Reef Water Quality Protection Plan 2013

Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments

Whole of GBR

Technical Report

Volume 1

Australian Government

Queensland Government

Prepared by

David Waters

Department of Natural Resources and Mines (DNRM), Toowoomba

Contact

David Waters

Senior Hydrologist

Email: david.waters@dnrm.qld.gov.au

Phone: (07) 4529 1395

To reference this volume:

Waters, DK, Carroll, C, Ellis, R, Hateley, L, McCloskey, GL, Packett, R, Dougall, C, Fentie, 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Whole of GBR, Technical Report, Volume 1*, Queensland Department of Natural Resources and Mines, Toowoomba, Queensland (ISBN: 978-1-7423-0999).

Acknowledgements

This project is part of the Queensland and Australian Government's Paddock to Reef program. The project is funded by the Queensland Department of Natural Resources and Mines '*Queensland Regional Natural Resource Management Investment Program 2013–2018'* with support from the Department of Science, Information Technology, Innovation and the Arts (DSITIA).

Technical support was provided by a number of organisations and individuals, including Environmental Monitoring and Assessment Science (DSITIA), Queensland Hydrology (DSITIA) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). We would also like to thank three reviewers for providing feedback on this report.

Executive Summary

In response to a decline in water quality entering the Great Barrier Reef (GBR) lagoon, the Reef Water Quality Protection Plan 2003 was developed through a joint Queensland and Australian Government initiative. The long-term goal is to ensure that by 2020 the quality of water entering the GBR from adjacent catchments has no detrimental impact on the health and resilience of the GBR. Reef Plan 2003 was subsequently updated, (Reef Plan 2009) and included a clear set of water quality and management practice targets to reduce sediment, nutrient and photosystem-II (PSII) inhibiting herbicide loads to the GBR lagoon. This report provides a summary of the estimated sediment, nutrient and PSII herbicide loads discharged from all GBR catchments and secondly the progress made towards achieving the Reef Plan 2009 water quality targets from the baseline year 2008–2009, for four reporting periods: 2008–2010, 2010–2011, 2011–2012 and 2012–2013 (Report Cards 2010–2013).

The GBR catchments drain an area of 423,134 km^2 of coastal Queensland, consisting of 35 major basins and covering 2,300 km. The predominant land uses are grazing (75%), nature conservation (13%), sugar cane (1%) and rain-fed summer and winter cropping (<3%). Relatively small areas of horticulture crops are grown in the high rainfall and coastal irrigation areas, with irrigated cotton mainly found in inland areas of the Fitzroy region. There are six NRM regions—Cape York the most northern, Wet Tropics, Burdekin Dry Tropics, Mackay Whitsunday, Fitzroy and the Burnett Mary at the most southern part of the GBR system.

Detecting changes in water quality to assess progress towards targets using monitoring alone, would be extremely difficult due to variability in rainfall (rate and amount), antecedent conditions such as ground cover and changing land use and land management practices. Therefore the Paddock to Reef (P2R) program uses catchment modelling as one of multiple lines of evidence to report on progress towards Reef Plan 2009 targets. It is important to note that this report summarises the modelled, not measured, average annual loads and load reductions of key constituents. Management changes reflected in the model were based on practice adoption data provided by regional Natural Resource Management (NRM) groups and industry.

The eWater CRC Source Catchments modelling framework was used to simulate sediment, nutrient and pesticide loads entering the GBR lagoon and the subsequent reductions in loads. A Source Catchments model was produced for each of the six NRM regions. For hillslope constituent generation, two paddock models (HowLeaky and APSIM) were used to generate the daily pollutant loads and the subsequent reductions in loads due to the adoption of improved land management practices for cropping and cane land uses respectively. In grazing areas, the Universal Soil Loss Equation (USLE) was used to generate daily loads, with the grazing systems model GRASP used to derive changes in ground cover (C-factor) in the USLE model, reflecting different grazing management practice. The selection of the three paddock models was based on their proven ability to represent management practices specific to each of the major GBR agricultural industries. An Event Mean Concentration (EMC) approach was used to generate loads for conservation and remaining land use areas where no specific industry models were available. SedNet modelling functionality was incorporated into the Source Catchments framework to provide estimates of gully and streambank erosion and floodplain deposition.

The Reef Plan 2009 water quality targets were set against the estimated anthropogenic baseline load (total load minus predevelopment load). In order to reduce the effect of climate variability, a static climate period was used (1986–2009) for each scenario to produce average annual loads and the relative change in loads due to industry and government investments in improved land

management practices.

Land management practices were defined under an ABCD practice framework for each major industry, with A (cutting edge in cane and highly likely to maintain land in good condition for grazing), B (best practice in cane and likely to maintain land in good/fair condition for grazing), C (common practice in cane and likely to degrade some land for grazing) and D (unacceptable in cane and highly likely to degrade land to poor condition in grazing) management practice. The proportion of each industry in ABC or D class of management was firstly established for the baseline year (2008–2009) and for each subsequent year following implementation of improved management practices.

Improvements in water quality as a result of the adoption of improved management practices were simulated in paddock models for cropping land uses. The paddock model time series outputs were aggregated and loaded into the Source Catchments modelling framework. For grazing, all loads were generated within Source Catchments.

Source Catchments was coupled to an independent Parameter EStimation Tool (PEST) to perform hydrology calibrations. Once calibrated, three criteria were used to assess the calibration performance at each gauging station: the Nash Sutcliffe coefficient of efficiency (NSE), calculated for daily and monthly flows and the difference between total measured and modelled stream flow volumes. Similarly, modelled constituent loads were assessed against measured estimates for the full 23 year modelling period at 10 end-of-system (EOS) monitoring sites using three modelling performance criteria at a monthly time-step: 1) the ratio of the root mean square error to the standard deviation (RSR), 2) NSE and 3) the volume difference or per cent bias (PBIAS). In addition, average annual constituent load comparisons were made with four years of GBR loads monitoring program (GBRLMP) data and other regionally specific load estimates. Finally, GBR Source Catchments loads were compared with previously published monitored and modelled load estimates.

The hydrology calibration for the six regions showed good agreement with observed flows. Over 80% of gauges in the Cape York, Wet Tropics and Mackay Whitsunday regions met the three performance criteria. Over 60% of all gauges across the GBR met two of the three performance criteria.

The constituent load validation statistics for the 23 year modelling period were rated satisfactory to very good against the performance criteria at eight of the 10 EOS catchment monitoring sites. Monthly NSE coefficient values for total suspended sediment (TSS) ranged from 0.56 to 0.91; total phosphorus (TP) ranging from 0.50 to 0.81 (eight of the 10 sites); and total nitrogen (TN) ranging from 0.61 to 0.93. There was also favourable comparison with average annual loads derived from short-term (2006–2010) estimates at the 10 key catchment monitoring sites.

For the whole of GBR, modelled estimates of TSS, TP and TN exported loads have increased by 2.9, 2.3 and 1.8 fold respectively from predevelopment loads. Increase factors were smaller than previously reported increases of 5.5, 8.9 and 5.8 fold for TSS, TP and TN (Kroon et al. 2012). Differences in increase factors and current load estimates are a result of the methods used to derive loads and the period over which the models were run. For example the current Source Catchments models include; representation of all major water storages in each basin, the removal of flow and constituents via irrigation extraction, greater spatial and temporal representation of ground cover from remotely sensed data (used to derive a cover factor for the USLE) and the use of industry specific paddock models to generate sediment, nutrient and pesticide loads and their associated improved management.

Over the reporting period of Reef Plan 2009, the modelling indicates that the adoption of improved land management practices were estimated to have reduced loads of TSS, TP, TN and PSII herbicides to the reef lagoon by 11% (615 kt/yr), 13% (444 t/yr), 10% (1,646 t/yr) and 28% (4,626 kg/yr) respectively (Table 1).

The major sources of sediment to the GBR were from the Burdekin and Fitzroy NRM regions, contributing over 70% of the total modelled anthropogenic TSS load. Over half of the reduction in TSS load occurred in the Burdekin region, with a large proportion of the reductions a result of riparian fencing projects to reduce streambank erosion and through improved grazing land management practices, in particular fencing by land type. Whilst the catchment load targets are regarded as ambitious, the TSS load reduction of 11% is halfway towards the Reef Plan 2009 target of 20% reduction by 2020.

The TP average annual load reduction for the GBR was 13% with the majority particulate phosphorus. The Wet Tropics region had the highest reduction at 19%. The reductions were predominately achieved through improved grazing management practices over the five years, The major sources of TN to the GBR were from the Burdekin and Wet Tropics NRM regions, contributing over 70% of the total modelled anthropogenic TN load. The Mackay Whitsundays (17%) and Burnett Mary (15%) regions achieved the greatest reductions. For all cane growing regions, over half of the reductions were attributed to the adoption of improved management of dissolved nutrients. The largest water quality load reduction across the GBR was for PSII herbicides. The average annual PSII herbicide load leaving the GBR basins reduced by 28% for Report Card 2013 (2008-2013). Over 80% of the reduction in the PSII load occurred in the sugarcane areas of Wet Tropics and Mackay Whitsunday NRM regions.

When assessing load reductions against the Reef Plan 2009 progress criteria outlined in Table 2, there has been *very good* progress towards meeting the TSS load reduction target and *moderate* overall progress towards meeting the PSII reduction targets, with *poor* to *very poor* progress towards the TP and TN targets. The slow progress towards the nutrient targets highlight that alternative fertiliser management strategies, particularly in sugar cane, will need to be considered if future nutrient targets are to be achieved.

A number of additional scenarios were run to assess the potential to achieve the targets. Model results (Report Card 2011 only) were encouraging and suggested that the Reef Plan 2009 20% TSS reduction target could be met if 50% of A class practices and 50% B class practices were adopted, PSII target could be achieved under an “All B” class practice adoption whilst achieving the 50% TN and DIN reduction is more challenging.

There are a number of industries and practices where the effect of improved management on water quality was not modelled due to a lack of data to support the modelling. For example water quality improvements for horticulture, dairy and bananas and DIN in grains and grazing. A detailed description of the caveats around the modelling is included in the report. Consistent with the P2R program’s continual improvement approach, a number of data inputs to the model will be updated prior to delivery of model results for Report Card 2014. It is important to note that updates to the model can only occur at the commencement of each Reef Plan cycle. This approach ensures consistency in reporting across each Report Card. Therefore updated data layers will be implemented prior to delivery of model results for Report Card 2014. Updates for Report Card 2014 will include improving the hydrology calibration, extension of the model climate period by five years to include the recent extreme events and the inclusion of the most recent spatial data layers such as seasonal cover all of which will improve modelled load estimates. In addition, more spatially explicit management practice change data, to be provided by regional NRM groups, will be a critical update to improve the spatial representation and hence relative change in exported constituent loads from the regional catchments.

The current modelling framework is flexible, innovative and has improved the capacity to model management practice change compared to previous GBR catchment modelling approaches. A consistent methodology was adopted across all NRM regions to enable comparison across regions and a consistent approach to be applied for reporting of load reductions. The Source Catchments modelling framework has proven to be an appropriate tool for assessing load reductions due to improved land management practices across the GBR.

Table 1 Progress towards water quality load reduction targets for Reef Plan 2009 period (2008–2013)

Region	Load reductions (%)				
	TSS	TP	TN	DIN	PSII
Cape York	9	7	6	0	0
Wet Tropics	13	19	8	13	26
Burdekin	16	11	10	14	13
Mackay Whitsunday	9	14	17	24	42
Fitzroy	4	6	3	0	5
Burnett Mary	3	10	15	31	28
GBR wide reductions	**11**	**13**	**10**	**16**	**28**

Table 2 Criteria used to define progress towards the Reef Plan 2009 water quality targets
See http://www.reefplan.qld.gov.au/measuring-success/methods/scoring-system.aspx

Progress towards water quality targets	Pesticides, nitrogen and phosphorus			Sediment		
	Target: 50% reduction in load by 2013			Target: 20% reduction in load by 2020		
	June 2011	June 2012	June 2013	June 2011	June 2012	June 2013
Very poor	None	0–5%	5–12.5%	None	0–1%	1–3%
Poor	0–5%	5–12.5%	12.5–25%	0–1%	1–3%	3–5%
Moderate	5–12.5%	12.5–25%	25–37.5%	1–3%	3–5%	5–7%
Good	12.5–25%	25–37.5%	37.5–49%	3–4%	5–6%	7–8%
Very good	>25%	>37.5%	>50%	>4%	>6%	>8%

Table of Contents

List of Tables

List of Figures

Acronyms

Acronym	Description
ANNEX	Annual Network Nutrient Export—SedNet module speciates dissolved nutrients into organic and inorganic forms
ASRIS	Australian Soils Resource Information System
DERM	Department of Environment and Resource Management (now incorporated into the Department of Natural Resources and Mines)
DNRM	Department of Natural Resources and Mines
DS	Dynamic SedNet—a Source Catchments 'plug-in' developed by DNRM/DSITIA, which provides a suite of constituent generation and in-stream processing models that simulate the processes represented in the SedNet and ANNEX catchment scale water quality model at a finer temporal resolution than the original average annual SedNet model
DSITIA	Department of Science, Information Technology, Innovation and the Arts
DWC	Dry weather concentration—a fixed constituent concentration assumed to represent the concentration during base or slowflow runoff. The product of the two is the baseflow load for a given functional unit
E2	Former catchment modelling framework—a forerunner to Source Catchments that could be used to simulate catchment processes to investigate management issues
EMC	Event mean concentration— a fixed constituent concentration assumed to represent the concentration during quickflow or storm runoff. The product of the two is the quickflow load for a given functional unit
EOS	End-of-system
ERS	Environment Resource Sciences
FPC	Foliage projected cover
FRCE	Flow Range Concentration Estimator—a modified Beale ratio method used to calculate daily loads from monitored data
FU	Functional unit
GBR	Great Barrier Reef
GBRCLMP	Great Barrier Reef Catchment Event Monitoring Program (supersedes GBRI5)
HowLeaky	Water balance and crop growth model based on PERFECT
HRU	Hydrological response unit

HSDR	Hillslope sediment delivery ratio
NLWRA	National Land and Water Resources Audit
NRM	Natural Resource Management
NRW	Natural Resources and Water (incorporated into the Department of Environment and Resource Management, now incorporated into the Department of Natural Resources and Mines)
NSE	Nash Sutcliffe Coefficient of Efficiency
Paddock to Reef program	Paddock to Reef Integrated Monitoring, Modelling and Reporting Program
PET	Potential evapotranspiration
PSII herbicides	Photosystem II herbicides—ametryn, atrazine, diuron, hexazinone and tebuthiuron
QLUMP	Queensland Land Use Mapping Project
Quickflow	Defined in this report as surface runoff (includes interflow, infiltration excess and saturation excess) exiting the land surface (entering the stream)
Report Cards 2010–2013	Annual reporting approach communicating outputs of Reef Plan/Paddock to Reef
Reef Rescue	An ongoing and key component of Caring for our Country Australian Government funding program. Reef Rescue represents a coordinated approach to environmental management in Australia and is the single largest commitment ever made to address the threats of declining water quality and climate change to the Great Barrier Reef World Heritage Area
RUSLE	Revised Universal Soil Loss Equation
SedNet	Catchment model that constructs average annual sediment and nutrient (phosphorus and nitrogen) budgets for regional scale river networks (3,000–1,000,000 km^2) to identify patterns in the material fluxes
Six Easy Steps program	Integrated sugarcane nutrient management tool that enables the adoption of best practice nutrient management on farm. The Six Easy Steps nutrient management program forms part of the nutrient management initiative involving BSES limited, CSR Ltd and the Queensland Department of Environment and Resource Management (DERM). It is supported by CANEGROWERS and receives funding from Sugar Research and Development corporation (SRDC), Queensland Primary Industries and Fisheries and the Australian Department of the Environment, Water, Heritage and the Arts
Slowflow	Subsurface seepage and low energy overland flow otherwise known as baseflow. The

	seepage could be related to ground water interaction, but this is not an explicit design assumption in the GBR modelling
STM	Short-term modelling project
TSS	Total suspended sediment

Units

Units	Description
kg/ha	kilograms per hectare
kg/ha/yr	kilograms per hectare per year
kt/yr	kilotonnes per year
mg/L	milligrams per litre
mm	millimetres
t/m^3	tonnes per cubic metre
g/cm^3	grams per centimetre cubed
ML	megalitres
t/ha	tonnes per hectare
t/ha/yr	tonnes per hectare per year
µg/L	micrograms per litre

Full list of Technical Reports in this series

Waters, DK, Carroll, C, Ellis, R, Hateley, L, McCloskey, GL, Packett, R, Dougall, C, Fentie, B 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Whole of GBR, Technical Report, Volume 1*, Queensland Department of Natural Resources and Mines, Toowoomba, Queensland (ISBN: 978-1-7423-0999).

McCloskey, GL, Ellis, R, Waters, DK, Carroll, C 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Cape York NRM Region, Technical Report, Volume 2,* Queensland Department of Natural Resources and Mines, Cairns, Queensland (ISBN: 978-0-7345-0440-1).

Hateley, L, Ellis, R, Shaw, M, Waters, D, Carroll, C 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Wet Tropics NRM region, Technical Report, Volume 3,* Queensland Department of Natural Resources and Mines, Cairns, Queensland (ISBN: 978-0-7345-0441-8).

Dougall, C, Ellis, R, Shaw, M, Waters, D, Carroll, C 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Burdekin NRM region, Technical Report, Volume 4,* Queensland Department of Natural Resources and Mines, Rockhampton, Queensland (ISBN: 978-0-7345-0442-5).

Packett, R, Dougall, C, Ellis, R, Waters, D, Carroll, C 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Mackay Whitsunday NRM region, Technical Report, Volume 5,* Queensland Department of Natural Resources and Mines, Rockhampton, Queensland (ISBN: 978-0-7345-0443-2).

Dougall, C, McCloskey, GL, Ellis, R, Shaw, M, Waters, D, Carroll, C 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Fitzroy NRM region, Technical Report, Volume 6,* Queensland Department of Natural Resources and Mines, Rockhampton, Queensland (ISBN: 978-0-7345-0444-9).

Fentie, B, Ellis, R, Waters, D, Carroll, C 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Burnett Mary NRM region, Technical Report, Volume 7,* Queensland Department of Natural Resources and Mines, Brisbane, Queensland (ISBN: 978-0-7345-0445-6).

