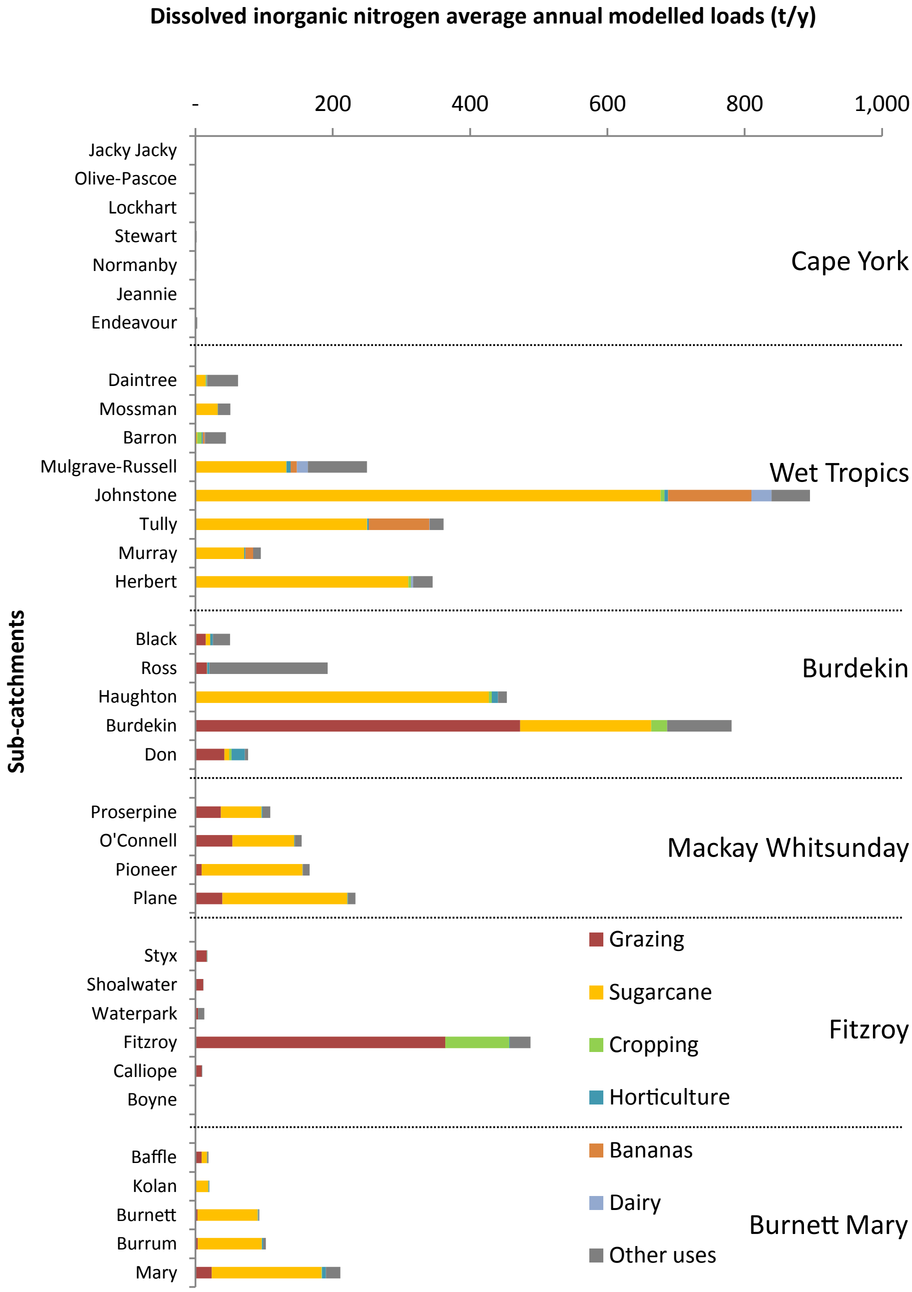
Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land.