Advancements and assumptions in Source Catchments modelling

The key modelling advancements to note are:

- Use of two locally developed paddock models to generate the daily pollutant loads for cane and grain land uses, with extensive application representing land management change for agricultural industries across the GBR
- Ability to run the models and interrogate the results down to a daily time-step
- Incorporation of annual spatial and temporally variable cover over the 23 year modelling period, rather than a single static cover factor for a particular land use
- Representation of hillslope, gully and streambank erosion processes
- Inclusion of small coastal catchments not previously modelled
- Integration of monitoring and modelling through (a) validation and (b) identifying monitoring sites where data deficiencies occur
- Use of a consistent modelling platform and methodology across the six GBR NRM regions, enabling direct comparison of results between each region

The key modelling assumptions to note are:

- Loads reported for each scenario reflect the modelled average annual load for the specified model run period (1986–2009)
- Land use areas in the model remain static over the model run period and between scenarios. Land use areas were based on the latest available QLUMP data
- Predevelopment land use scenario includes all storages, weirs and water extractions, with no change to hydrology. Hence, a change to water quality represented in the model is due solely to a change in land management practice
- Paddock model runs used to populate the catchment models represent ‘typical’ management practices within a region and do not reflect the actual array of management practices being used within the GBR catchments
- Application rates of herbicides used to populate the paddock models were derived through consultation with relevant industry groups and stakeholders
- Practice adoption areas represented in the model were applied at the spatial scale that the data was supplied by regional bodies, which currently is not spatially explicit for all areas. Where it is not spatially explicit, estimates of A, B, C and D areas (where A is cutting edge and D is unacceptable; see section 3.5.1) were averaged across catchment areas. Depending on the availability of useful practice adoption data, there may be instances where a load reduction was reported for a particular subcatchment that in reality had no investment in land management improvement. Reef Plan 2013 data capture process aims to report spatially explicit management change data
- Water quality improvements for the horticulture, dairy, bananas and cotton industries are currently not modelled due to a lack of management practice data and/or limited experimental data on which to base load reductions
- Dissolved inorganic nitrogen (DIN) reductions were not modelled for the grains industry as there was no DIN model available in HowLeaky. A DIN model will be added for Report Card 2014

- The management practice change data provided from Regional NRM groups for Report Cards 2010–2013 were not supplied for each individual management component (ie soil, nutrient and herbicides). Therefore the assumption was made that management practice change from a 'B' practice to an 'A' practice in herbicide management for example also resulted in a shift from B to A for soil and nutrient management. This assumption has the potential to overstate the water quality benefits. A new ABCD framework and modelling approach using more specific practice combinations will be adopted for the Report Card 2014
- For land uses that require spatially variable data inputs for pollutant generation (USLE based estimates of hillslope erosion and SedNet-style gully erosion), data pre-processing captures the relevant spatially variable characteristics using the specific 'footprint' of each land use within each subcatchment. These characteristics are then used to provide a single representation of aggregated pollutant generation per land use in each subcatchment
- Benefits of adoption of a management practice (e.g. reduced tillage) are assigned in the year that an investment occurs. Hence water quality benefits were assumed to happen in the same year
- Gully density mapping is largely based on the coarse NLWRA mapping at present. Updated gully mapping will be undertaken to improve this particular input layer of the models for Reef Plan 2013
- Recycling of tailwater was not included in the current round of reporting due to a lack of data on the extent of Tailwater capture. This will be addressed in Reef Plan 2013
- Groundwater is not explicitly modelled and is represented as a calibrated baseflow contribution. A 'dry weather concentrations' (DWC) of constituents is multiplied by the baseflow runoff to derive a baseflow load. These loads are not subject to management effects
- Deposition of fine sediment and particulate nutrients is modelled on floodplains and in storages. No attempt to include in-stream deposition/re-entrainment of fine sediment and particulate nutrients has been undertaken at this point
- It is important to note these are modelled average annual pollutant load reductions not measured loads and are based on practice adoption data provided by regional NRM groups and Industry. It is important to note that this report summarises modelled, not actual, average annual load reductions of key constituents to the GBR lagoon based on improved land management adoption data supplied by regional NRM groups. Results from this modelling project are therefore indicative of the likely (theoretical) effects of adoption of improved land management practices for a given scenario rather than a measured (empirical) reduction in loads

1 Introduction

1.1 GBR Paddock to Reef Integrated Monitoring, Modelling and Reporting Program

Great Barrier Reef (GBR) catchments have been extensively modified over the past 150 years for agricultural production and urban settlement, leading to a decline in water quality entering the GBR lagoon (Brodie et al. 2013). In response to these water quality concerns, the Reef Water Quality Protection Plan 2003 was initiated, it was updated in 2009 and again in 2013 in a joint Queensland and Australian government initiative (Department of the Premier and Cabinet 2009, Department of the Premier and Cabinet 2013). A set of water quality and management practice targets are outlined for catchments discharging to the GBR, with the long-term goal to ensure that the quality of water entering the reef has no detrimental impact on the health and resilience of the reef. Progress towards targets is assessed through the Paddock to Reef Integrated Monitoring, Modelling and Reporting (P2R) Program. The program uses a combination of monitoring and modelling at paddock through to basin and reef scales.

The Reef Plan 2009 water quality targets are:

- By 2013 there will be a minimum 50% reduction in nitrogen, phosphorus and herbicide loads at the end of catchment
- By 2020 there will be a minimum 20% reduction in sediment load at the end of catchment

Reef Report Cards are produced to show cumulative progress towards the Reef Plan 2009 water quality targets following regional investments in improved land management practices. Modelled reductions in constituent loads resulting from the adoption of improved land management practices in 2008–2009 and 2009–2010 are outlined in Report Card 2010; 2008–2011 in Report Card 2011; 2008–2012 in Report Card 2012; and 2008–2013 in Report Card 2013. The Reef Plan 2009 water quality targets were set for the whole GBR with progress reported for the whole of GBR plus six contributing NRM regions: Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary.

Detecting changes in water quality to assess progress towards targets, using monitoring alone, is extremely difficult due to variability in rainfall (rate and amount), antecedent conditions such as ground cover and changing land use and management practices. Consequently, pollutant loads exported from a catchment can be highly variable year to year. The P2R program therefore uses catchment modelling to report on progress towards targets.

Modelling is a way to extrapolate monitoring data through time and space providing and to explore the climate and management interactions and their associated impacts on water quality. The monitoring data is the point of truth for model validation and parameterisation. Combining the two programs ensures continual improvement in modelled load estimates, at the same time identifying data gaps and priorities for future monitoring. Catchment modelling is used to predict total average annual end of catchment pollutant loads entering the GBR for predevelopment, anthropogenic baseline (total minus predevelopment) load and load reductions due to adoption of improved land management practices.

1.2 Modelling approach

Over the past 30 years, there have been a series of empirical and catchment modelling approaches undertaken, estimating constituent loads from GBR catchments over the past 30 years. These estimates differed greatly due to the different methods, assumptions, modelling and monitoring periods covered and types of data used.

In an early empirical approach Belperio (1979), assumed constant sediment to discharge relationship for all Queensland catchments based on data from the Burdekin River. This tended to overestimate sediment loads, particularly in northern GBR catchments. Moss et al. (1992) attempted to accommodate the regional difference in concentrations by assuming a lower uniform sediment concentration for the northern (125 mg/L) compared with southern (250 mg/L) Queensland catchments. In another approach, Neil & Yu (1996) developed a relationship between unit sediment yield (t/km^2/mm/yr) and mean annual runoff (mm/yr) to estimate the total mean annual sediment load for the GBR catchments.

The SedNet/ANNEX catchment model was extensively used to provide estimates of average annual sediment and nutrient loads from GBR catchments (Brodie et al. 2003, McKergow et al. 2005a, McKergow et al. 2005b, Cogle, Carroll & Sherman 2006). Most recently, Kroon et al. (2012), collated modelling and monitoring information including estimates from Brodie et al. (2009) to estimate natural and total catchments loads across the GBR. Kroon et al. (2012) estimated current TSS, TP and TN loads had increased by 5.5-, 8.9- and 5.8-fold respectively over predevelopment loads.

There was no ‘off the shelf’ modelling framework that could be applied to meet all the modelling objectives required for reef plan reporting. SedNet alone could not provide the finer resolution time-stepping required. Source Catchments (eWater Ltd 2012) was another popular water quantity and quality modelling framework developed and applied extensively in Australia. Source Catchments could not inherently represent the many variations of a spatially varying management practice such as cropping, to the level of detail required to allow subtle changes in management systems to be reflected in model outputs. To address these issues and answer the questions being posed by policy makers, customised plug-ins were developed for the Source Catchments modelling framework. These plug-ins allowed for integration of the best available data sources and landscape erosion processes into the catchment model. Purpose built routines were developed enabling representations of temporally and spatially variable ground cover, the aggregation of deterministic crop model outputs and the incorporation of gully and streambank erosion and deposition process (Ellis & Searle 2013). An expanded outline of the modelling framework is provided in section 3 of this report.

This report presents a summary of the:

- The methods and results of the model calibration and validation
- Regional total baseline loads, predevelopment and anthropogenic loads for 1986–2009 climate sequence
- Change in loads and progress towards Reef Plan 2009 water quality targets following the adoption of improved land management practices for the period 2008–2013

2 GBR background

The GBR catchments drain an area of 423,134 km^2 of coastal Queensland and cover a distance of approximately 2,100 km. There are six NRM regions across the GBR with the Burdekin and Fitzroy NRM regions making up 70% of the total GBR area. The six regions are made up of 35 Australian Water Resources Council (AWRC) Basins (ANRA 2002) (Figure 1). A summary of the six NRM regions are presented in Table 3.

Large climatic variation occurs across the study area with average annual rainfall in the coastal areas of the Wet Tropics exceeding 3,000 mm. Large areas of the Burdekin, Fitzroy and Burnett Mary regions have average annual rainfall in the 500–750 mm range (Figure 2). For the northern basins, rainfall is dominated by major events such as rain depressions, monsoons and cyclones. Cape York and Wet tropics regions experience a typically tropical climate with a distinct wet and dry season. These two regions generate 60% of the average annual runoff for the GBR.

The modelled pollutants of concern to the GBR ecosystem are sediments, nutrients and pesticides. For the high rainfall areas such as the Wet Tropics and Mackay Whitsunday regions, nutrients and pesticides from cane lands are the major pollutants of concern. For Cape York, the Burdekin, Fitzroy and Burnett Mary regions, which are predominantly grazing and nature conservation areas (>80%), sediment and nutrients from hillslope and gully erosion are a major source of pollutants. The Burdekin, Fitzroy and Burnett Mary regions have a number of highly regulated irrigation areas containing large water storages with significant irrigation extraction. Representing these storages is important given they can influence hydrology and sediment trapping downstream.

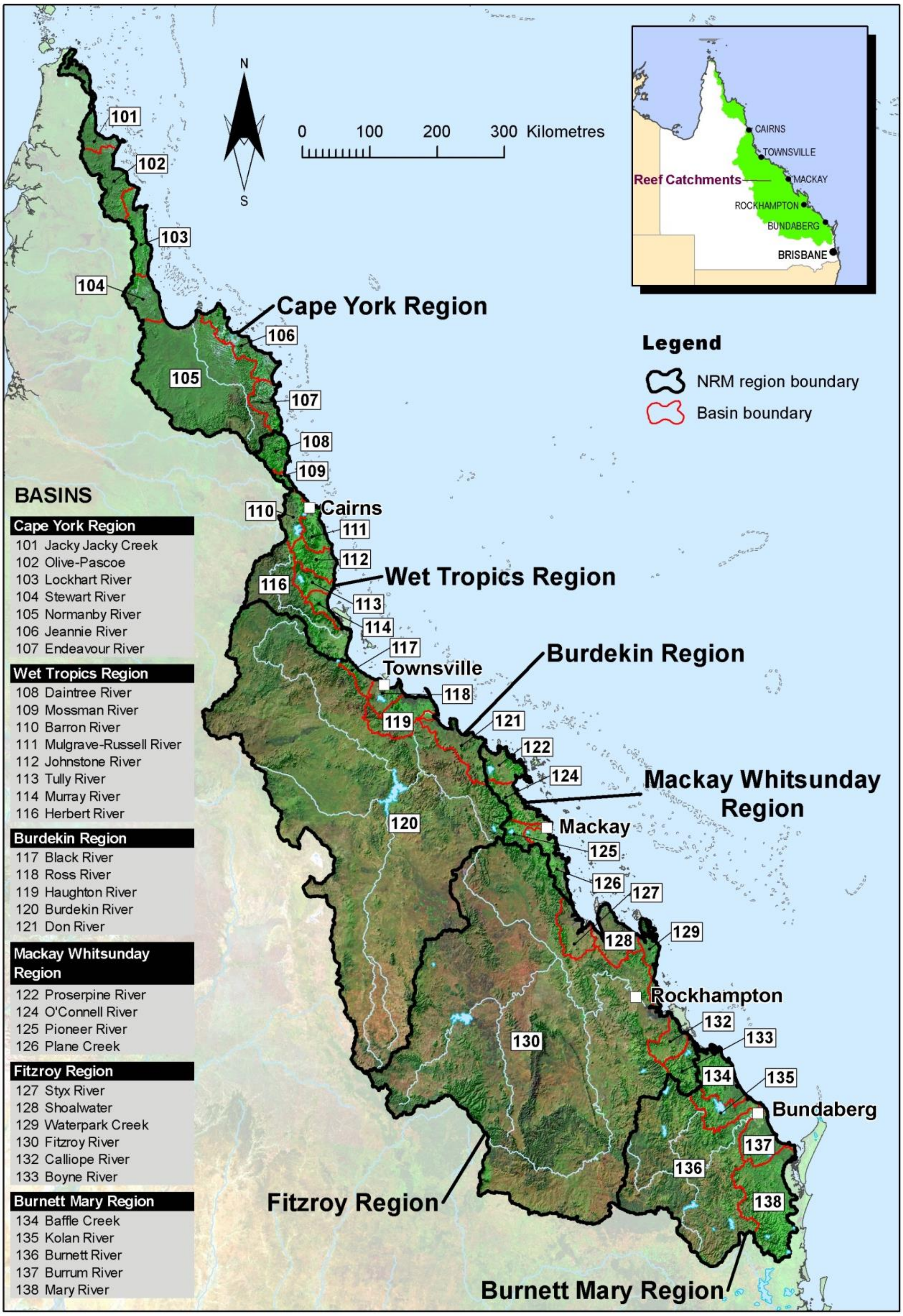


Figure 1 The six NRM regions and 35 AWRC basins making up the GBR

Table 3 Summary of the six NRM regions modelled

NRM region	Catchment area (km^2)	Climate	Rainfall (mm/yr)	Number of modelled subcatchments	Dominant land uses
Cape York	42,988	Tropical with distinct wet and dry seasons	920–2,080	546	Grazing 50%, forest & nature cons. 48%
Wet Tropics	21,722	Tropical	700–4,400	450	Grazing 33%, forest & nature cons. 51%, sugarcane 8%
Burdekin	140,671	Subtropical	500–2,000	1,568	Grazing 90%, forest & nature cons. 7%, sugarcane <1%
Mackay Whitsunday	8,992	Humid, tropical	940–2,000	191	Grazing 44%, forest & nature cons. 28%, sugarcane 19%
Fitzroy	155,740	Subtropical north east to temperate south east	500–1,700	1976	Grazing 78%, forest & nature cons. 14%, cropping 6%
Burnett Mary	53,021	Subtropical conditions	630–1,980	597	Grazing 69%, forest & nature cons. 23%, cropping 2%, sugarcane 2%

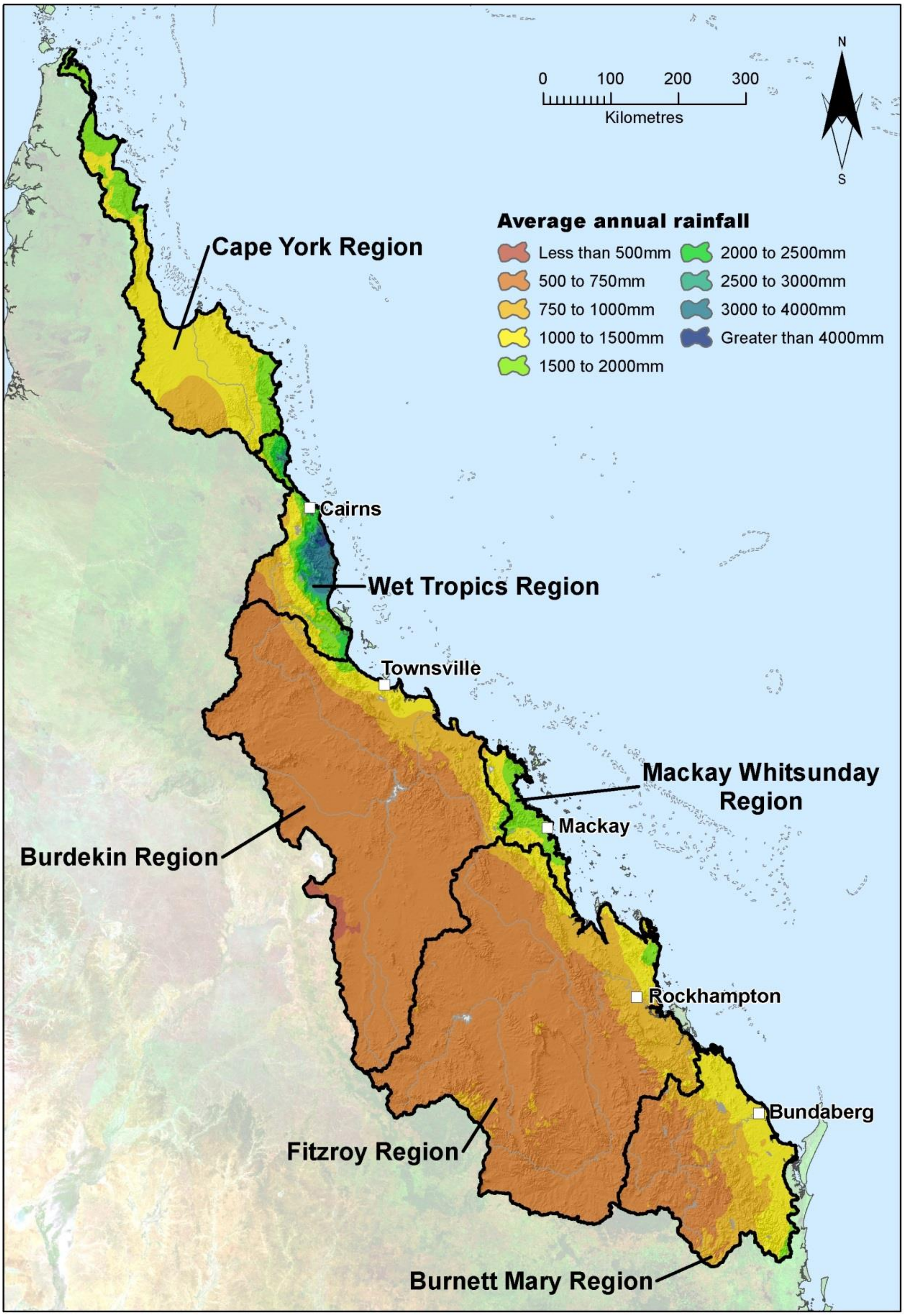


Figure 2 Spatial variability of average annual rainfall across the GBR

2.1 Land use

Land use in the GBR is dominated by grazing (75%), followed by nature conservation (13%) and forestry (5.1%). Dryland and irrigated cropping occupies 3% of the GBR with sugarcane 1.3% of the GBR area. Approximately 85% of the sugarcane is grown in the Wet Tropics, Mackay Whitsunday and Burdekin NRM regions (DSITIA 2012) (Figure 3). The Burdekin and Fitzroy NRM regions contain 78% of the total grazing area with the Fitzroy region containing 76% of the total GBR cropping area.

The 2009 land use map from the Queensland Land Use Mapping project (QLUMP) (DSITIA, 2012) was used as the basis for defining the land use categories for the models. QLUMP land use categories were aggregated into 11–13 major groups (Table 4) considered to be representative of each region.

Table 4 GBR land use grouping and areas

Land use	Area (km^2)	Area (%)
Grazing (open)	177,079	41.9
Grazing (closed)	139,747	33.0
Forestry	21,592	5.1
Dryland cropping	10,054	2.4
Water	6,797	1.6
Sugarcane	5,406	1.3
Urban	2,430	<1
Other	1,962	<1
Irrigated cropping	1,961	<1
Horticulture	598	<1
Dairy	300	<1
Banana	156	<1
Total	**423,134**	**100**

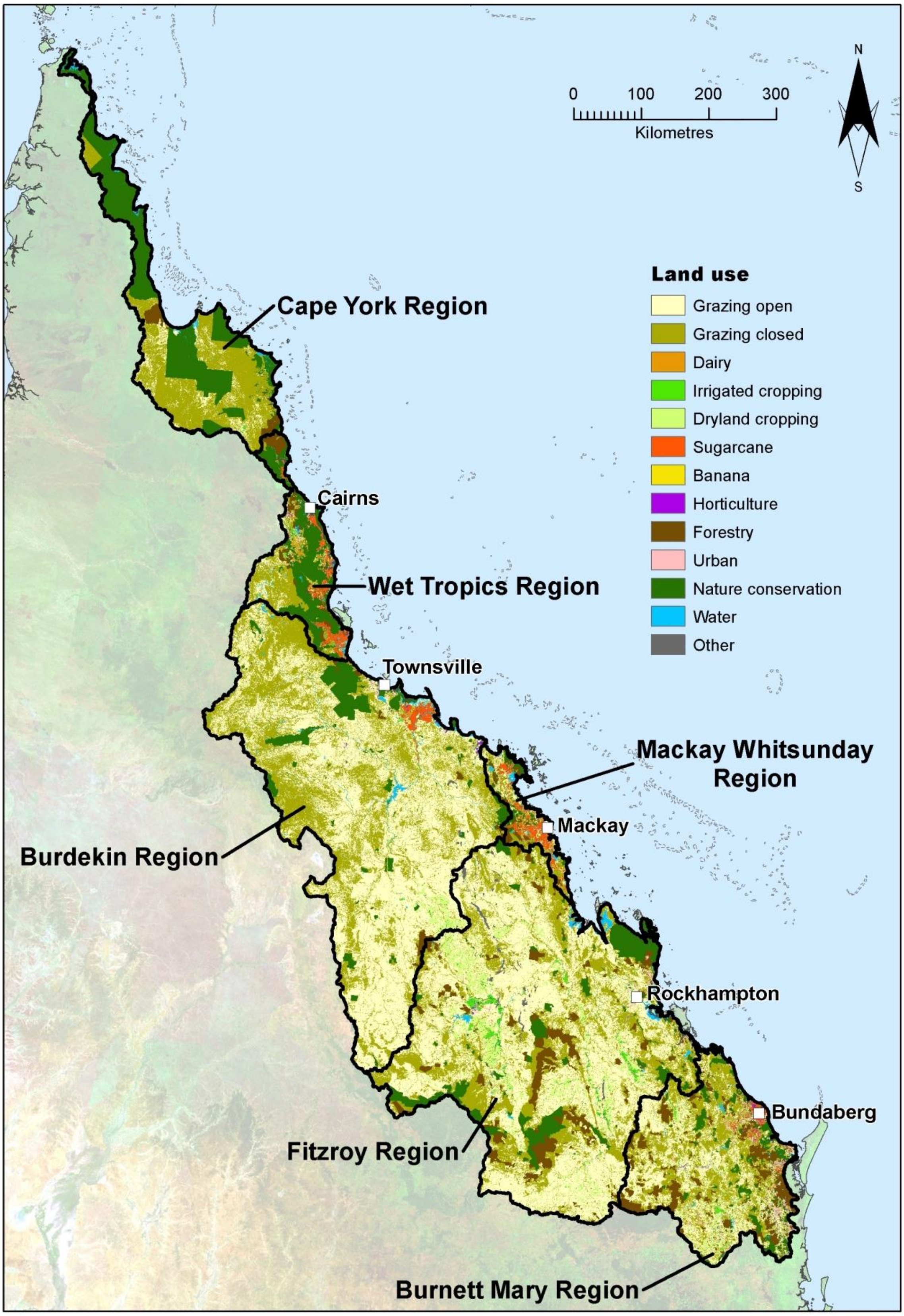


Figure 3 GBR land use distribution using the model land use classifications

2.2 Water quality

The relative risk of pollutants to the GBR from agricultural land uses has recently been assessed (Waterhouse et al. 2013). The main source of excess nutrients, fine sediments and pesticides from GBR catchments is diffuse source pollution from agriculture (Brodie et al. 2013). Overall, nitrogen poses the greatest risk of pollution to coral reefs. For the high rainfall areas such as the Wet Tropics and Mackay Whitsunday regions, nutrients and pesticides from cane lands are the major pollutants of concern. Runoff from rivers in these regions during extreme and early wet seasons is associated with outbreak cycles of the coral-eating crown-of-thorns starfish. On a regional basis, the Burdekin and Fitzroy regions, predominately grazing lands, present the greatest risk to the GBR in terms of sediment loads.

A risk assessment of the five commonly used photosystem-II (PSII) inhibiting herbicides (Waterhouse et al. 2013) identified the Mackay Whitsunday and Burdekin regions as priority areas for managing PSII herbicides, Wet Tropics for nitrogen management and Burdekin and Fitzroy regions for suspended sediment management. Fertilised agricultural areas are hotspots for nutrient and herbicide loss, with sediment fluxes less of a concern due to high vegetation cover maintained throughout the year (Brodie et al. 2013).

3 Methods

In contrast to previous approaches used to estimates loads to the GBR, a consistent modelling approach was used to enable direct comparisons of loads across regions. The eWater Ltd Source Catchments modelling framework was used to generate sediment, nutrient and herbicide loads entering the GBR lagoon, with SedNet modelling functionality incorporated to provide estimates of gully and streambank erosion and floodplain deposition (Ellis & Searle 2014). Two locally developed paddock models, HowLeaky (Rattray et al. 2004) and APSIM (Keating et al. 2003) were used to generate loads and reduction in loads due to the adoption of land management practices for cropping and cane areas respectively. For grazing areas, the Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) was used to generate daily loads. The grazing systems model GRASP (McKeon et al. 1990) was used to derive changes in ground cover (C-factor) to represent reductions in loads for different grazing management practices. An Event Mean Concentration (EMC) approach was used to generate loads for conservation areas and the remaining minor land uses. In order to reduce the effect of climate variability a static climate period was used (1986–2009) to produce average annual loads and the relative change in loads due to industry and government investments in improved land management practices.

Water quality monitoring data is a critical point of truth for model validation and to support model parameterisation, to ensure continual improvement in modelled load estimates, whilst at the same time identifying priorities areas for future monitoring. GBR Source Catchments constituent loads were validated against loads estimated from measured data in four ways. Firstly, using water quality data collected at 10 EOS gauging stations over a four year monitoring period. Secondly, load estimates derived from monitoring data for the 23 year modelling period. Thirdly, using any additional regionally specific data sets and finally against previous GBR modelling (Kroon et al. 20012). The following sections outline the methods used to generate pollutant loads, the validation and calibration process and the subsequent load reductions.

3.1 GBR Source Catchments framework

A Source Catchments model is built upon a network of subcatchments, links and nodes (Figure 4). Subcatchments are the basic spatial unit in Source Catchments. A subcatchment is further delineated into ‘functional units’ (FUs) based on common hydrological response or land use (eWater Ltd 2013). In the case of the GBR Source Catchments framework, FUs were defined as land use categories.

There are two modelling components assigned to each FU representing the processes of:

- Runoff generation
- Constituent generation

Nodes and links represent the stream network. Runoff and constituents are routed from a subcatchment through the stream network via nodes and links.

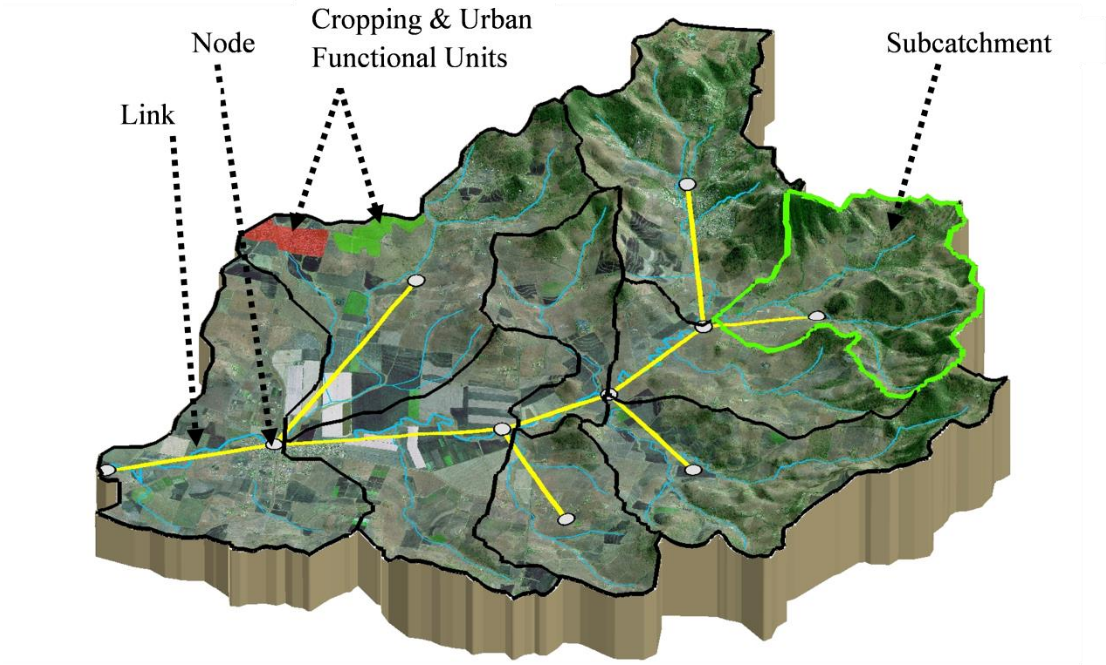


Figure 4 Example of a functional unit (FU) and node-link network generated in Source Catchments. These components represent the subcatchment and stream network

3.1.1 Land use functional units

The data supplied by the QLUMP (DSITIA 2012) was used to generate subcatchments define the land use FUs which were mapped using 2009 imagery. The original detailed land use classifications were aggregated into 11–13 of the major agricultural land uses (Table 4).

3.1.2 Subcatchment generation

A 100 m Digital Elevation Model (DEM) was used to generate subcatchments for each of the six NRM regions. A drainage threshold of 30–50 km^2 was used to identify the major stream networks and contributing subcatchments. In this process, some flat coastal areas were not captured. In order to rectify this, the flat coastal areas were manually added to the DEM derived subcatchment layer in a GIS environment, based on visual assessment of aerial photography and local knowledge. The final subcatchment map was then reimported into Source Catchments. The addition of the flat coastal areas, some of which were not included in previous published modelling programs, improves the overall load estimates to the EOS. An arbitrary node was also created as an 'outlet' node to enable the aggregation of loads for the entire region for reporting purposes. Figure 5 provides an example of the final subcatchment definition, node and link network and final outlet node aggregating the total load for the Wet Tropics model.

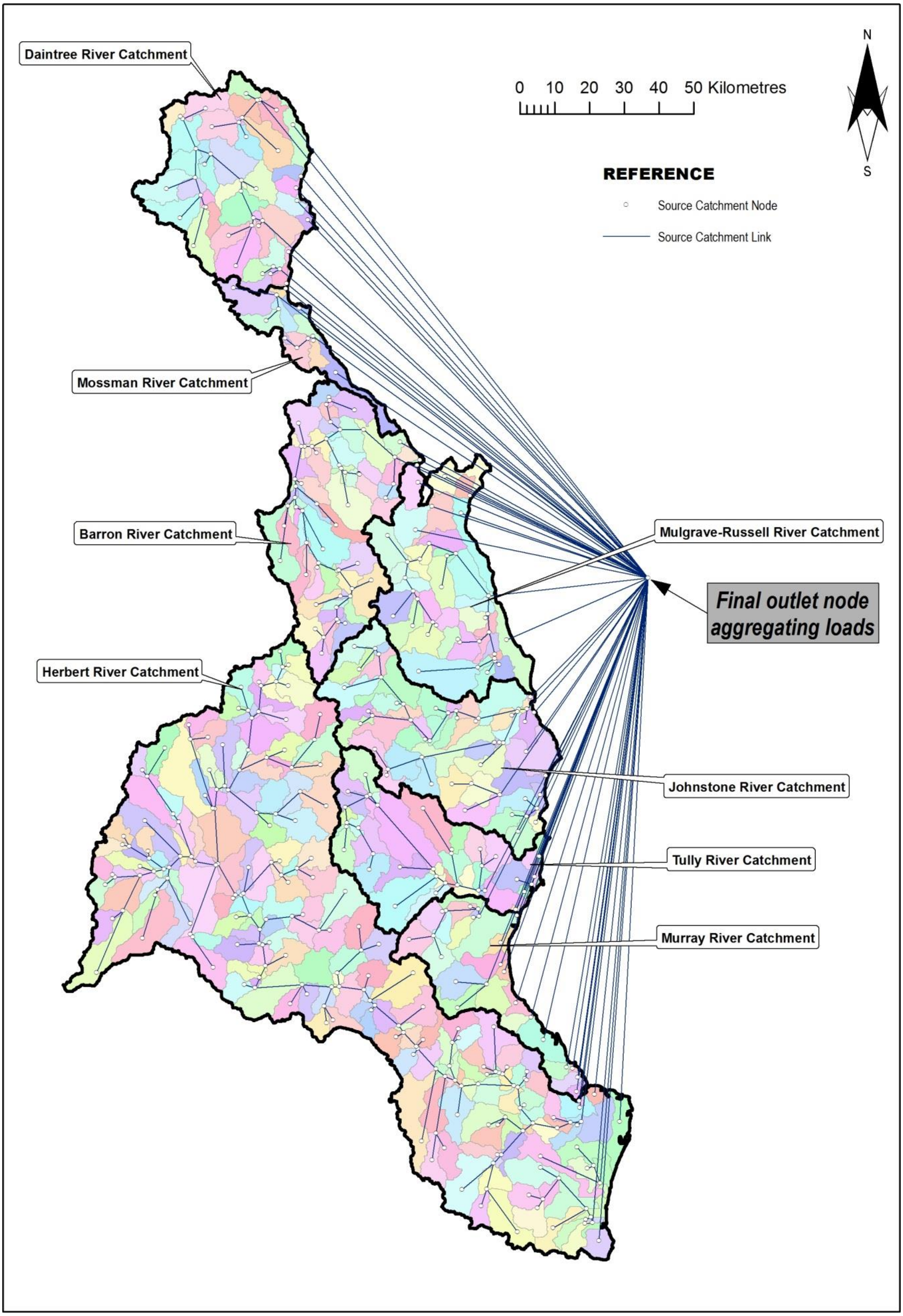


Figure 5 Subcatchment definition, node and link network and final outlet node aggregating the total load for the Wet Tropics model (Hateley et al. 2014)

3.1.3 Climate simulation period

A 23 year climate simulation period was chosen (1/7/1986–30/6/2009). The modelling was constrained to this period for three reasons: 1) it coincided with the availability of bare ground satellite imagery, required in the calculation of hillslope erosion, 2) the average annual rainfall for the simulation period was within 5% of the long-term average rainfall for the majority of the regions and 3) at the time of model development in 2009, this period included a range of high and low flow periods which is an important consideration for hydrology calibration. The climate period will be extended for Reef Plan 2013 to include the extreme wet years, post 2009.

Daily climate files generated for each subcatchment were used to calculate daily runoff. Daily rainfall and potential evapotranspiration (PET) data for each subcatchment were derived from the Department of Natural Resources and Mines (DNRM) Silo Data Drill database (Queensland Government 2011). The data drill accesses grids of data derived by interpolating the Bureau of Meteorology's station records. The data are supplied as a series of individual files of interpolated daily rainfall or PET on a 5 km grid. Source Catchments interrogates each daily grid and produces an 'averaged' continuous daily time series of rainfall and PET data for each 30–50 km^2 subcatchment, over the modelling period (1986–2009).

3.2 Runoff generation

Six rainfall runoff models are available within the Source Catchments framework. Vaze et al. (2011) concluded that there is little difference between these six models for broad scale application. The SIMHYD rainfall runoff model was chosen due to its extensive application and proven performance to satisfactorily estimate streamflow across Australia (Chiew et al. 2002) and in particular for a large catchment in the GBR (Ellis et al. 2009).

SIMHYD is a catchment scale conceptual rainfall runoff model that estimates daily stream flow from daily rainfall and areal PET data (eWater Ltd 2013). Each FU possesses a unique instance of the SIMHYD rainfall runoff model.

In Source Catchments a rainfall runoff model converts time series climate inputs to runoff, with a constituent load created by the generation model 'carried' by the runoff. Water and constituent loads are routed through the node-link network to the catchment outlet. Nodes represent stream confluences, features such as gauging stations and dams, extraction points and subcatchment outlets. Links connect nodes and represent streams. A range of models were applied to links to route or process water and constituents throughout the network.

3.2.1 Hydrology calibration process

Hydrology calibration is a major aspect of pollutant load modelling given loads are a function of pollutant concentrations and runoff volume. Calibration involves optimising a set of rainfall runoff and routing parameters to meet a nominated objective function. The overall objective is thus to simulate surface runoff and 'slowflow' (subsurface seepage and low energy overland flow) which is then transferred to the stream network and routed through the link system. The stream network included storages/weirs, irrigation extractions, channel losses and inflows such as sewage treatment plant discharges. These structures, inflows and extractions were incorporated into the model as part of the calibration process.

The calibration process followed previous work in the GBR (Ellis et al. 2009) coupling Source Catchments to a model-independent Parameter Estimation Tool (PEST) (Doherty 2005). Parameter optimisation incorporated both the SIMHYD rainfall runoff parameters and the two flow routing parameters within a subcatchment. The estimation of rainfall runoff and flow routing parameters was undertaken simultaneously for an entire drainage basin.

A three-part objective function was employed to achieve an optimum calibration, using:

1. log transformed daily flows
2. monthly flow volumes
3. flow duration curves

The monthly flow volume component ensures that modelled volumes match measured gauging station volumes over long periods, the exceedance values ensure the flow volumes are proportioned well into base flows and event flows, while the log transformed daily flows replicates the hydrograph shape. The three objective functions have been used successfully in other modelling applications (Stewart 2011).

3.2.2 Regionalisation of calibration parameter sets

To further simplify the number of adjustable parameters during calibration, land uses/FUs deemed to have similar hydrologic response characteristics were grouped into three broad ‘hydrologic response units’ (HRUs); namely timbered areas, cleared pastures and cropping areas. These broad groupings were selected from previous research in Queensland which suggested these land uses have measurably different drainage and runoff rates given the same climate and soils (Thornton et al. 2007, Yee Yet & Silburn 2003). Flow routing models were also grouped according to the calibration regions. FUs, links and nodes continued to operate as discrete units within the Source Catchments structure. Each gauging station included in the calibration represented its catchment area, based on the contributing flow to a gauge. Nested gauges (gauged upstream or downstream by other gauges) had contributing areas minus the contributing area of the upstream gauge. The nearest neighbour approach was used to derive parameters for ungauged subcatchments (Chiew & Siriwardena 2005, Zhang & Chiew 2009). After flow calibration, the parameter sets were applied to each subcatchment which included the ungauged areas.

3.2.3 Stream gauge data selection for calibration

Flow data were extracted from the Hydstra Surface Water Database (DNRM) to provide the ‘observed’ flow values for calibration. Gauging stations were identified as suitable for PEST calibration based on the following criteria:

- Located on the modelled stream network
- Minimum of 10 years of flow record (post 1970) with suitable corresponding quality codes in the DNRM database
- Little or no influence from upstream storages (subjective)

3.3 Constituent generation

3.3.1 Water quality constituents modelled

The water quality constituents required to be modelled under Reef Plan are outlined in Table 5. Total suspended sediment (TSS) was based on the international particle size fraction classification and is restricted to the <20 µm fraction (National Committee on Soil and Terrain 2009). Fine sediment (<16 µm) is the fraction most likely to reach the GBR lagoon (Scientific Consensus statement, Brodie et al. 2013). The choice of a <20 µm to determine the fine sediment fraction is also consistent with previous SedNet modelling studies, which used a clay percentage layer from the ASRIS database based on the international particle size fraction classification, to calculate particulate nutrient (PN and PP) loads. Moreover, Packett et al. (2009) found that for the in-stream sediment sampled for some subcatchments and at the Fitzroy River outlet, >95% of the TSS was very fine sediment (<20 µm).

There are five ‘priority’ PSIIs outlined in Reef Plan; atrazine, ametryn, diuron, hexazinone and tebuthiuron. These are used for residual herbicide control. They are considered priority pollutants due to their extensive use and frequent detection in GBR waterways and in the GBR lagoon (Lewis et al. 2009, Shaw et al. 2010, Smith et al. 2012). Tebuthiuron was only modelled in the Fitzroy and Burnett Mary regions where use data was available. A reduced reliance on the use of residual herbicides in favour of knockdown herbicides is considered an improved farming practice under best management practice guidelines. It should be noted that many alternative herbicides are in use in the GBR catchment that are not represented in the current modelling and reporting process.