FIGURE 18 Anthropogenic baseline – particulate nitrogen – average annual modelled loads (1986–2009) exported from sub-catchments (tonnes per year) by land use



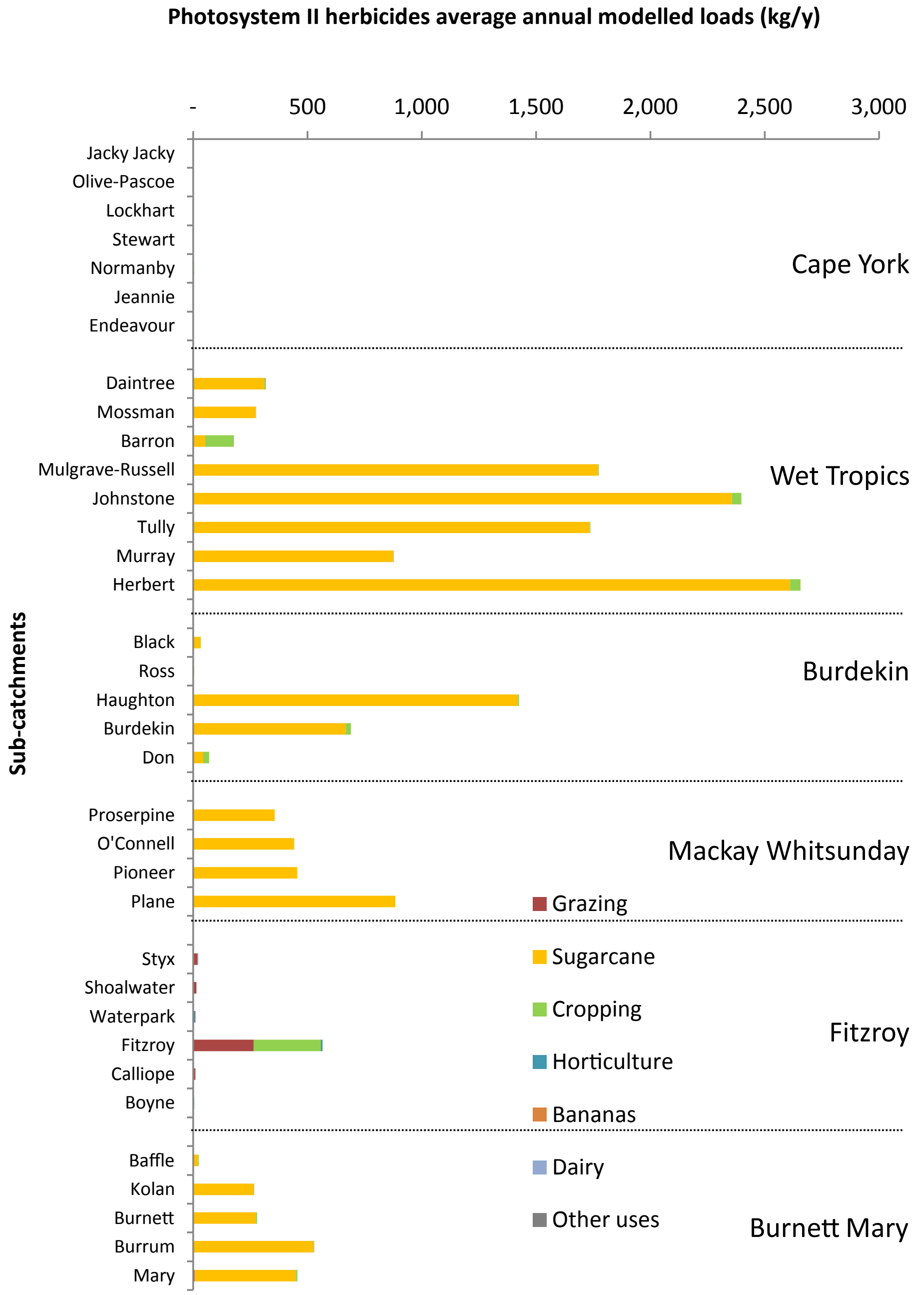
Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land.

FIGURE 19 Anthropogenic baseline – dissolved inorganic nitrogen – average annual modelled loads (1986–2009) exported from sub-catchments (tonnes per year) by land use



Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land.