Table 5 Constituents modelled

Sediment	
Total suspended sediment (TSS)	
Nutrients	
Total nitrogen (TN)	Total phosphorus (TP)
Particulate nitrogen (PN)	Particulate phosphorus (PP)
Dissolved inorganic nitrogen (DIN)	Dissolved inorganic phosphorus (DIP)
Dissolved organic nitrogen (DON)	Dissolved organic phosphorus (DOP)
PSII herbicides	
atrazine, ametryn, diuron, hexazinone, tebuthiuron	

3.3.2 Conceptual approach for constituent generation

Source Catchments framework allows specific customised models to be added as ‘plug-ins’ to meet a particular modelling objective. In the regional GBR Source Catchments models, this capability has been extensively used to incorporate the most appropriate constituent generation models across the GBR (Table 6, Figure 6). The plug-in which encompasses all the constituent generation models was named Dynamic SedNet. The Source Catchments framework was tailored to enable the water quality response resulting from the complex interactions of soils x climate x land management practices to be reflected. The paddock scale models used to generate daily loads for each land use were: APSIM for sugarcane, combined with HowLeaky for pesticides and phosphorus, HowLeaky for cropping, RUSLE for grazing and EMC/DWC models for the remainder. A summary of the models used for individual constituents in sugarcane, cropping and grazing are shown in Table 6. A more detailed description of these models is provided in sections 3.3.2–3.3.4.

In addition, SedNet/ANNEX (Wilkinson et al. 2004) modelling functionality has been incorporated to generate gully and streambank erosion and floodplain deposition, within the daily time-step model (Ellis & Searle 2014, Wilkinson et al. 2014). This included the daily disaggregation of long-term average annual estimates of gully and streambank generation. The simple daily disaggregation of the long-term load estimates should be treated with caution, given outputs at a subannual resolution will not necessarily match observed subannual event estimates in the catchments due to the disaggregation approach.

Point source inputs of pollutants from major sewage treatment plants (STP), losses from the channel and stream as irrigation extractions were also represented at relevant nodes in the model as a daily time-series of flow and concentration. In-stream transport process such as decay and deposition of sediment and particulate nutrients were also represented (Figure 6). A more detailed description of the modelling methodology and algorithms are available in Ellis & Searle (2014) and Wilkinson et al. (2014).

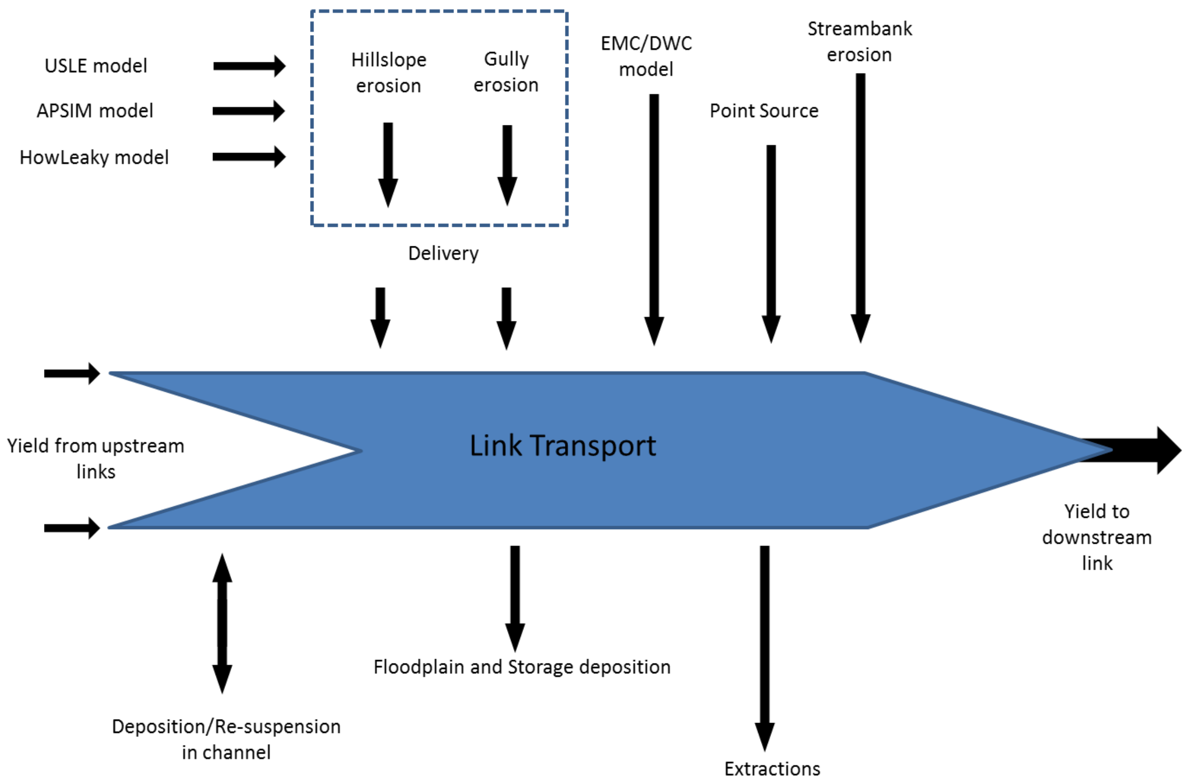


Figure 6 Conceptual diagram of GBR Source Catchments framework

Table 6 Summary of the models used for individual constituents for sugarcane, cropping and grazing

Constituents	Sugarcane	Cropping	Grazing
TSS	APSIM + Gully	HowLeaky + Gully	RUSLE + Gully
DIN	APSIM	EMC	EMC
DON	EMC	EMC	EMC
PN	Function of sediment	Function of sediment	Function of sediment
DIP and DOP	HowLeaky functions on APSIM water balance	HowLeaky	EMC
PP	Function of sediment	Function of sediment	Function of sediment
PSII herbicides	HowLeaky functions on APSIM water balance	HowLeaky	EMC

The Dynamic SedNet 'plug-in', provided a suite of constituent generation and in-stream processing models. The following sections describe the Source Catchments Dynamic SedNet model components used to simulate constituent generation and transport processes for each FU within a subcatchment, link (in-stream losses, decay, deposition and remobilisation) and node (extractions and inputs to the stream).

3.3.3 Grazing constituent generation

Rainfall and ground cover are two dominant factors affecting hillslope runoff and erosion in the GBR. Previous studies reported that gully erosion is also a significant source of sediment to the GBR (Wilkinson et al. 2005, Dougall et al. 2009, Wilkinson et al. 2013). Given grazing occupies over 75% of the GBR, it was important that the models chosen were able to reflect the dominant erosion processes occurring in these landscapes and the spatial variability observed across such a large area. Dynamic SedNet incorporates daily rainfall, spatially and temporally variable cover to generate hillslope erosion. Gully and streambank erosion and floodplain deposition processes have also been represented.

3.3.3.1 Hillslope sediment, nutrient and herbicide generation

Sediment generation model

A modified version of the Universal Soil Loss Equation (USLE) was used to generate hillslope erosion in grazing lands (Renard et al. 1997, Lu et al. 2001, Renard & Ferreira 1993). This modified version is based on the Revised Universal Soil Loss Equation and is referred to as the RUSLE in this document (Lu et al. 2001, Renard & Ferreira 1993). The RUSLE model was chosen due to its proven ability to provide reasonable estimates of hillslope erosion worldwide, including various GBR SedNet models, the ability to apply the model across a large spatial extent and at the same time incorporate detailed spatial and temporal data layers including cover and rainfall components.

A daily time-step, spatially variable RUSLE (equation 1) was used to generate hillslope erosion in grazing areas. The spatial data inputs were processed for *each grid cell*, with results accumulated up to a single representation of the particular grazing instance within each subcatchment at a daily time-step. The model is:

$$A = R * K * S * L * C * P \qquad (1)$$

where

A = soil erosion per unit area (t/ha) (generated as a daily value)

R = rainfall erosivity EI30 (MJ.mm/ha.h.day) (generated as a daily value)

K = soil erodibility (t.ha.h/ha.MJ.mm) (static)

L = slope length (static)

S = slope steepness (static)

C = cover management factor (derived from remotely sensed cover imagery, one value generated per year for each 25 m x 25 m grid cell)

P = practice management factor (static)

The daily RUSLE soil loss calculation provides an estimate of the sediment generation rate at the hillslope scale. To estimate the suspended sediment fraction of the total soil loss which is delivered to the stream, the RUSLE load was multiplied by the clay and silt fraction, for each grid cell, derived from Australian Soil Resource Information System (ASRIS) soils information (Brough, Claridge & Grundy 2006). The use of a particle size distribution raster to determine the fine sediment fraction is an improvement from previous SedNet modelling studies (e.g. Brodie et al. 2003 and Cogle et al. 2006) which used a single delivery ratio across all catchments. The silt and clay layer incorporates the spatial variability of fine sediment fractions across the GBR. A hillslope sediment delivery ratio (HSDR) was then applied to this load (equation 2) and was selected based on past research using a standard 10% delivery ratio (Wilkinson, Henderson & Chen 2004). However, in some regions the HSDR was increased so that the generated fine sediment load better matched monitored data. The TSS load is therefore:

$$\text{TSS load to stream (kg/day)} = \text{RUSLE sediment load (kg/day)} * (\text{silt}_{prop} + \text{clay}_{prop}) * \text{HSDR} \qquad (2)$$

Nutrient generation models

Hillslope particulate nutrient generation was derived as a function of the clay proportion of the daily RUSLE soil loss, the surface soil nutrient (total nitrogen and phosphorus) concentration and an enrichment ratio (Young, Prosser & Hughes 2001) (equation 3). This algorithm assumes that all nutrients in the soil are attached to the clay proportion where:

$$\text{Hillslope particulate nutrient load (kg/ha)} = \text{RUSLE sediment load (kg/day)} * \text{clay}_{prop} * \text{Surface nutrient concentration (kg/kg)} * \text{Enrichment factor} * \text{Nutrient Delivery Ratio (NDR)} \qquad (3)$$

This is the total particulate nutrient load which reaches the stream.

For the dissolved nutrient load, user supplied EMC/DWC values (mg/L) for a given land use in a subcatchment were multiplied by the quickflow and slowflow runoff volumes to derive a total dissolved nutrient load. These models are described in Ellis & Searle (2014) and replicate the original SedNet approach for dissolved and particulate nutrient generation, modified for a daily time-step.

Herbicide generation models

Tebuthiuron, a PSII herbicide, is the main herbicide used in grazing lands for control of regrowth. Tebuthiuron is applied as a once off application to selected areas of land and not reapplied on a regular basis. This makes it difficult to model an accurate representation of the usage pattern across a 23 year climate period. Because of this, a static EMC/DWC concentration model was used, based on measured in-stream data from the Fitzroy basin to ensure a very conservative estimate of the average annual total baseline load is generated in the model to reflect loads estimated from measured data in the stream. No data has been provided to model spatial changes in its application beyond the baseline year and was therefore not modelled.

3.3.3.2 Gully sediment and nutrient generation models

Gully modelling was based on published SedNet gully modelling methodology (Prosser et al. 2001a) extensively used across the GBR (Hateley et al. 2005, McKergow et al. 2005b).

Gully sediment contribution to the stream was calculated as a function of the gully density, gully cross sectional area and likely year of initiation (equation 4). Once the volume of the gullies in each FU was calculated for a subcatchment, this volume was converted to an 'eroded' soil mass. This eroded mass was then distributed over the model run period as a function of runoff. The gully average annual sediment supply (AASS) was calculated by:

$$AASS\ (t/yr) = (P_s * \alpha_{xs} * GD_{FU} * A_{FU}) / Age \qquad (4)$$

where

P_s = dry soil bulk density (t/m^3 or g/cm^3)

α_{xs} = gully cross sectional area (m^2)

GD_{FU} = gully density (m/m^2) within FU

A_{FU} = area of FUs (m^2)

Age = years of activity to time of volume estimation (e.g. year of disturbance to year of estimation)

To derive a daily gully erosion load, the long-term average annual gully erosion load is multiplied by the ratio of daily runoff to annual runoff to apportion a daily gully load.

Similar to the hillslope nutrient generation, gully nutrients were derived as a function of the gully particulate sediment load. Subsurface soil nutrient concentrations are multiplied by the gully sediment load and the subsurface clay proportion to provide an estimate of the gully nutrient contribution. Raster inputs to these models were two nutrient rasters (subsurface nitrogen and phosphorus) and a subsurface clay proportion raster.

3.3.4 Sugarcane constituent generation

For sugarcane areas, a combination of APSIM, HowLeaky and EMC/DWC models were used to derive daily constituent loads (Table 6). The hill and gully loads are combined to derive a fine sediment load to the stream for a given land use within a subcatchment.

3.3.4.1 Hillslope sediment, nutrient and herbicide generation

Sediment generation model

Runoff in APSIM was modelled using the curve number approach. Model runs for the range of soil types represented across the GBR were mapped to soils in each region on the basis of similarity of surface texture and curve number in an effort to assign appropriate runoff estimates. APSIM loads were then passed to Source Catchments. An analysis was undertaken to ensure the loads transferred from APSIM to the Source Catchments model only occurred on days where Source Catchments had generated runoff. This analysis attempted to ensure pollutant load mass balance was consistent on a monthly basis.

Hillslope erosion was predicted in APSIM using the Freebairn & Wockner (1986) form of the RUSLE described in Littleboy et al. (1989). Erosion estimates from APSIM were adjusted for slope and slope length before being passed into Source Catchments. Slope and slope length were derived from the intersected DEM and slope values. Cropping areas can at times be assigned incorrect slope values due to misalignment of land use layers derived from remotely sensed data, and the topography layer. Slopes were therefore capped in cropping areas with the assumption that the majority of crops are grown on slopes less than 8%.

The product of the total hillslope erosion, silt + clay proportion and hillslope delivery ratio provided an estimate of the fine sediment load exported to the stream for cane areas within a given subcatchment.

Nutrient and pesticide generation models

DIN loads modelled by APSIM were imported directly into the catchment model. Herbicide and phosphorus loads were modelled using HowLeaky functions and the outputs of the APSIM water balance and crop growth models. Herbicide and phosphorus are modelled in HowLeaky using the same approach as for dryland and irrigated cropping described in section 3.3.4. DON was represented as a static EMC model. Further details on the APSIM and HowLeaky models are in Shaw & Silburn (2014).

3.3.4.2 Gully sediment and nutrient generation

Gully modelling for sugarcane used the same methodology as for grazing lands (section 3.3.3.2). Similar to grazing, the total subcatchment contribution for sugarcane FUs combined the hillslope and gully loads. Gully nutrients were derived as a function of the gully particulate sediment load, the subsurface clay proportion and the subsurface soil nutrient concentrations.

3.3.5 Cropping constituent generation

The daily fine sediment load, particulate and dissolved phosphorus and herbicide loads were calculated by HowLeaky, with dissolved nitrogen component represented as a static EMC/DWEC model.

3.3.5.1 Hillslope sediment, nutrient and herbicide generation

Runoff was modelled in HowLeaky using a modified version of the Curve Number approach (Littleboy et al. 1989, Shaw & Silburn 2014). Soils in the GBR catchment were grouped according to hydrologic function and assigned a curve number parameter to represent the rainfall versus runoff response for average antecedent moisture conditions and for bare and untilled soil. This curve number was modified within the HowLeaky model (daily) to account for crop cover, surface residue cover and surface roughness.

Daily time series loads of fine sediment, phosphorus species and individual herbicides in runoff were supplied from HowLeaky model runs for the dryland and irrigated cropping FUs (Shaw & Silburn 2014). Simulations of a range of typical cropping systems were run to represent unique combinations of soil groups, climate and land management.

Sediment generation model

Hillslope erosion was predicted in HowLeaky using the modelled runoff, RUSLE K, L and S and a cover-sediment concentration relationship derived by Freebairn & Wockner (1986). This generalised equation applies anywhere where the cover-sediment concentration relationship holds. The Freebairn and Wockner equation has been tested and calibrated for 14 sites in Queensland, predominantly in the GBR (for a detailed summary of the results refer to http://www.howleaky.net/index.php/library/supersites). For each of the unique combinations of soil and climate, an average slope value was derived from the intersected DEM and applied in the soil loss equation.

Nutrient generation model

Dissolved phosphorus (P) in runoff was modelled in HowLeaky as a function of saturation of the soil P sorption complex. Particulate phosphorus was modelled as a function of sediment concentration in runoff and the soil P status (Robinson et al. 2010). As the HowLeaky model did not differentiate between forms of dissolved P, a ratio was applied to the dissolved P portion prior to being passed to Source Catchments. While the fractions of DIP/DOP are known to vary by site and situation, values were selected from the limited available literature (e.g. Chapman, Edwards & Shand 1997) which showed that DOP could represent up to 20% of dissolved P in leachate/soil water. The effects of management practices on P runoff are not modelled, except where management practices affect suspended sediment movement and thus particulate P in runoff. Management effects on P in runoff could not be modelled because a) there is no GBR P management practice framework and b) there is no reporting on P management practices. DIN and DON were modelled using an EMC (Table 6).

Herbicide generation model

Herbicide mass balance and runoff losses were modelled using HowLeaky (Rattray et al. 2004, Robinson et al. 2010) with a number of enhancements added (Shaw et al. 2011). Modelling of herbicide applications at the paddock scale were based on theoretical scenarios that represent a ‘typical’ set of applications under an A, B, C or D set of management practices (described in section 3.5.1). The scenarios modelled describe the products applied and the timing and rates of those applications. An emphasis was placed on modelling the

PSII herbicides considered priority under Reef Plan 2009. Half-lives of herbicides of interest were taken from available studies in the literature or from Paddock to Reef field monitoring results where possible. Partitioning coefficients between soil and water were calculated from both soil and herbicide chemistry. Further details on the HowLeaky model and the parameters used to define simulations of cropping and sugarcane are provided in Shaw & Silburn (2014).

3.3.5.2 Gully sediment and nutrient generation

Gully modelling for cropping used the same methodology as for grazing lands (section 3.3.3.2). Similar to grazing, the total subcatchment contribution for cropping FUs combined the hillslope and gully loads. Gully nutrients were derived as a function of the gully particulate sediment load, the subsurface clay proportion and the soil nutrient concentrations.

3.3.6 Other land uses: Event Mean Concentration, Dry Weather Concentration

The remaining land uses: forestry, nature conservation, urban, horticulture, dairy, bananas and the ‘other’ land use category had Event Mean Concentration/Dry Weather Concentration (EMC/DWC) models applied. In comparison to grazing, cropping and sugarcane areas, these land uses had a small relative contribution to region loads. In the absence of specific models for these land uses, EMC/DWC models were applied where daily load is:

$$\text{Daily Load (kg)} = (\text{EMC (mg/L)} \times \text{quickflow runoff (ML)}) + (\text{DWC (mg/L)} \times \text{slowflow runoff (ML)}) \quad (5)$$

Where quickflow represents the storm runoff component of daily runoff, the remainder was attributed to slowflow. EMC/DWC values were derived from monitoring data, or where monitoring data was not available, from previous studies (Waters & Packett 2007, Rohde et al. 2008, Bartley et al. 2012, Turner et al. 2012).

It is important to highlight that the EMC/DWC applied in this model represented the in-stream generation rates. Hence, the assumption is that any physical processes such as hillslope and gully erosion and/or deposition are reflected in the EMC/DWC value. Further work is required to collate regionally specific DWC values particularly in cane growing areas.

Sediment generation models that use an EMC/DWC approach assume that the EMC/DWC derived load reflect the combined hillslope and gully contributions. To estimate the percentage of hillslope versus gully erosion for EMC/DWC generation models the generated load was apportioned to hill or gully erosion sources by applying the same proportion of hill and gully estimated for the remainder of the region. Future model runs will separate gully erosion from the EMC/DWC model.

3.3.7 Representation of extractions, inflows, losses and storages

Nodes represent points in a stream network where links are joined (eWater Ltd 2013). Catchment processes can be represented at nodes. For a detailed description of how these models work refer to the Source Catchments Scientific Reference Guide (eWater Ltd. 2013). In the GBR Source Catchments models, irrigation extractions, sewage treatment plant (STP) inflows and storages/weirs were represented at nodes. The following sections provide a brief outline of how these models were applied.

3.3.7.1 Extraction, inflows and loss node models

To simulate the removal of water and the associated load of constituents from storages and or rivers, daily extraction estimates for a river reach were incorporated at relevant nodes. The irrigation extraction data was obtained from Integrated Quantity and Quality Model (IQQM) runs provided by Queensland Hydrology (DSITIA) for each region. Multiple types of extractions were aggregated and allocated at the appropriate downstream nodes. Regionally specific loss models were included to account for channel losses where necessary (regional report references are listed in the front of this document).