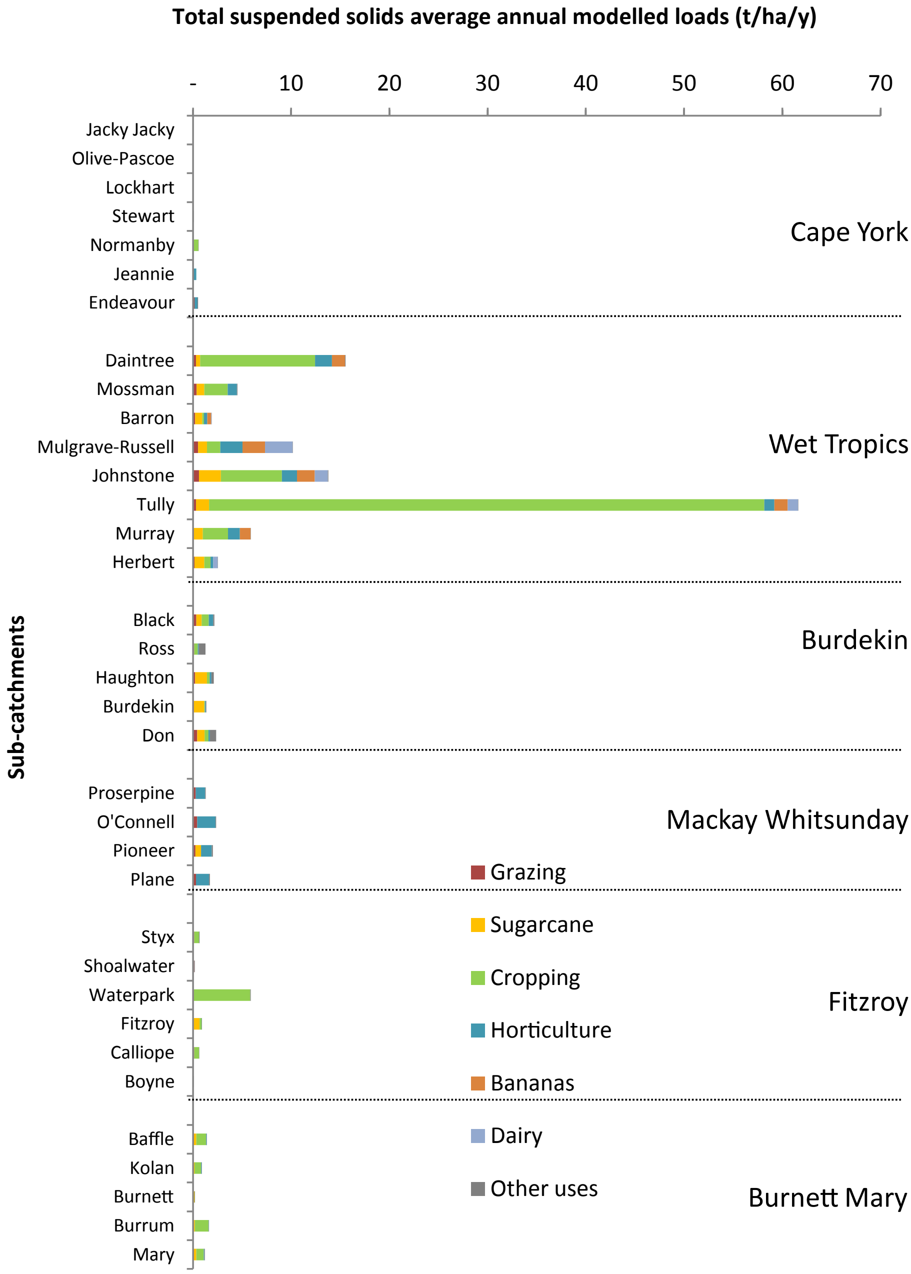
FIGURE 20 Anthropogenic baseline – photosystem II herbicides – average annual modelled loads (1986–2009) exported from sub-catchments (kilograms per year) by land use



Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land.

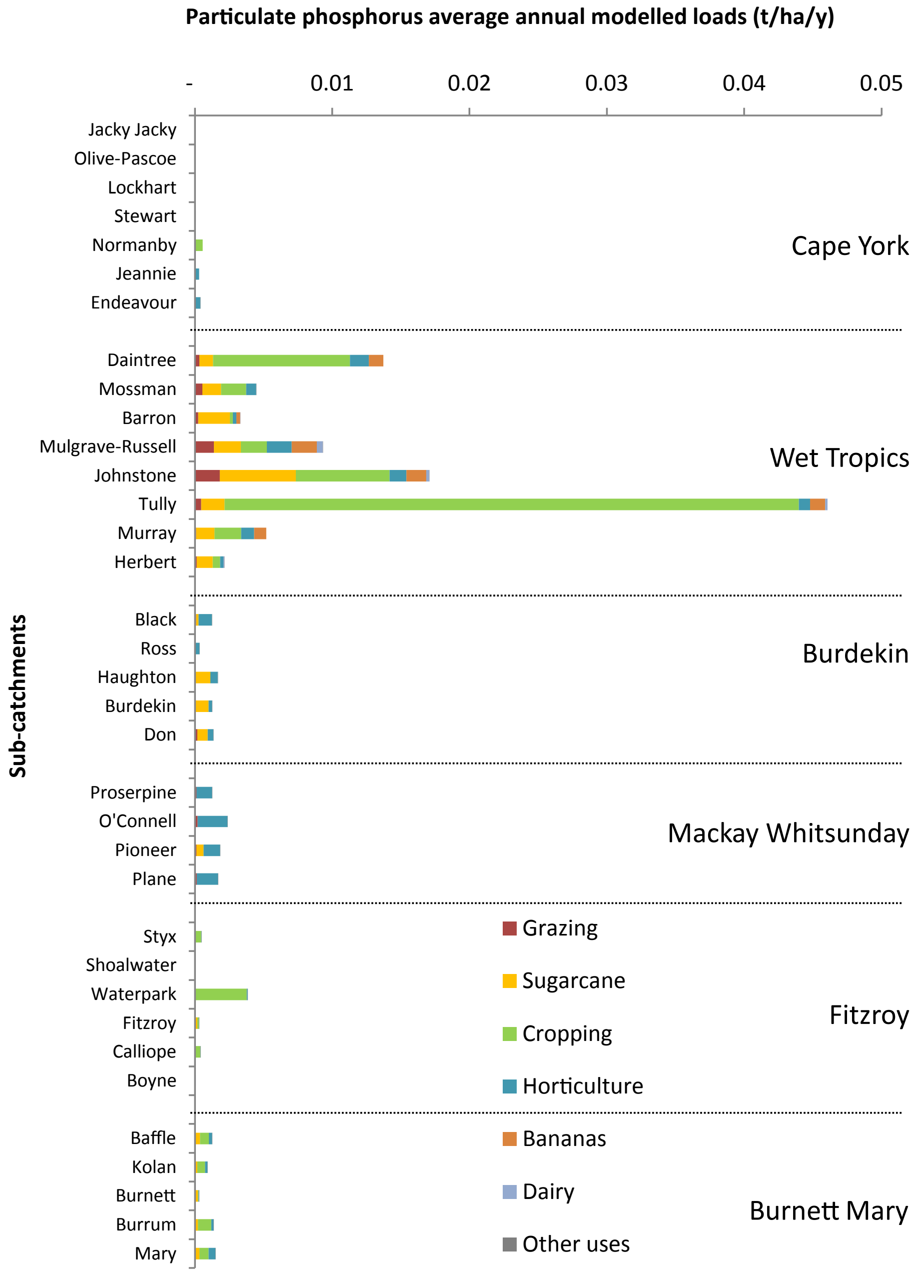
Appendix 11 Anthropogenic baseline – total suspended solids – average annual modelled loads (1986–2009) exported by sub-catchments (tonnes per hectare per year) by land use

FIGURE 21 Anthropogenic baseline – total suspended solids – average annual modelled loads (1986–2009) exported from sub-catchments (tonnes per hectare per year) by land use