3.3.7.2 Storages

Storages (dams and weirs) with a capacity >10,000 ML were incorporated into the model at nodes. Only storages of significant capacity were incorporated as it was impractical to include all storages and it was assumed the smaller storages would have minimal impact on the overall water balance and pollutant transport dynamics. Storage locations, dimensions and flow statistics were used to simulate the storage dynamics on a daily basis. Trapping of fine sediment and particulate nutrients were simulated. Fine sediment and particulate nutrients were captured using a 'trapping' algorithm based on daily storage capacity, length and discharge rate (Lewis et al. 2013). Dissolved constituents were decayed in storages using a first order decay model.

3.3.8 In-stream models

The in-stream process models can represent streambank erosion, in-stream deposition, decay and remobilisation of fine and course sediment and particulate nutrients and floodplain deposition. The following sections provide a brief outline of their application.

3.3.8.1 Streambank erosion

The streambank erosion model implemented is based on the SedNet modelling approach (Wilkinson et al. 2010). A mean annual rate of fine streambank erosion (t/yr) is calculated as a function of riparian vegetation extent, streambank erodibility and retreat rate. The mean annual streambank erosion was then disaggregated as a function of the daily flow. For a full description of the method refer to Ellis & Searle (2014).

For particulate nutrients, particulate N and P contribution from streambanks was estimated by taking the mean annual rate of streambank erosion (t/yr) multiplied by the ASRIS subsurface soil N and P concentrations. The mean annual streambank erosion was then disaggregated as a function of the daily flow.

3.3.8.2 In-stream deposition, decay and remobilisation

The in-stream transport model allows for the deposition and remobilisation of fine and coarse sediment and particulate nutrients. However with limited data available to validate this component; remobilisation was not included in any of the GBR models. The assumption was made that all course sediment deposits in the main stream with no remobilisation occurring. Hughes et al. (2010) noted in the Fitzroy and Brookes et al. (2013) in the Normanby catchment that in-channel benches are an important store of large volumes of sediment. Hughes noted however that these benches are predominantly comprised of sand. A small fraction of fine sediment may be trapped in these coarse (bedload) deposits, however the time scale for fine sediment movement is much shorter and thus this fraction is ignored in the bedload budget (Wilkinson, Henderson & Chen 2004). For fine sediment it was assumed that there was no long-term fine sediment deposition in-stream and that all suspended sediment supplied to the stream network is transported (Wilkinson, Henderson & Chen 2004). As new science becomes available on fine sediment deposition and remobilisation processes, applying these models will be investigated. Research undertaken in the Fitzroy (Hughes et al. (2010), Burdekin and Normanby catchments (Brooks et al. 2013) may help to validate this component. Details on the in-stream deposition and remobilisation models can be found in Ellis & Searle (2014).

The in-stream decay of dissolved nutrients was not implemented in any model at this point in time. Monitoring data (Turner et al. 2012) suggests that dissolved nutrient concentrations showed little reduction from source to the catchment outlet therefore decay models were not applied. However further research is required to improve our understanding of in-stream decay process for dissolved nutrients.

Herbicides were decayed in-stream using a first order exponential decay function. Local monitoring data was used where available, in combination with half-life data from the Pesticide Properties Database (PPDB) (Agriculture & Environment Research Unit (AERU) 2006–2013) to parameterise the models. Where values were not available for a specific herbicide in the PPDB database, a value was assigned from a compound with similar chemical properties or derived from the GBRCLMP monitored program data.

3.3.8.3 Floodplain deposition

When floodwater rises above river banks the water that spills out onto the rivers floodplain is defined as overbank flow. Floodplain trapping or deposition occurs during overbank flows. The velocity of the flow on the floodplain is significantly less than that in the channel allowing fine sediment to deposit on the floodplain. The amount of fine sediment deposited on the floodplain is regulated by the floodplain area, the amount of fine sediment supplied, the residence time of water on the floodplain and the settling velocity of the sediment (Prosser et al. 2001, Wilkinson et al. 2010, Ellis & Searle 2014). For particulate nutrients, the particulate nutrient load deposited on the floodplain was a proportion of fine sediment deposition. The loss of dissolved nutrients and herbicides on the floodplain were not modelled. Details on the floodplain deposition and remobilisation models can be found in Ellis & Searle (2014).

3.4 Assessment of hydrology and load performance

Hydrology calibration involved the optimisation of an objective function comprised of the sum of squared differences between modelled and observed flow. The objective function was made up of log-transformed daily flows, monthly flow volumes, and flow duration curves. Model performance was then assessed using a range of performance criteria. Modelled load estimates were validated against loads estimated from measured data and assessed using a set of performance criteria. The following section outlines the methods used for hydrology calibration and load validation.

3.4.1 Hydrology calibration

A selection of suitable gauging station flow data was used in calibration. Model performance was assessed for the calibration period 1970–2010.

The model performance was assessed against observed flow data using the following criteria:

- Daily Nash Sutcliffe coefficient of Efficiency (NSE) >0.5
- Monthly NSE >0.8
- Percentage volume difference ±20%

Values for NSE can range from 1 to negative infinity. Results between zero and one are indicative of the most efficient parameters for model predictive ability and NSE values of 1 indicate perfect alignment between modelled and observed values (Chiew & McMahon 1993). If NSE=0, then the model prediction is no better than using average annual runoff volume as a predictor of runoff.

3.4.2 Load validation

It is important to note that the catchment model load outputs were compared or 'validated' against loads estimated from measured data as opposed to calibration whereby model parameters are adjusted to fit the measured data. Four approaches were used to validate the GBR Source Catchments modelled load estimates. Firstly, a short-term comparison (2006–2010) was made using load estimates from the GBR loads monitoring program (GBRLMP) for 10 EOS sites (Turner et al. 2012). Secondly, a long-term comparison (23 years) was made with catchment load estimates derived from all available measured data for the modelling period (Joo et al. 2014). Thirdly, other regionally specific estimated loads derived from measured data collected at various time scales. Finally, a comparison was made with the previous modelled estimates used in the first Report Card (2009) (Kroon et al. 2010). The following section provides a brief description of these data sources.

3.4.2.1 GBR Catchment Loads Monitoring Program (2006–2010)

In 2006, the Queensland Government commenced a GBR wide Catchment Loads Monitoring Program (GBRCLMP) designed to measure sediment and nutrient loads entering the GBR lagoon (Turner et al. 2013). The water quality monitoring focussed at the EOS of ten priority rivers; Normanby, Barron, Johnstone, Tully, Herbert, Burdekin, O'Connell, Pioneer, Fitzroy, Burnett and 13 major sub-basins. Water sampling of herbicides commenced in 2009–2010 in eight EOS gauges and three subcatchment sites (Smith et al. 2012). Modelled and GBRLMP load estimates were compared for the 2006 to 2010 period for TSS, TP, PP, TN, PN and DIN (Joo et al. 2012, Turner et al. 2012). Herbicide load data was not collected prior to 2009 hence no corresponding load validation data was available.

3.4.2.2 Long-term Flow Range Concentration Estimator (1986–2009)

Annual sediment and nutrient load estimates were required to validate the GBR Source Catchments outputs for the period July 1986 to June 2009 (23 years). Prior to the GBR Catchment Loads Monitoring Program (GBRCLMP), water quality data was collected sporadically and often not sampled for critical parts of the hydrograph. Joo et al. (2014) used all suitable data from the Hydstra Surface Water Database (DNRM) covering the model run period to estimate daily loads. A modified Beale ratio method (Beale 1962) was used to provide load estimates from daily to average annual time-step. The method was named the Flow Range Concentration Estimator (FRCE) method. The mean modelled loads were compared with the likely upper and lower and mean, FRCE load for TSS, TN, DIN, TP, PP and DIP across 23 years.

Calculation of monthly loads from measured data enabled a consistent statistical model evaluation technique to then be applied to both the modelled and measured data for sediment and nutrients (Moriasi et al. 2007). Three quantitative statistics used for the comparison were: the ratio of the root mean square error to the standard deviation of validation data (RSR), Nash Sutcliffe coefficient of efficiency (NSE) and per cent difference in load or bias (PBIAS). Model evaluation performance ratings for each statistic are presented in Table 7. The statistics were calculated and model performance rated.

Table 7 General performance ratings for recommended statistics for a monthly time-step (from Moriasi et al. 2007)

Performance rating	RSR	NSE	PBIAS	
			Sediment	N, P
Very good	0.00–0.50	0.75–1.00	<±15	±25
Good	0.50–0.60	0.65–0.75	±15–±30	±25–<±40
Satisfactory	0.60–0.70	0.50–0.65	±30–±55	±40–±70
Unsatisfactory	>0.70	<0.50	>±55	>±70

3.4.2.3 Other regional loads monitoring

In addition to the short and long-term load comparisons, regional datasets were used for validation. For example in the Wet Tropics region, a long-term Australian Institute of Marine Science (AIMS) dataset collected in the Tully River (Mitchell et al. 2007) was used and at a shorter time scale, a comparison was also made with event loads calculated during cyclone Sadie for the Herbert River from 30/4/1994 to 5/2/1994 (Mitchell, Bramley & Johnson 1997). In the Burdekin region, Burdekin Falls Dam load estimates from 2005–2009 (Lewis et al. 2013).

3.4.2.4 Previous modelled estimates

The first Report Card, provided a collation of current (total baseline), pre-European and anthropogenic loads from the 35 reef catchments (in six NRM regions), based on the best available data at the time and included a combination of monitoring and modelling (Kroon et al. 2010). The best estimates for ‘current’ loads (except PSII herbicides) were either based on SedNet modelling or loads generated from the Loads Regression Estimator (LRE) (Kroon et al. 2012). The pre-European loads described were from (McKergow et al. 2005a, McKergow et al. 2005b). The PSII herbicide catchment load estimates reported in Kroon et al. (2012) were derived from Brodie, Mitchell & Waterhouse (2009).

3.5 Progress towards Reef Plan 2009 targets

Water quality targets were set under Reef Plan 2009 in relation to the anthropogenic baseline load; that is, the estimated increase in human induced constituent loads from predevelopment conditions. The progress made towards the Reef Plan water quality targets due to in the adoption of improved land management practices are therefore reported as a reduction in the anthropogenic baseline loads (Figure 7).

$$\text{Anthropogenic baseline load} = \text{total baseline load} - \text{predevelopment baseline load} \qquad (6)$$

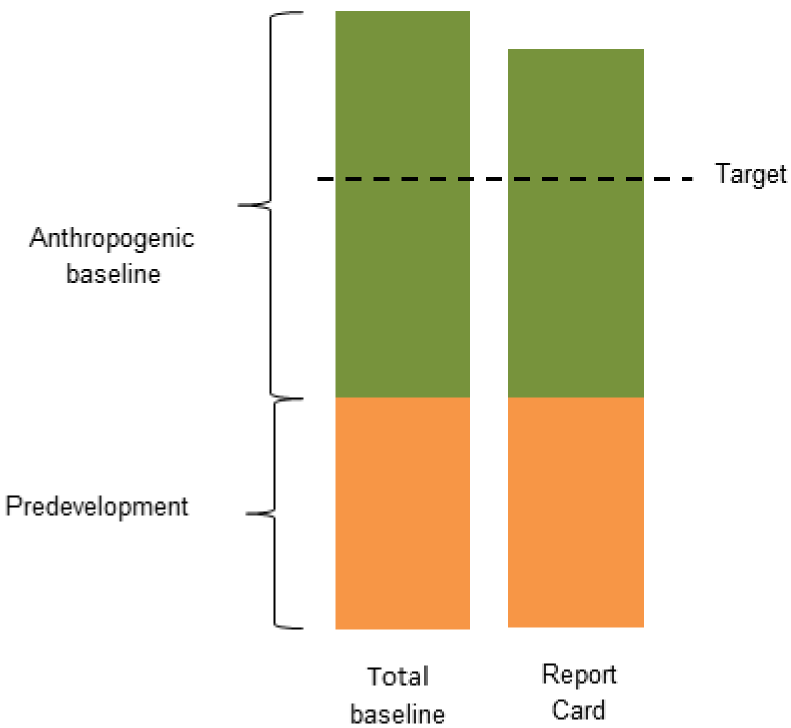


Figure 7 Representation of the modelled Report Card load reduction resulting from the adoption of improved management practices

The percentage reduction in load for Report Card 2013 is calculated as:

$$\text{Reduction in load (\%)} = \frac{(\text{Total baseline load} - \text{Report Card 2013 load}) \times 100}{\text{Anthropogenic baseline load}} \qquad (7)$$

3.5.1 Modelling baseline management practice and practice change

State and Australian government funds were made available under Reef Plan 2009 to the six Regional NRM groups and industry bodies to co-fund landholder implementation of improved land management practices. The typical practices that were funded under the program for grazing included:

- Fencing by land type
- Fencing of riparian areas
- Installation of off stream watering points

The aim of these practices was to reduce grazing pressure of vulnerable areas and improve ground cover in the longer term.

For sugarcane, typical practices included:

- Adoption of controlled traffic farming
- Modification of farm machinery to optimise fertiliser and herbicide application efficiency
- Promoting the shift from residual to knockdown herbicides and reduced tillage

These identified management changes were (subject to review) attributed with achieving improvements in land management which were assumed to result in improvements in offsite water quality. For a summary of typical management practice changes attracting co-investment, refer to Appendix A.

To model management practice change, a baseline of management practices needed to be established and incorporated into the model. An ABCD management framework was developed for this purpose. This framework was developed for each industry (sugarcane, cropping and grazing) and was used to describe and categorise farming practices within a given land use according to recognised water quality improvements for soil, nutrient and herbicide land management (Drewry, Higham & Mitchell 2008).

Farm management systems were classed as:

A – Cutting edge practices, achievable with more precise technology and farming techniques for cane and highly likely to maintain land in good condition for grazing

B – Best management practice, generally recommended by industry for cane and likely to maintain land in good/fair condition for grazing

C – Code of practice or common practices for cane and likely to degrade some land for grazing

D – Unacceptable practices that normally have both production and environmental inefficiencies and highly likely to degrade land to poor condition in grazing

The proportion of each industry in A, B, C or D condition was firstly established. The area of A, B, C or D was then reflected in the total baseline model. The proportion of area of A, B, C or D then changed each year between 2008 and 2013 (Report Cards 2010-2013) based on the adoption of improved practices. The portion of area that changed each year was provided by the regional NRM groups. For more information on the ABCD framework and associated management practices see the Reef Plan website (www.reefplan.qld.gov.au).

The total baseline load was modelled using 1999 land use and 2008–2009 land management practices. The most recent Queensland land use mapping program (QLUMP) map was used to define the spatial location of the major land uses in the region (DSITIA 2012). Land use categories in QLUMP were amalgamated to represent broader land use classes and are listed in Table 4.

There was a suite of specific management practices and systems defined under the ABCD framework relevant to soil, nutrient and herbicide management. The prevalence and location of management practice, was central to the modelling and reporting progress towards meeting reef water quality targets. The sources of information collected in the baseline year (start of 2008–2009 financial year) and adoption data collated by industry and regional NRM groups are outlined in Reef Plan (Department of the Premier and Cabinet 2013).

Catchment modelling aimed to show cumulative progress towards Reef Plan 2009 water quality targets following annual regional investments in improved land management practices such as those listed in Appendix A. In this report, reductions in constituent load due to adoption of improved land management practices in 2008–2009 and 2009–2010 are identified as Report Card 2010; Report Card 2011 includes the additional 2010–2011 adoption; Report Card 2012 includes the 2011–2012 adoption and Report Card 2013 2012–2013 adoption and hence are the cumulative load reduction over the Reef Plan 2009 period (Table 8). The water quality targets were set for the whole GBR with progress reported for the whole of GBR and the six contributing NRM regions: Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary.

Once the percentage load reduction was determined from the modelled loads, the progress towards the target was classified for each constituent from very poor to very good depending on the magnitude of the reduction (Table 9).

Table 8 Total and anthropogenic baseline and Report Card model run details

Scenario	Reporting Period	Land use	Model run period
Total and anthropogenic baseline	2008–2009	1999	1986–2009
Report Card 2010	2008–2010	1999	1986–2009
Report Card 2011	2008–2011	1999	1986–2009
Report Card 2012	2008–2012	1999	1986–2009
Report Card 2013	2008–2013	1999	1986–2009

Management changes funded through the Reef Rescue Caring for Our Country Program were provided as the numbers of hectares that have moved ‘from’ and ‘to’ each management class level. The thresholds and criteria used to determine progress towards the targets are outlined in Table 9.

Table 9 Pollutant load definitions of the status/progress towards the Reef Plan 2009 water quality targets (Report Cards 2010-2013)

Status/progress	Pesticides, nitrogen and phosphorus			Sediment		
	Target: 50% reduction in load by 2013			Target: 20% reduction in load by 2020		
	June 2011 reductions	June 2012 reductions	June 2013 reductions	June 2011 reductions	June 2012 reductions	June 2013 reductions
Very poor progress towards target—'Increase in the catchment load'	None	0–5%	5–12.5%	None	0–1%	1–3%
Poor progress towards target—'No or small increase in the catchment load'	0–5%	5–12.5%	12.5–25%	0–1%	1–3%	3–5%
Moderate progress towards target—'A small reduction in catchment load'	5–12.5%	12.5–25%	25–37.5%	1–3%	3–5%	5–7%
Good progress towards target—'A significant reduction in catchment load'	12.5–25%	25–37.5%	37.5–49%	3–4%	5–6%	7–8%
Very good progress towards target—'A high reduction in catchment load'	>25%	>37.5%	>50%	>4%	>6%	>8%

3.5.1.1 Management practice change – sugarcane

To represent the effects of A, B, C or D management practices for sugarcane, daily time series files of loads in runoff per day per unit area were generated from APSIM or HowLeaky model for combinations of soil type, climate, constituent and management practices. These daily loads were then accumulated into a single time series (per constituent) and passed to Source Catchments model for each subcatchment. This process allowed the inclusion of spatial (and management) complexity that the Source Catchments model was unable to represent. The impact of fertiliser and soil management practice changes on DON in runoff was not been modelled. For further details on this methodology, see Shaw & Silburn (2014).

3.5.1.2 Management practice change – cropping

To represent the effects of A, B, C or D management practices for cropping, daily time series files of loads in runoff per day per unit area were generated from the HowLeaky model for combination of soil type, climate, constituent and ABCD management system. These daily loads were then accumulated into a single time series (per constituent) and passed to Source Catchments model for each subcatchment. For further details on this methodology, see Shaw & Silburn (2014).

3.5.1.3 Management practice change – grazing

In grazing lands, for the baseline condition, the ABCD management practice proportions were represented by different ground cover classifications with the assumption that land condition is related to ground cover. Cover for the grazing areas were derived from the Ground Cover Index (GCI) grids, which were then translated into a cover factor or C-factor. The C-factor is required in the RUSLE used for sediment generation in grazing lands.

The GRASs Production model (GRASP) (McKeon et al. 1990) provided scaling factors for adjusting RUSLE C-factors where management practice change occurred. These C-factor scaling factors have been derived for a range of climates and pasture productivity levels or land types that occur within the GBR catchments. The GRASP model was chosen to relate cover to management due to its extensive application across northern Australian grazing systems (McKeon et al. 1990). The C-factor decreases (ground cover increases) related to an improvement in management practice were then applied to the GCI derived C-factor values used to model the baseline. For management changes (e.g. from C to B) to be assigned in a reportable and repeatable fashion, the farms ('properties' as discernable from cadastral data) representing grazing needed to be spatially allocated into a baseline A, B, C or D management class according to the average GCI conditions observed at that property over time. A methodology was adopted which compared GCI in properties for two very dry years a decade apart (Scarth et al. 2006). Properties that maintained or increased cover over this time were considered to be well managed while properties where cover decreased were considered to have been poorly managed. Higher ranked properties were assigned into 'A' management until the area matched the required regional baseline area and this was repeated for B, C and finally D management classes. Changes were assigned randomly within the relevant management class in each region. For example changes from C to B were assigned randomly to areas defined as 'C' management for the baseline year within the river basin specified. Changes were assigned randomly as the data was not available spatially, often provided at a basin scale. Table 10 provides an example of the change in the proportion of grazing lands in A,B,C or D class from the baseline year through to the end of the 2012–2013 investment year. Regional reports also provide specific details of annual ABCD management changes.