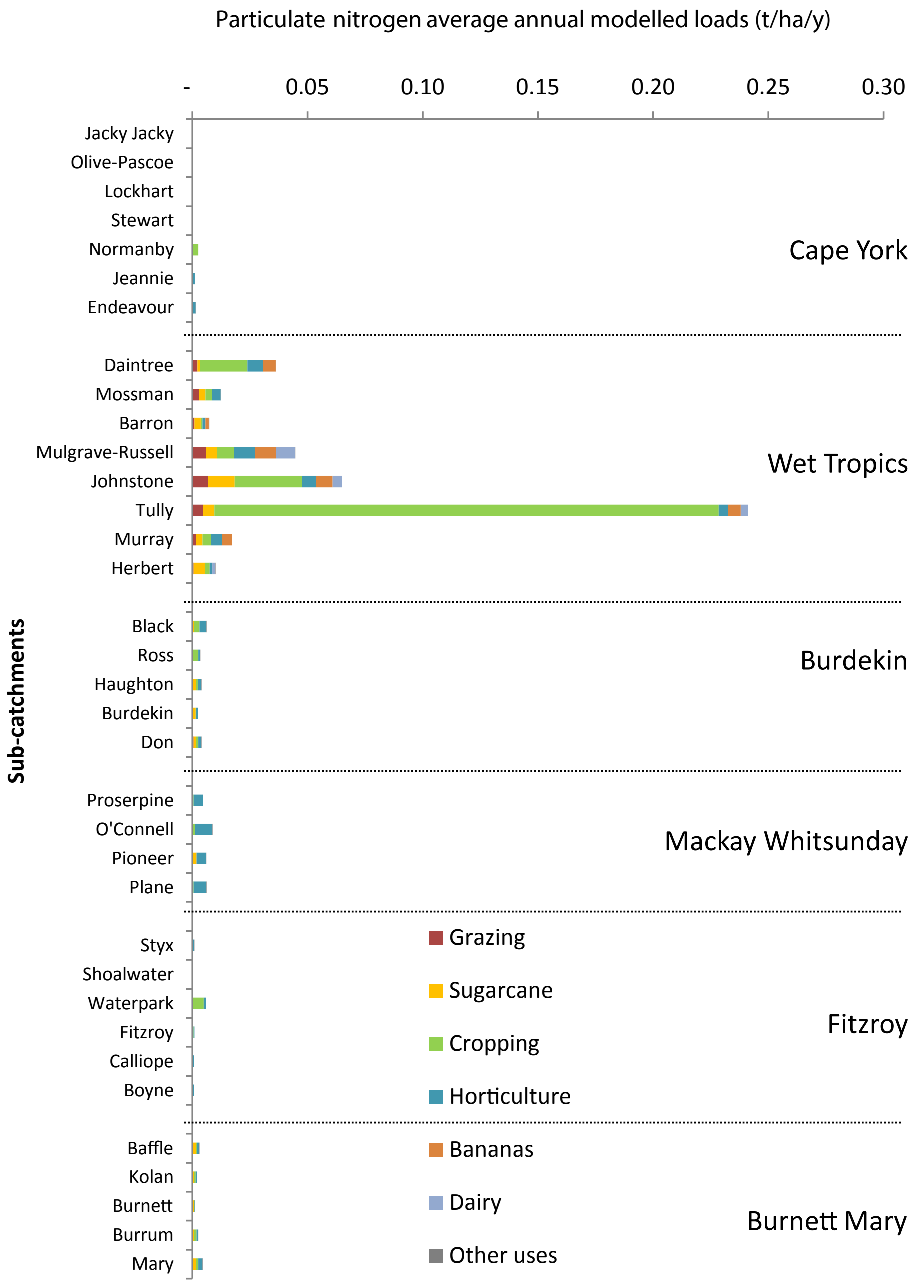
Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land. Loads for individual land uses should not be added.