For further detail on the GRASP modelling and spatial allocation of the derived cover factor changes refer to Shaw & Silburn (2014). The paddock model outputs for the baseline scenario and for each subsequent scenario following changed management practices were then loaded into Source Catchments to produce relative changes in catchment loads.

Table 10 Example of the baseline management and management changes for grazing (% area) for the Cape York baseline year and Report Card 2010–2013

Management class	Period	A	B	C	D
		(%)			
Soil	Baseline	0	8	56	36
	2008-2010	0	12	54	34
	2008-2011	0	20	47	33
	2008-2012	0	20	49	31
	2008-2013	0	21	49	30

Riparian fencing

Improved grazing management (in particular cover management) can have both a direct and indirect beneficial effect on gully and streambank erosion rates.

Indirect effects of improved grazing management, i.e. increasing cover on hillslopes, can reduce runoff rates and volumes from upstream contributing areas to a gully or stream. This process is represented in the gully model by applying a relative reduction in erosion per management class as described by Thorburn & Wilkinson (2012) and shown in (Table 11), applied to a given stream reach where investment has occurred.

Similarly, the gully erosion model implemented by Dynamic SedNet has a management factor parameter, to which the area-weighted average of relative gully erosion rates (based on predicted distribution of grazing management practices) was applied for both the total baseline and other modelling scenarios.

Table 11 Gully and streambank erosion rates relative to C class practice. Adapted from Table 4, Thorburn & Wilkinson (2012)

Grazing practice change	A	B	C	D
	(%)			
Relative gully erosion rate	0.75	0.90	1	1.25
Relative streambank erosion rate	0.6	0.75	1	1.1

A relative reduction (Table 11) was also applied to the streambank model to reflect this indirect effect on streambank erosion. To identify the proportion of stream associated with each grazing management class in a subcatchment, a desk top GIS investigation was undertaken. The proportion of ABCD grazing area within a 100 m buffer of the modelled ‘main stream channel’ was firstly ascertained (buffer extended 100 m each side of the stream channel). The relative streambank erosion rate adjustment factor was applied to the bank erosion coefficient for the relevant stream.

The direct effects of riparian fencing are a result of increased cover on the actual stream or gully. To assess the direct effect of riparian fencing where investments were identified, the riparian vegetation percentage for the gully or stream was increased linearly with respect to the proportion of the stream fenced. Appendix B provides a summary of the reported riparian fencing investment from 2008–2013.

3.5.2 Predevelopment catchment condition

A series of assumptions on the catchment condition and erosion attributes were used to derive the predevelopment load. The predevelopment load, refers to the period prior to European settlement. Hence, the anthropogenic baseline load is the load for the period since European settlement to the present.

The assumptions made to represent predevelopment conditions were:

- Ground cover was increased to 95% in non-timbered grazing areas
- With the exception of grazing, all other land uses reverted to nature conservation area with corresponding constituent generation concentrations applied for sediment and nutrient generation
- A foliage projected cover layer was created to reflect 100% riparian cover
- Gully cross-section area were reduced by 90% of total baseline values

To be consistent with previous catchment modelling undertaken in the GBR, the hydrology, storages/weirs were left unchanged in each model. Therefore, the load reductions reported were solely due to land management change.

3.5.3 Potential to achieve targets

At the completion of Report Card 2010 a series of additional model runs were undertaken for the Department of the Premier and Cabinet to look at the feasibility of achieving the Reef Plan 2009 targets. The additional modelling scenarios were:

- All A management practices adopted throughout the GBR catchments
- All B practices adopted
- A 50:50 A and B practice adoption
- all C and all D management practices

It is important to note that no riparian investment data was modelled for Report Card 2010 and therefore did not contribute to these load reduction estimates.

4 Results

4.1 Hydrology and load performance

Results from the Source Catchments model calibration and validation are provided in the following section. The water quality results section includes modelled total baseline sediment, nutrient and herbicide loads and the anthropogenic baseline and predevelopment loads. Load reductions due to management changes are reported against the anthropogenic baseline from Report Cards 2010-2013.

4.1.1 Hydrology calibration

Once the models were calibrated, model performance was assessed against the three performance criteria; daily and monthly NSE and total modelled and measured volume difference. Calibration results were variable between regions. The three catchments receiving the highest annual rainfall, Cape York, Wet Tropics and Mackay Whitsunday had over 80% of gauges in their region, meeting the three performance criteria (Table 12). Approximately 60% of all gauges used in calibration across the GBR met two of the three performance criteria. Seventy-six per cent of gauges used for calibration achieved a monthly NSE >0.8 which is regarded as very good (Moriasi et al. 2007). Examples of calibration statistics used to assess model performance are provided in Table 13 for a range of catchment areas. More detailed statics for each region are provided in the regional reports (regional report references are listed in the front of this document). Generally the wetter regions such as Wet Tropics and Mackay Whitsunday achieved better calibration statistics than the larger drier catchments.

Table 12 Summary hydrology calibration for the six GBR regions

NRM region	Catchment area (km^2)	Number of gauges used in calibration	Proportion of gauges meeting all 3 performance criteria (%)	Proportion of gauges meeting at least 2 performance criteria (%)
Cape York	42,988	18	89	94
Wet Tropics	21,722	21	81	95
Burdekin	140,671	37	38	62
Mackay Whitsunday	8,992	9	89	89
Fitzroy	155,740	86	38	70
Burnett Mary	53,021	32	25	69

Table 13 Examples of hydrology calibration across the six NRM regions

NRM region	Gauge name (number)	Catchment area (km^2)	Daily NSE	Monthly NSE	Total volume difference (%)
CY	Kennedy River at Fairlight (105103)	1,083	0.50	0.90	-7.8
CY	Normanby River at Kalpowar Crossing (GS 105107)*	12,934	0.57	0.66	25
WT	Barron River at Myola (110001)	1,945	0.71	0.95	-9
WT	Tully River at Euramo (112006)	1,450	0.81	0.94	-7
BURD	Burdekin River at Selheim (120002)	36,260	0.73	0.97	2
BURD	Burdekin River at Clare (120006)	129,876	0.80	0.96	6
MW	O'Connell River at Stafford's (124001)	342	0.81	0.93	3
MW	Pioneer River at Sarich's (125002)	757	0.85	0.94	3
FITZ	Fitzroy River at The Gap (130005)	135,757	0.43	0.89	-2
FITZ	Isaac River (130401)	19,719	0.34	0.94	-11
BM	Burnett River at Figtree Creek (136007)	30,712	0.11	0.51	3
BM	Mary River at Home Park (138014)	6,845	0.51	0.97	1

* Site only had 5 years of data for calibration, included in calibration as it was the only water quality monitoring site for region

Model performance was also assessed using graphical techniques. Graphical assessment revealed that the models were generally underestimating high flows and overestimating low flows (Figure 8 and Figure 9). As an example, annual comparisons for wet and dry periods were selected for the extreme years. Measured and modelled annual discharge for the three wettest and three driest years at the EOS gauge at Tully (113006A) in the Wet Tropics are shown in (Figure 8) (from Hateley et al. 2014). The modelled simulation period (1986–2009) captured two of the three highest discharge years on record at the site and the driest years 1991–1992 and 2001–2003. The model run period was extended to include a third wet year, 1979. The average per cent volume difference for the three wettest years was -10% and for the three driest years +19%. Detailed summary of the calibration statistics are provided in each of the regional technical reports (regional report references are listed in the front of this document).

Figure 8 Annual measured and modelled discharge (ML/yr) for Tully River at Euramo for the three wettest and three driest years

A second example is the Pioneer River gauge in the Mackay Whitsunday region (Figure 9). Whilst it can be seen that the model is tracking observed runoff extremely well, for the larger events, peak flows are under estimated.

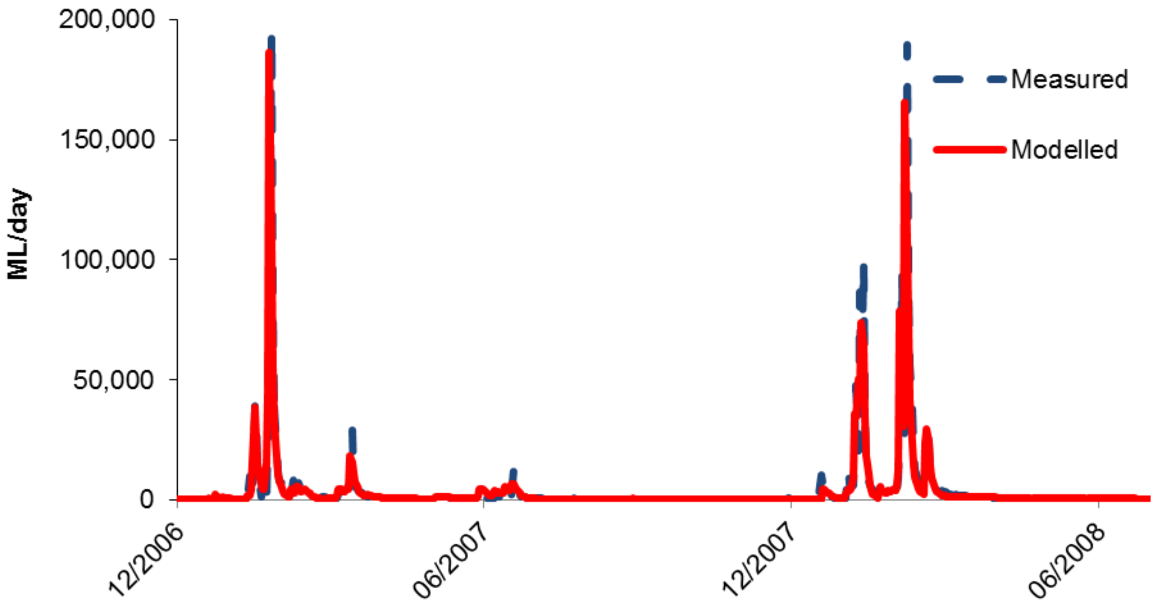


Figure 9 Underestimation of peak modelled flow for Pioneer River, Mackay Whitsunday

4.1.2 Load validation

Four sources of data were used for model validation:

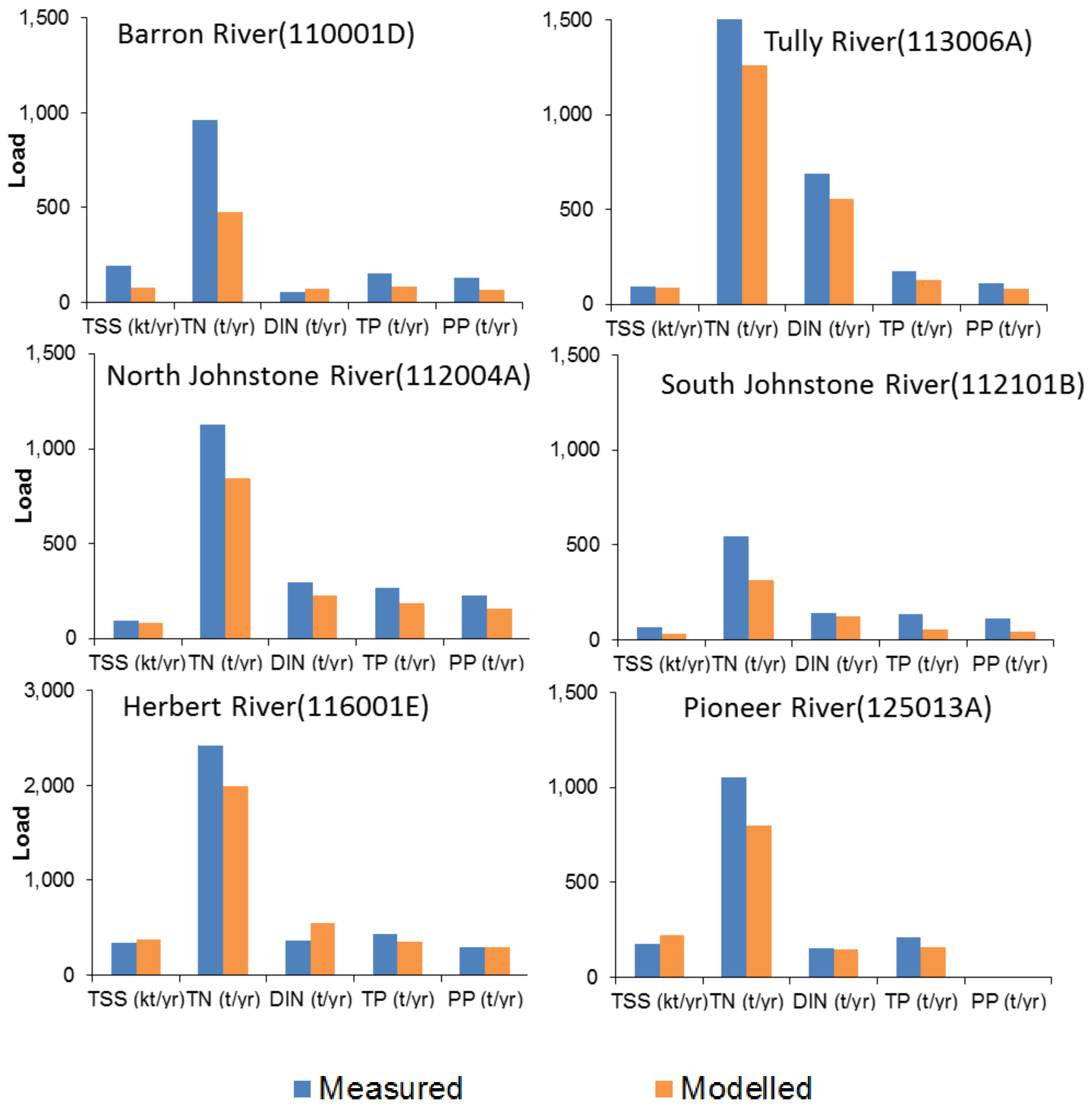
- Data collected under the GBR loads monitoring program (GBRCLMP) provided data for short–term comparison (2006–2010) (Joo et al. 2012, Turner et al. 2012)
- Long-term average annual load estimates (1986–2009) using the FRCE method (Joo et al. 2014) were compared to modelled loads for the same period
- Data source included a variety of data sets from short and long-term monitoring programs across the GBR that were region specific
- A comparison was made to previous best estimates based on modelling and or monitoring data (Kroon et al. 2012)

4.1.2.1 Short-term comparison – GBR Catchment Loads Monitoring Program (2006–2010)

For short-term validation, the modelled loads were validated against the GBR catchment loads monitoring program (GBRCLMP) load estimates (Turner et al. 2012).

A comparison was made between the mean GBRCLMP loads (averaged over four years, 2006–2010) and the Source Catchments modelled loads for the same period at the 10 EOS gauges (Figure 10). Source Catchments loads generally showed good agreement with the GBRCLMP loads with 90% of loads within ±50% of GBRCLMP load estimates. Modelled loads for TSS and TN were generally lower than GBRCLMP load estimates. DIN and TP were more variable across catchments. Modelled TP and PP loads were higher than GBRCLMP load estimates for the majority of sites. A detailed summary of results for each region are provided in the regional reports (regional report references are listed in the front of this document). A brief summary of the results in each region include:

- The five Wet Tropics gauges, modelled loads were generally lower than GBRCLMP load estimates. All modelled load estimates for the North Johnstone, Tully and Herbert River gauges were within 30% of GBRCLMP load estimates for the four year period. The exception being the DIN estimate in the Herbert at -50% of GBRCLMP load. For the Barron and South Johnstone, modelled loads were within 60% of GBRCLMP loads
- Pioneer River gauge in the Mackay Whitsunday region, modelled loads were generally lower than GBRCLMP load estimates. All modelled load were within 30% of GBRCLMP load estimates for the three year period
- Cape York, at the Normanby gauge, modelled loads were generally higher than GBRCLMP load estimates. All modelled loads were within 40% of GBRCLMP for the four years
- Burdekin River gauge, modelled loads were generally lower than GBRCLMP load estimates with the exception of DIN which was 10% higher than the GBRCLMP load estimate. All modelled load were within 50% of GBRCLMP load estimates for the four year period
- Fitzroy River gauge, modelled loads were generally lower than GBRCLMP load estimates. Modelled TSS, TN and TP loads were all lower than GBRCLMP load estimates and were within 60%. Modelled DIN loads were approximately double the GBRCLMP load estimate
- Burnett River gauge (136014A), modelled loads were all lower than GBRCLMP load estimates. Modelled loads were approximately half the GBRCLMP load estimates for four of the five constituents (Figure 10)


Barron River(110001D)
Tully River(113006A)
North Johnstone River(112004A)
South Johnstone River(112101B)
Herbert River(116001E)
Pioneer River(125013A)
Load
TSS (kt/yr)
TN (t/yr)
DIN (t/yr)
TP (t/yr)
PP (t/yr)
0
500
1,000
1,500
2,000
3,000
Measured
Modelled

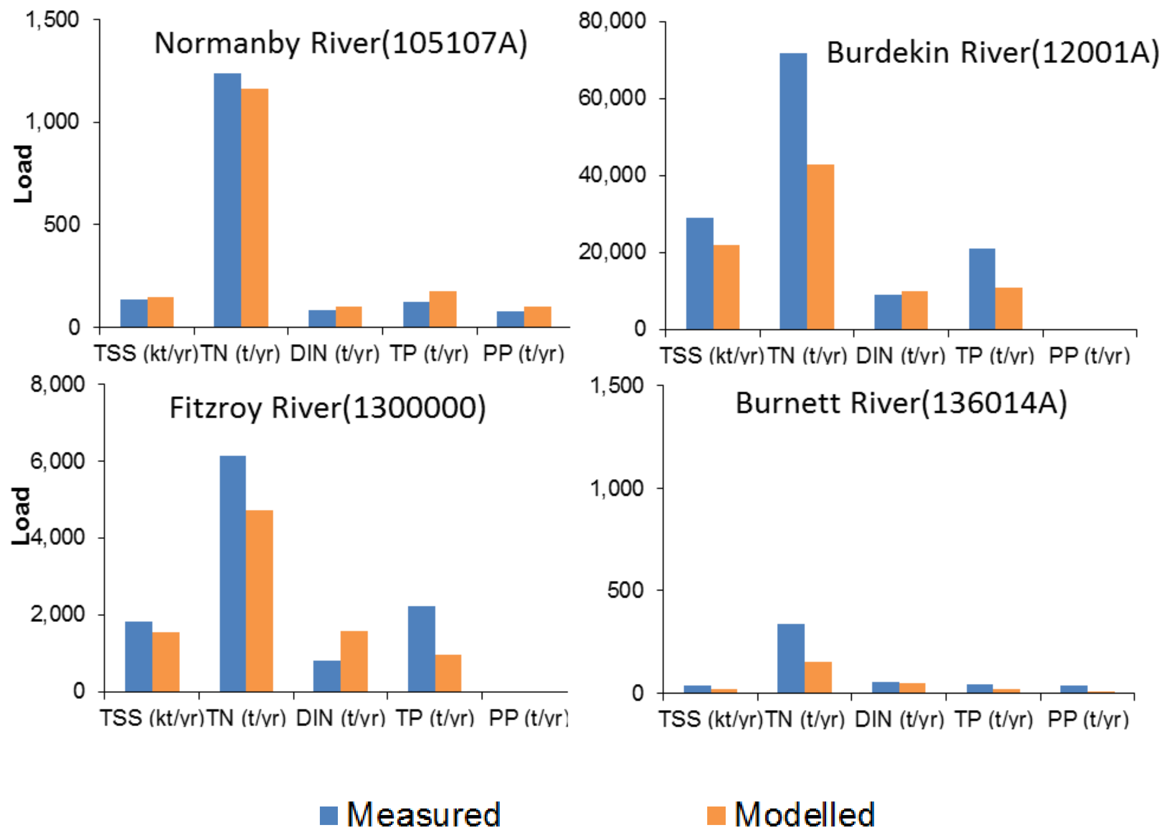


Figure 10 Average annual constituent load comparison between loads estimated from GBRLMP measured samples (measured) and Source Catchments load estimates for the 2006–2010 period (Note Pioneer River 2006–2009; PP data not available for all sites)

4.1.2.2 Long-term comparison – FRCE load estimates (1986–2009)

Daily load estimates were derived using a modified Beal Ratio method or the Flow Range Concentration Estimator (FRCE) for 10 EOS gauges across the GBR. Average annual loads were then calculated for the model period for comparison. All modelled loads fell within the FRCE likely range, with the exception of the Burnett River site (Figure 11–13). For TSS, the percentage difference (PBIAS) between modelled and FRCE loads ranged from 41 to -56% (Table 14). Eight of the 10 modelled TN estimates were lower than the FRCE estimates (Figure 12) with the per cent difference (PBIAS) between modelled and FRCE ranging from +25 to -38% for the eight sites. For DIN, eight of the 10 modelled estimates were higher than the FRCE (Figure 12) ranging from +19 to -48% of FRCE. For TP, results were quite variable (Figure 13) with differences ranging from +55 to -46%. PP follows a similar trend to TP with the difference between modelled and FRCE loads ranging from +62 to -41%.