FIGURE 22 Particulate phosphorus – average annual modelled loads (1986–2009) exported by sub-catchments (tonnes per hectare per year) by land use



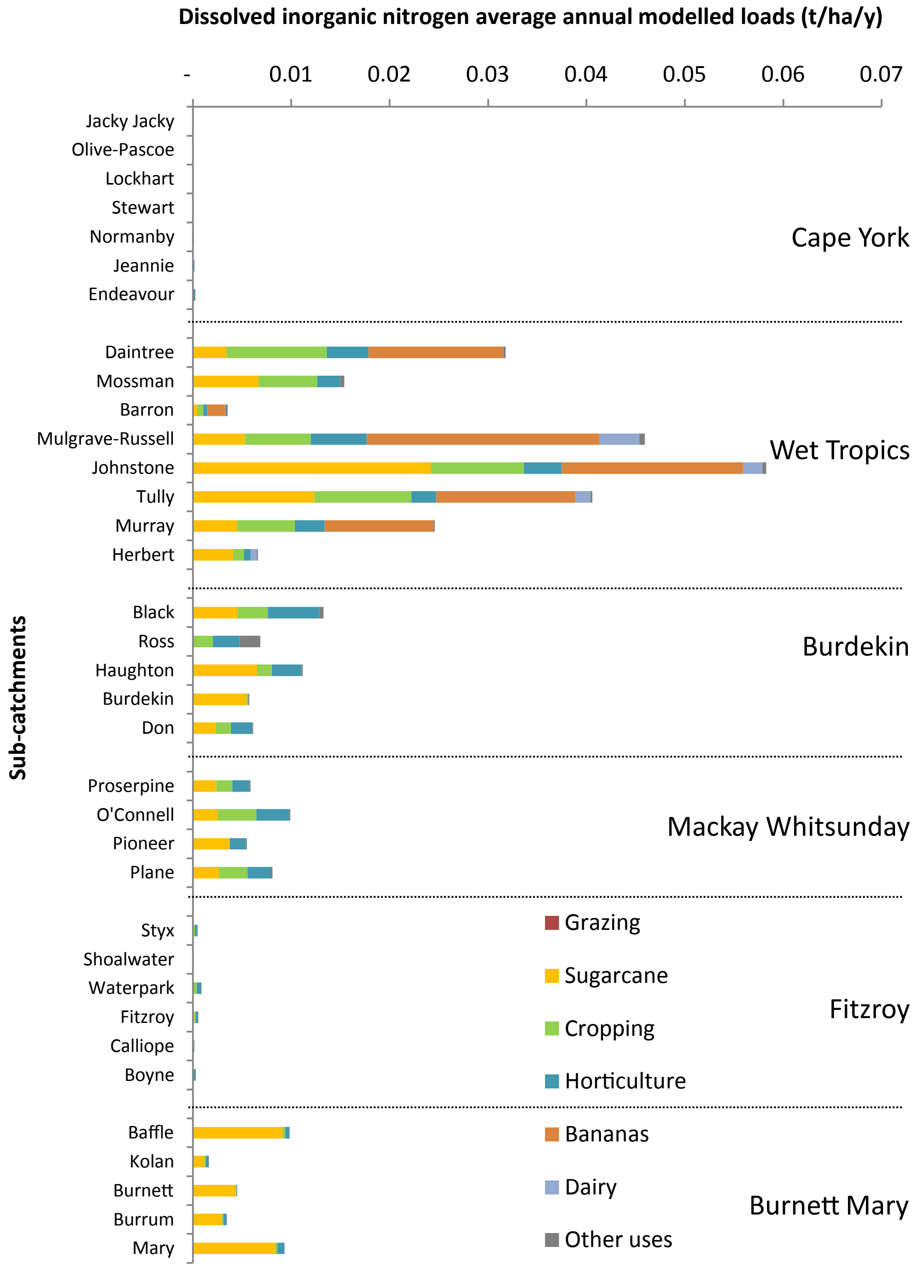
Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land. Loads for individual land uses should not be added

FIGURE 23 Anthropogenic baseline – particulate nitrogen – average annual modelled loads (1986–2009) exported by sub-catchments (tonnes per hectare per year) by land use