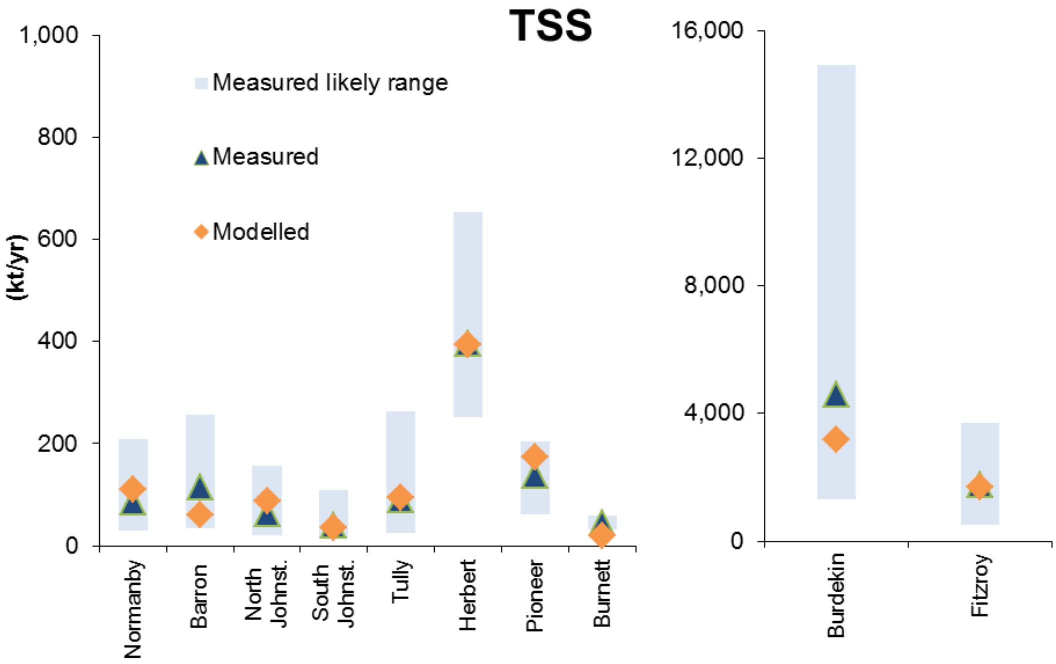


Figure 11 TSS (t/yr) comparison between Source Catchments (modelled) and FRCE load estimate (observed data) for the period 1986–2009 for the 10 EOS gauges

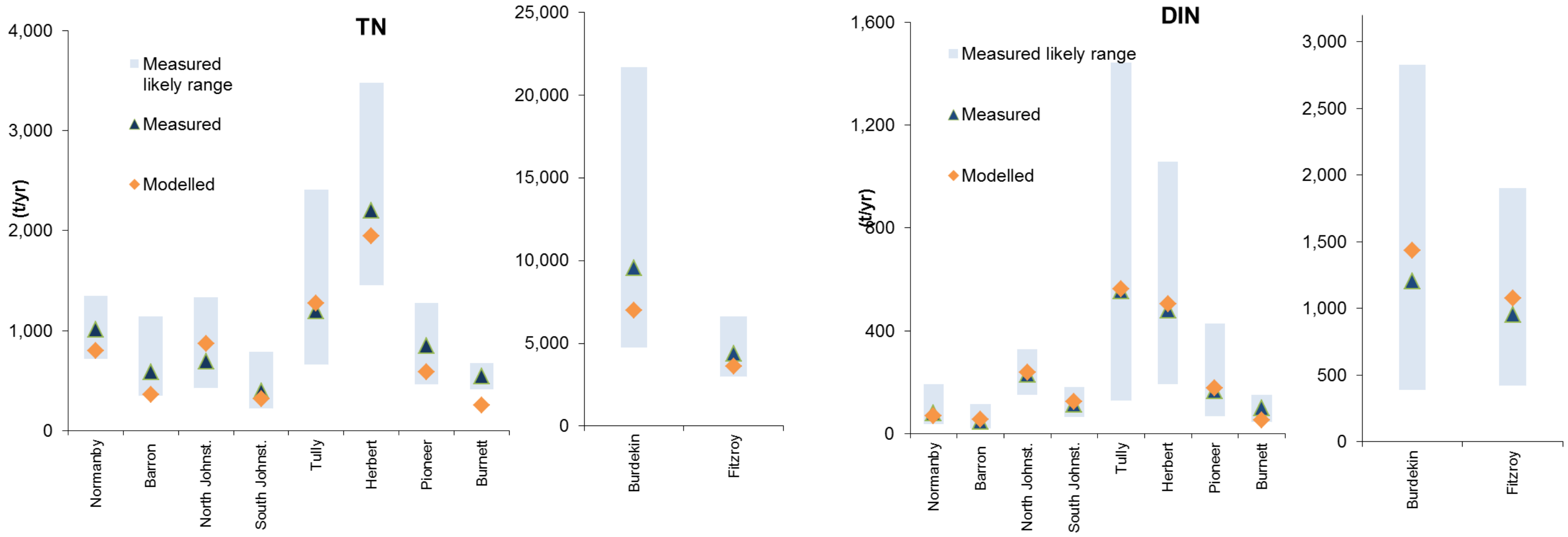


Figure 12 TN and DIN (t/yr) comparison between Source Catchments (modelled) and FRCE load estimate (observed data) for the period 1986–2009 for 10 EOS gauges

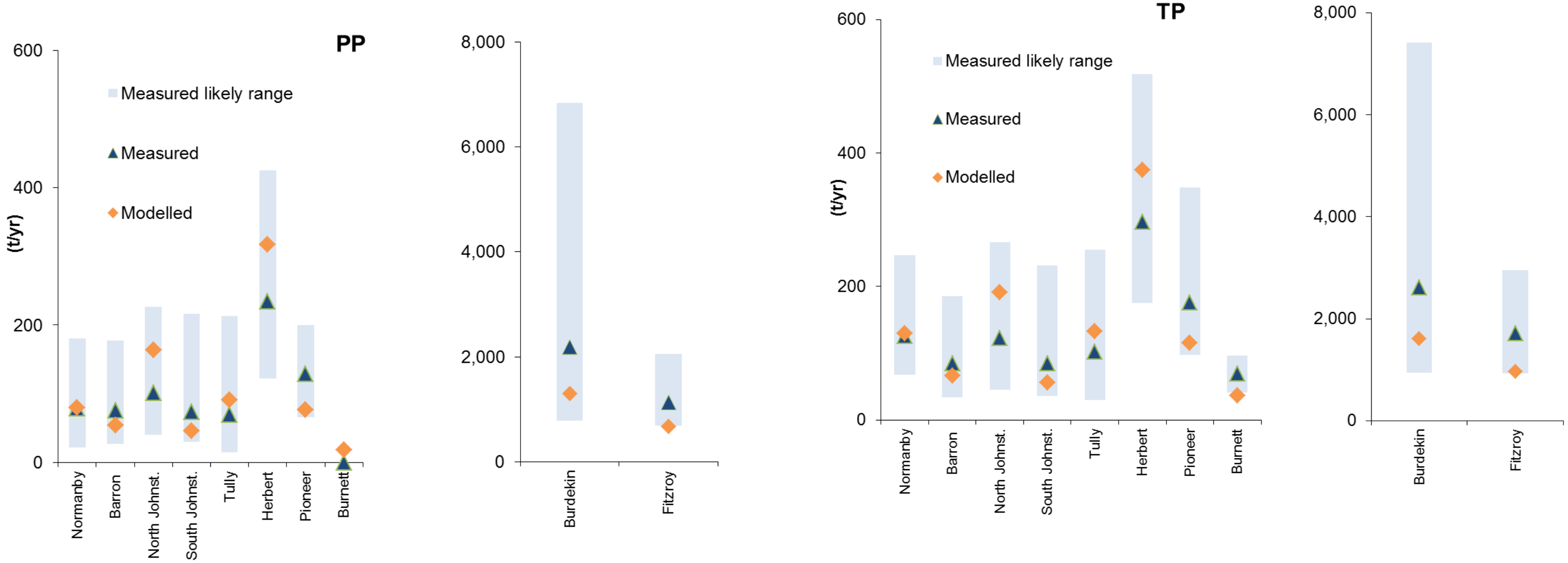


Figure 13 TP and PP (t/yr) comparison between Source Catchments (modelled) and FRCE load estimate (observed data) for the period 1986–2009 for 10 EOS gauges

In addition to the graphical comparison, three performance criteria were used (Table 7) for model evaluation RSR, NSE and PBIAS (volume difference), using the approach recommended by Moriasi et al. (2007). Statistical analysis of modelled total suspended sediment, total phosphorus and total nitrogen (Table 14–16) indicate over 60% of the ratings were ranked as Good or Very Good.

According to the evaluation criteria, modelled TSS loads were Satisfactory to Very Good for nine of the ten sites. Monthly NSE values ranged from 0.56–0.91 for nine of the ten sites (Table 14). The RSR values ranged from 0.3–0.67 for nine of the 10 sites. These results indicate model performance ranged from Satisfactory to Very Good for these sites. The percentage difference between modelled and FRCE derived load estimates (PBIAS) ranged from -56% to +41%.

For total nitrogen, the RSR values ranged from 0.27–0.73 for the 10 sites. Seven of these ratings were Very Good or Good with two Satisfactory and one Unsatisfactory (Table 15). Monthly NSE values ranged from 0.61–0.93 for nine of the 10 sites. These values are rated as Good to Very Good for nine sites. The PBIAS values varied from -68% to +25%.

For total phosphorus, according to the evaluation criteria modelled nutrient loads were Satisfactory to Very Good for eight sites (Table 16). The RSR values ranged from 0.33–0.87 for the 10 sites. Six of these ratings were Very Good or Good with one Satisfactory and three Unsatisfactory. Monthly NSE values ranged from 0.5–0.89 for eight of the 10 sites The PBIAS values varied from -70% to +55% (Table 16).

Table 14 TSS monthly load validation statistics for model run period (1986–2009)

NRM region	River	Gauge number	RSR	Rating	NSE	Rating	PBIAS	Rating
Cape York	Normanby	105107A	0.35	Very good	0.88	Very good	27.69	Good
Wet Tropics	Barron	110001D	0.64	Satisfactory	0.60	Satisfactory	-47.57	Satisfactory
Wet Tropics	North Johnstone	112004A	0.58	Good	0.66	Good	41.03	Satisfactory
Wet Tropics	South Johnstone	112101B	0.67	Satisfactory	0.56	Satisfactory	-14.70	Very good
Wet Tropics	Tully	113006A	0.34	Very good	0.88	Very good	3.52	Very good
Wet Tropics	Herbert	116001E	0.37	Very good	0.87	Very good	-0.34	Very good
Burdekin	Burdekin	120001A	0.60	Good	0.64	Satisfactory	-31.06	Satisfactory
Mackay Whitsunday	Pioneer	125013A	0.30	Very good	0.91	Very good	26.60	Good
Fitzroy	Fitzroy	1300000	0.97	Unsatisfactory	0.05	Unsatisfactory	-2.91	Very good
Burnett Mary	Burnett	136014A	0.63	Satisfactory	0.60	Satisfactory	-55.69	Unsatisfactory

Table 15 TN monthly load Validation statistics for model run period (1986–2009)

NRM region	River	Gauge number	RSR	Rating	NSE	Rating	PBIAS	Rating
Cape York	Normanby	105107A	0.28	Very good	0.92	Very good	-20.93	Very good
Wet Tropics	Barron	110001D	0.56	Good	0.69	Good	-37.65	Good
Wet Tropics	North Johnstone	112004A	0.40	Very good	0.84	Very good	25.47	Good
Wet Tropics	South Johnstone	112101B	0.61	Satisfactory	0.63	Satisfactory	-20.12	Very good
Wet Tropics	Tully	113006A	0.27	Very good	0.93	Very good	6.13	Very good
Wet Tropics	Herbert	116001E	0.36	Very good	0.87	Very good	-11.77	Very good
Burdekin	Burdekin	120001A	0.59	Good	0.65	Good	-26.96	Good
Mackay Whitsunday	Pioneer	125013A	0.57	Good	0.68	Good	-35.37	Good
Fitzroy	Fitzroy	1300000	0.63	Satisfactory	0.61	Satisfactory	-17.71	Very good
Burnett Mary	Burnett	136014A	0.73	Unsatisfactory	0.47	Unsatisfactory	-67.97	Satisfactory

Table 16 TP monthly load Validation statistics for model run period (1986–2009)

NRM region	River	Gauge number	RSR	Rating	NSE	Rating	PBIAS	Rating
Cape York	Normanby	105107A	0.35	Very good	0.88	Very good	2.49	Very good
Wet Tropics	Barron	110001D	0.47	Very good	0.78	Very good	-21.57	Very good
Wet Tropics	North Johnstone	112004A	0.60	Good	0.64	Satisfactory	55.45	Satisfactory
Wet Tropics	South Johnstone	112101B	0.71	Unsatisfactory	0.50	Satisfactory	-33.89	Good
Wet Tropics	Tully	113006A	0.46	Very good	0.79	Very good	30.88	Good
Wet Tropics	Herbert	116001E	0.33	Very good	0.89	Very good	26.02	Good
Burdekin	Burdekin	120001A	0.69	Satisfactory	0.53	Satisfactory	-38.55	Good
Mackay Whitsunday	Pioneer	125013A	0.60	Good	0.64	Satisfactory	-46.13	Satisfactory
Fitzroy	Fitzroy	1300000	0.87	Unsatisfactory	0.25	Unsatisfactory	-44.09	Satisfactory
Burnett Mary	Burnett	136014A	0.71	Unsatisfactory	0.49	Unsatisfactory	-70.04	Unsatisfactory

4.1.2.3 Regionally specific load estimates

Regionally specific data sets where available, were used to validate the models. One example is the AIMS load estimates (1988–2000) for the Wet Tropics region. Seven constituents were monitored at the EOS gauge at Tully (Mitchell et al. 2007). Modelled and AIMS loads were compared for the same period (1988–2000). All modelled loads were ± 50% of the AIMS load estimates except for DIP (+100%) (refer Hateley et al. 2014 for full details).

A second example is the comparisons for the Burdekin falls dam. A study looking at the trapping efficiency of the Burdekin Falls dam was undertaken from 2005 to 2009 (Lewis et al. 2011). The average annual (2005–2009) modelled estimate of the inflow and outflow (trapping efficiency) of fine sediment compared well for the study period (Figure 14) (Dougall et al. 2014a). The average trapping efficiency for the period estimated by Lewis was 66% compared to the model trapping efficiency of 68% for the same period.

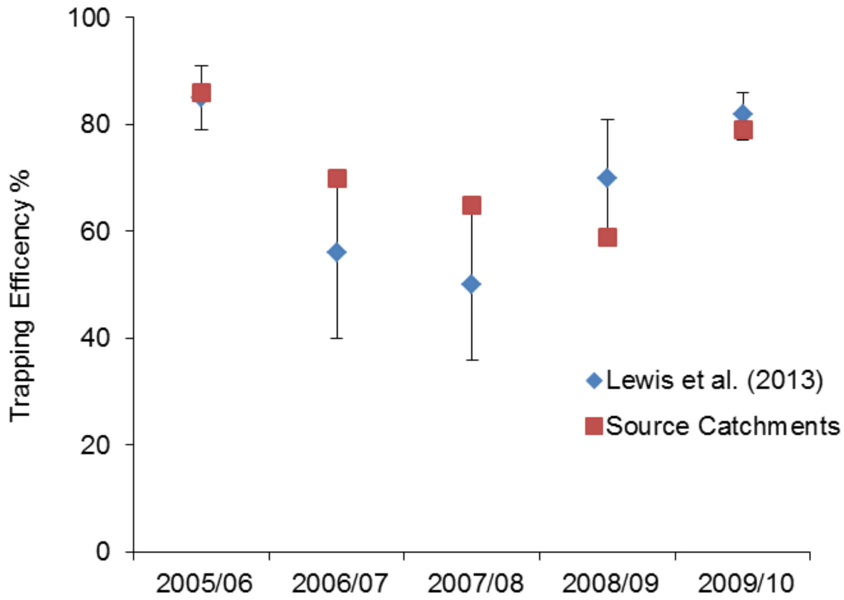


Figure 14 Burdekin Falls Dam trapping efficiency data used as an additional data source for model validation

These examples again highlight the value of the detailed spatial and temporal structure of the GBR Source Catchments models. Having the ability to generate daily outputs for discrete periods and locations, facilitating aggregation of the disparate monitoring data for use in model validation.

4.1.2.4 Previous estimates

Comparisons were made for each region between Kroon et al. (2012) load estimates and the Source Catchments modelled loads. The Source Catchments baseline loads were generally lower than Kroon et al. (2012) loads.

Source Catchments total baseline TSS, TP and TN load estimates for the GBR were 8,545 kt/yr, 6,294 t/yr and 36,699 t/yr respectively. This compares to Kroon et al. (2012) estimates of 17,000 kt/yr, 16,000 t/yr and 80,000 t/yr. Source Catchments loads are approximately half of Kroon et al.

(2012) estimates. For DIN, Source Catchments load estimate (10,532 kg/yr) was 35% lower than Kroon et al. (2012). For PSII herbicides, the Source Catchments load estimate (16,740 kg/yr) was approximately half the Kroon et al. (2012) estimate (30,000 kg/yr). Kroon et al. (2012) loads were derived from a range of data sources and differences in load estimates between Source Catchments and Kroon are due to differing methodologies and time periods over which long-term loads were calculated. These differences make direct comparison of loads difficult. These differences are outlined in the discussion.

4.2 Regional discharge

The modelled average annual runoff (1986–2009) for the GBR was 64,161,164 ML/yr (Table 17). The Wet Tropics had the largest average annual flow (21,236,645 ML/yr). Cape York region had the second largest modelled flow (17,536,797 ML/yr).

Per unit area the Wet Tropics produces the highest amount of runoff (978 mm) almost double Cape York (408 mm) and Mackay Whitsunday (568 mm) (Table 17). The remaining three larger regions generating less than 100 mm runoff per unit area.

Table 17 Average annual runoff for the GBR regions (1986–2009)

Basin	Average annual runoff (ML/yr)	Average annual runoff (mm)
Cape York	17,536,797	408
Wet Tropics	21,236,645	978
Burdekin	11,999,443	85
Mackay Whitsunday	5,103,153	568
Fitzroy	5,867,410	38
Burnett Mary	2,417,715	46
Total	64,161,164	152

4.3 Regional loads

The total modelled average annual baseline loads exported to the GBR for the 1986–2009 period and the loads expressed as a percentage of total load are presented in Table 18 and Table 19.