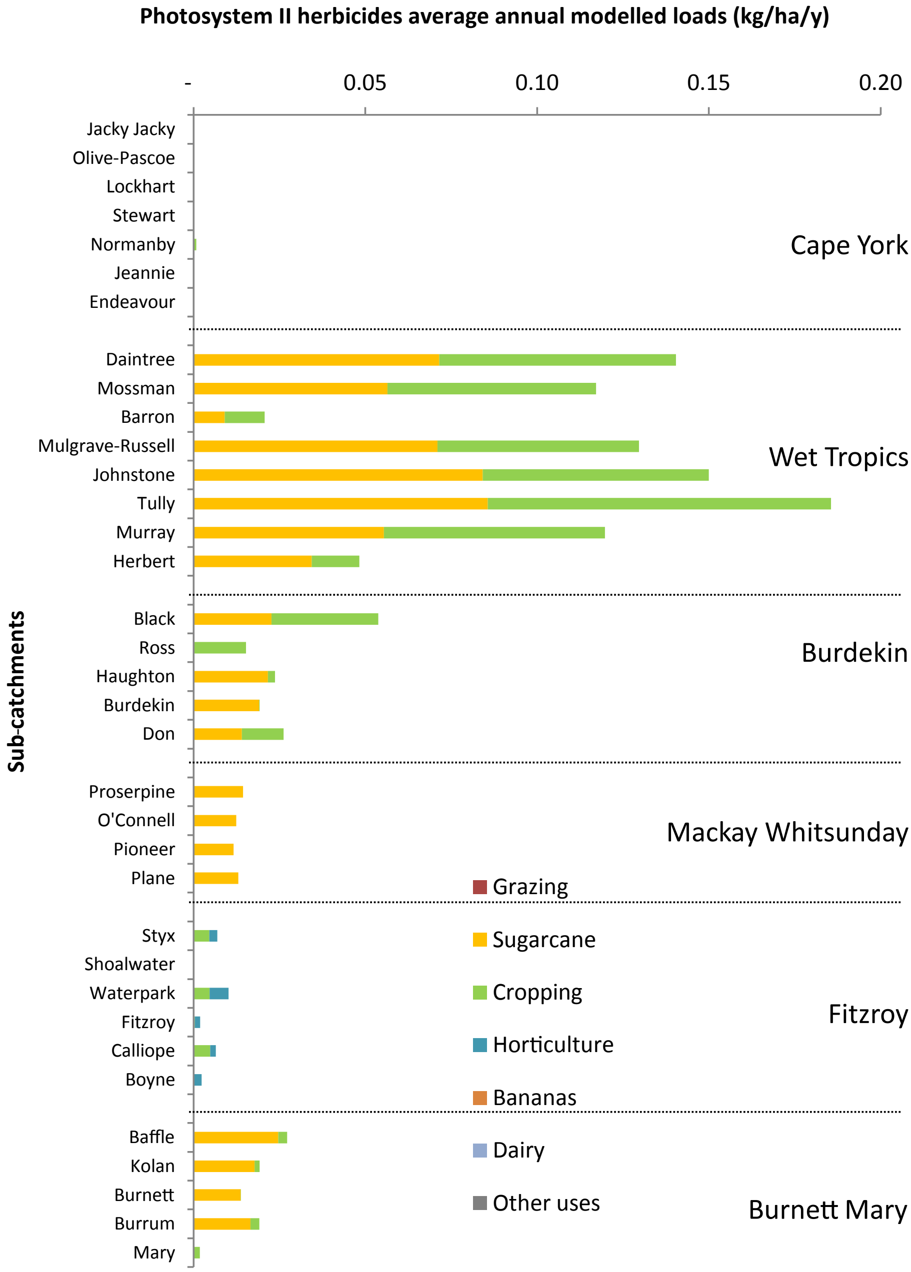
Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land. Loads for individual land uses should not be added

FIGURE 24 Anthropogenic baseline – dissolved inorganic nitrogen – average annual modelled loads (1986–2009) exported by sub-catchments (tonnes per hectare per year) by land use



Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land. Loads for individual land uses should not be added

FIGURE 25 Anthropogenic baseline – Photosystem II herbicides – average annual modelled loads (1986–2009) exported by sub-catchments (kilograms per hectare per year) by land use



Note: Other uses include contributions from stream bank erosion, nature conservation, forestry and urban land. Loads for individual land uses should not be added