Table 18 Total baseline loads (Report Card 2013) for the GBR regions

NRM region	Area (km^2)	TSS (kt/yr)	TN (t/yr)	PN (t/yr)	DIN (t/yr)	DON (t/yr)	TP (t/yr)	PP (t/yr)	DIP (t/yr)	DOP (t/yr)	PSIIs (kg/yr)
Cape York	42,988	429	5,173	1,030	492	3,652	531	238	98	195	3
Wet Tropics	21,722	1,219	12,151	3,844	4,437	3,870	1,656	1,297	228	130	8,596
Burdekin	140,671	3,976	10,110	4,278	2,647	3,185	2,184	1,690	341	153	2,091
Mackay Whitsunday	8,992	511	2,819	739	1,129	950	439	271	132	35	3,944
Fitzroy	155,740	1,948	4,244	1,181	1,272	1,790	1,093	759	278	56	579
Burnett Mary	53,021	462	2,202	775	554	873	392	278	78	35	1,528
GBR total	**423,134**	**8,545**	**36,699**	**11,847**	**10,532**	**14,320**	**6,294**	**4,532**	**1,155**	**606**	**16,740**

Table 19 Area, flow and regional contribution as a per cent of the GBR total for all constituents

NRM region	Area	Flow	TSS	TN	PN	DIN	DON	TP	PP	DIP	DOP	PSIIs
	% of GBR total											
Cape York	10	27	5	14	9	5	26	8	5	9	32	<1
Wet Tropics	5	33	14	33	32	42	27	26	29	20	22	51
Burdekin	33	19	47	28	36	25	22	35	37	30	25	13
Mackay Whitsunday	2	8	6	8	6	11	7	7	6	11	6	24
Fitzroy	37	9	23	12	10	12	13	17	17	24	9	4
Burnett Mary	13	4	5	6	7	5	6	6	6	7	6	9
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

The Wet Tropics and Burdekin NRM regions generated the highest loads for nine of the ten constituents modelled. The total modelled TSS baseline load exported to the GBR is 8,545 kt/yr (Table 18) with the Burdekin region contributing 3,976 kt/yr (Table 18) or 47% (Table 19, Figure 15a) of the total load.

For nutrients, the total modelled TN baseline load exported to the GBR is 36,699 t/yr (Table 18). PN and DIN each make up 30% of the TN load (Table 19). The Wet Tropics and Burdekin regions combined contribute 67% of the DIN load (Figure 16a).

The total modelled TP baseline load exported to the GBR is 6,294 t/yr (Table 18) with PP making up 72% of the total load. Similar to TN, the Wet Tropics and Burdekin regions combined contribute 61% of the TP load (Table 19 and Figure 15b).

The GBR PSII herbicide export load was 16,740 kg/yr of this the WT total load was 8,596 kg/yr (51%) and was considerably higher than the second highest contributor Mackay Whitsunday 3,944 kg/yr (24%) (Figure 16b).

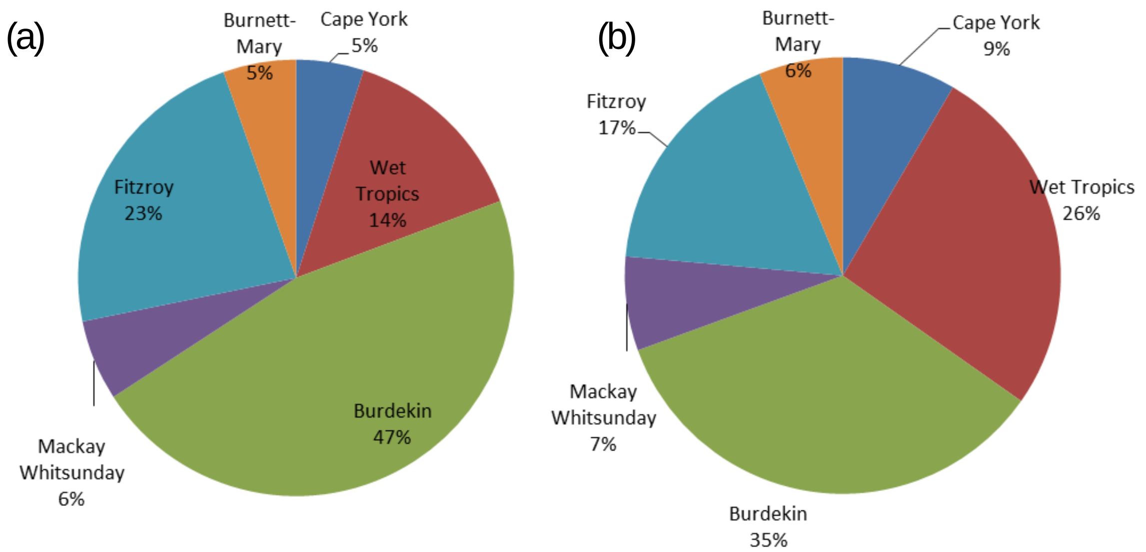


Figure 15 Regional contribution (%) to total modelled anthropogenic baseline load for (a) TSS and (b) TP

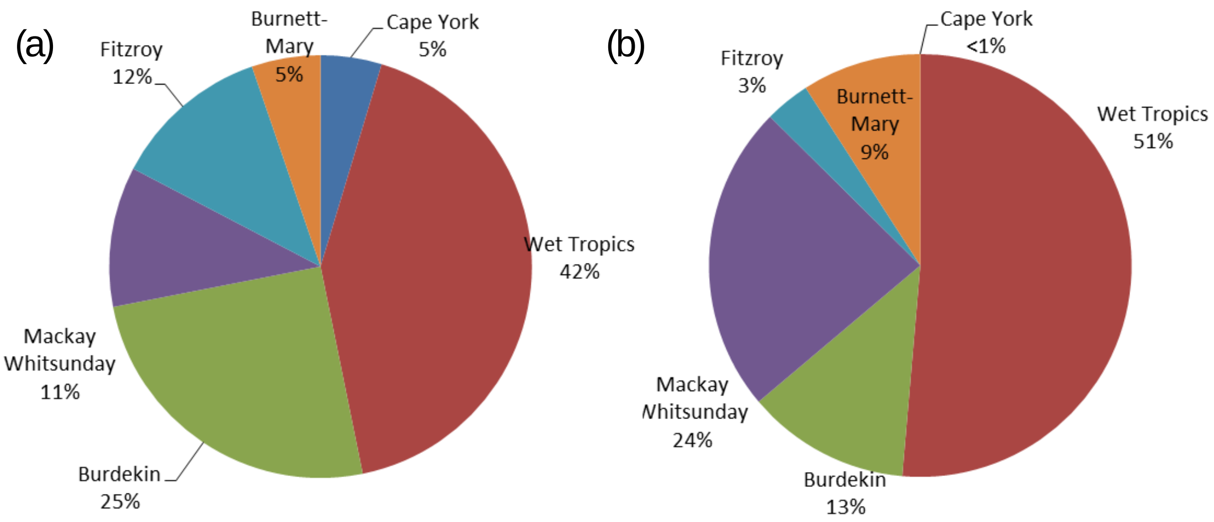


Figure 16 Regional contribution (%) to total modelled anthropogenic baseline load for (a) DIN and (b) PSII

4.3.1 Anthropogenic baseline and predevelopment loads

The anthropogenic baseline load was calculated by subtracting the predevelopment load from the total baseline load. Full details of the predevelopment and baseline load reductions and increase factors for each constituent and reporting basin are provided in Appendix C. TSS and DIN load results are presented (Figure 17 and Figure 18).

The TSS anthropogenic baseline load for the GBR was 5,613 kt/yr (Figure 17), an increase of 2.9 times the predevelopment load. Increase factors ranged from 1.7 in Cape York up to 5 for Burnett Mary region. TN and TP had increase factors of 1.8 (1.1–2.8) and 2.3 (1.5–2.6) respectively. The Burdekin NRM region contributes 45% of the TSS load whilst the Fitzroy region is the second highest at 25% of the anthropogenic TSS load. For particulate phosphorus and particulate nitrogen 83% of the PP and 65% of PN are from grazing lands. The Burdekin and Wet Tropics contribute 65 and 71% of the total load respectively.

The DIN anthropogenic baseline load for the GBR was 10,532 t/yr (Figure 18), an increase of two times the predevelopment to the baseline load. Increase factors ranged from minimal increase in Cape York up to 4.6 for the Burnett Mary region. The Wet Tropics NRM region contributes 38% of the DIN load whilst the Burdekin region is the second highest at 36%. The Wet Tropics contributes just over 50% of the total PSII load.

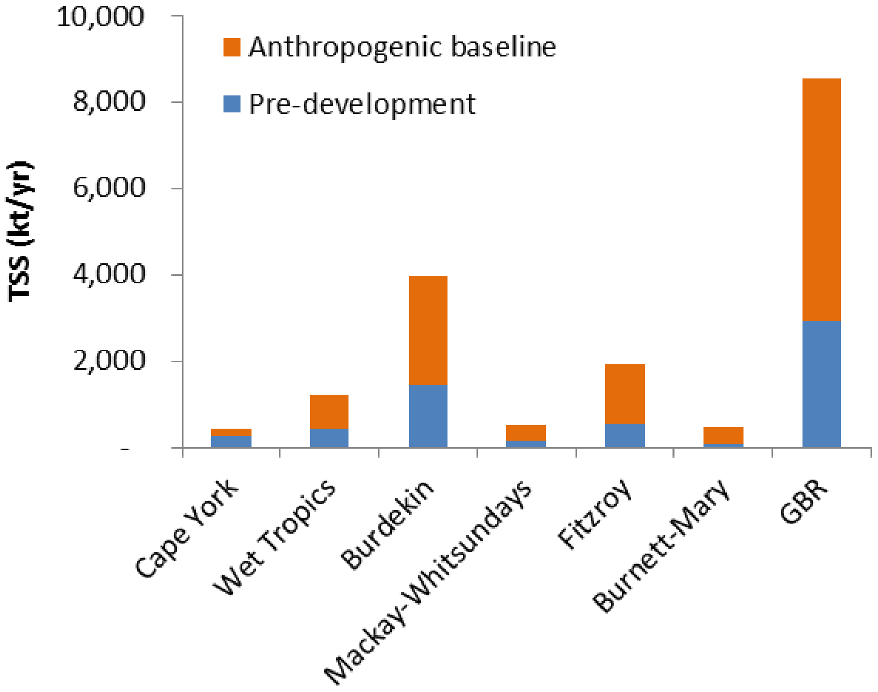


Figure 17 Modelled predevelopment and anthropogenic TSS (kt/yr) loads for each region and whole of GBR

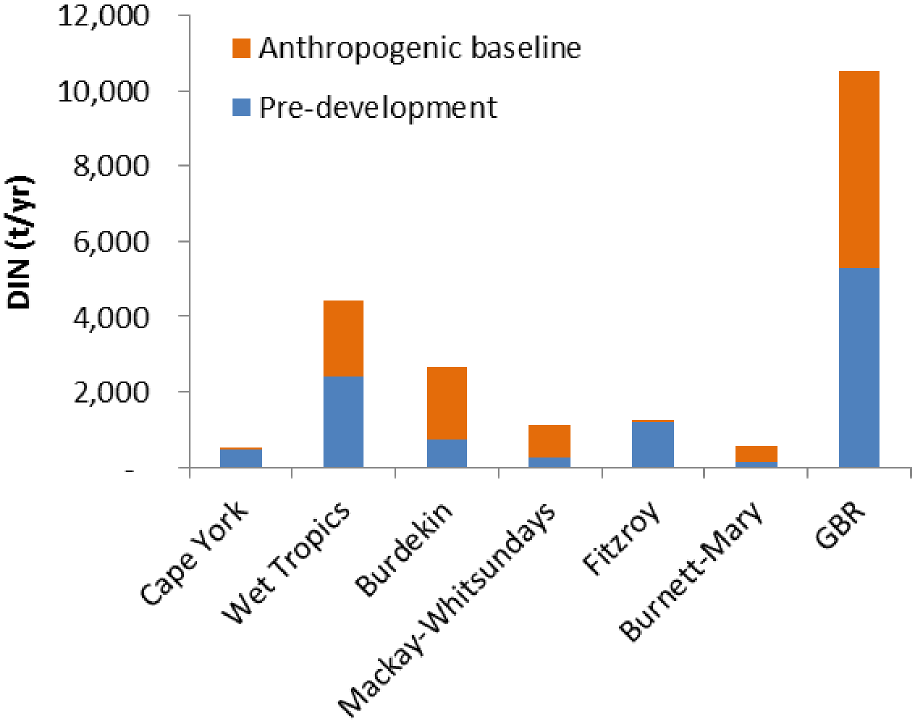


Figure 18 Modelled predevelopment and anthropogenic DIN (t/yr) loads for each region and whole of GBR

Looking at a finer scale, the contribution across the 35 reporting basins, the Burdekin and Fitzroy River basins contribute the majority of the TSS load (Figure 19). The Wet Tropics, Burdekin and Mackay regions contribute the majority of the total DIN load. The Johnstone and Burdekin River basins are the highest contributors to the anthropogenic DIN load (Figure 20).

Figure 19 Predevelopment and anthropogenic TSS load contribution for the 35 reporting basins

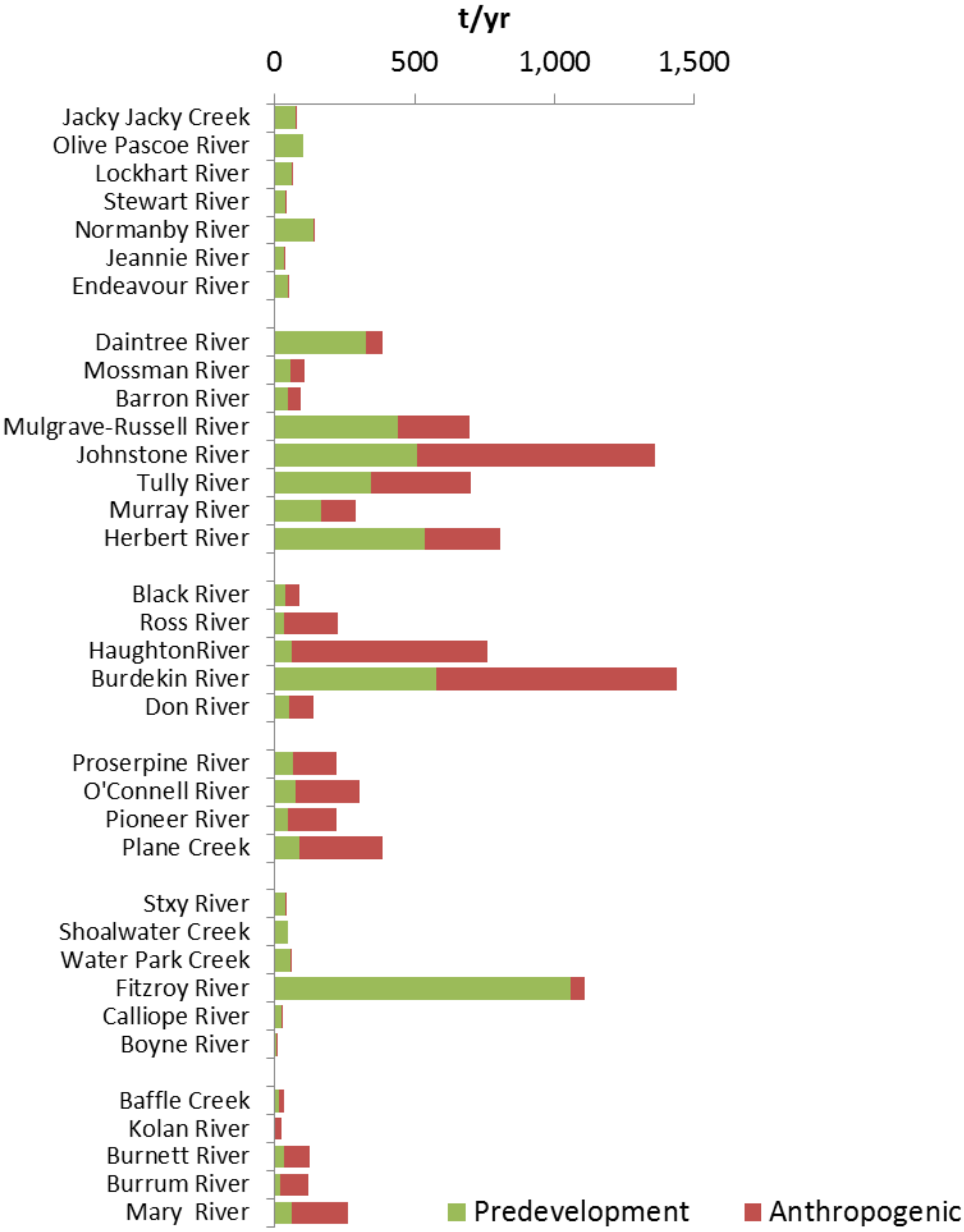


Figure 20 Predevelopment and anthropogenic DIN load contribution for the 35 reporting basins

4.3.2 Contribution by land use

Grazing was the largest source of total baseline TSS load at 3,816 kt/yr or 45% of total export load (Figure 21). Of the total baseline TSS load exported from grazing lands, 81% of the load comes from two regions, the Burdekin (51%) and Fitzroy (30%). Streambank erosion was also a major source of fine sediment making up 33% (2824 kt/yr) of the total TSS load exported. Nature conservation (11%) and sugarcane (5%) were the other landuses of note. A summary of the contribution by landuse are provided in Appendix E.

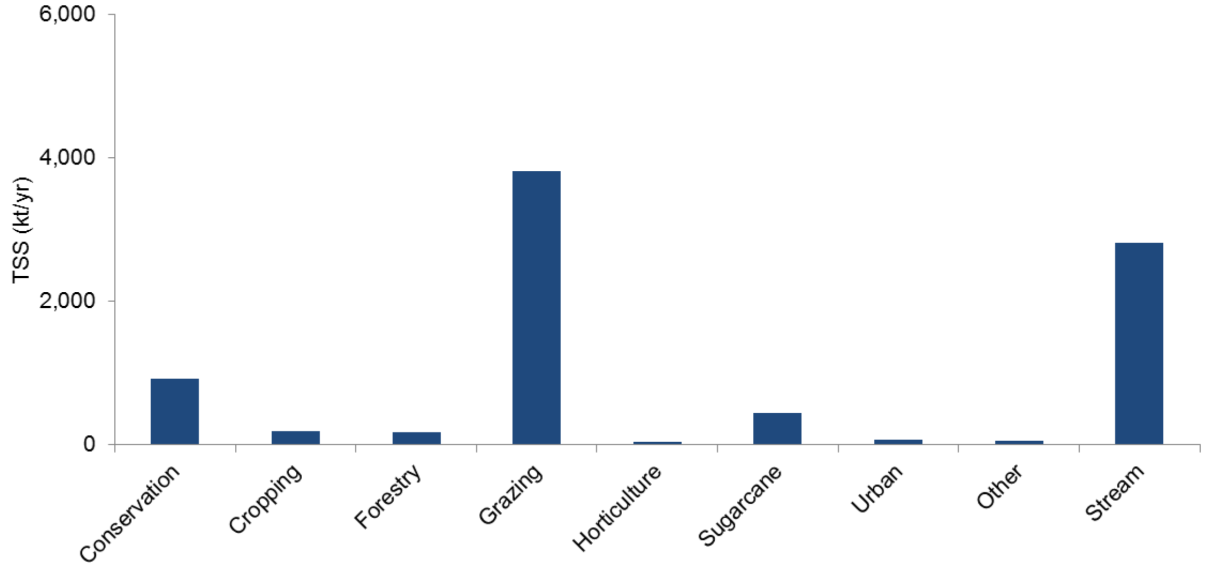


Figure 21 Whole of GBR TSS (kt/yr) total baseline load contribution by land use

Sugarcane had the highest proportion of the total baseline DIN export load at 37% (3,857 t/yr) followed by grazing with 2,952 t/yr (28%) and Nature Conservation 2,106 t/yr (20%) (Figure 22).

In relation to the anthropogenic loads, the contribution from sugarcane is much more significant at 68% of the total DIN load. Sugarcane contributed the highest PSII herbicide export load, contributing 15,663 kg/yr or 94% of the total PSII exported.

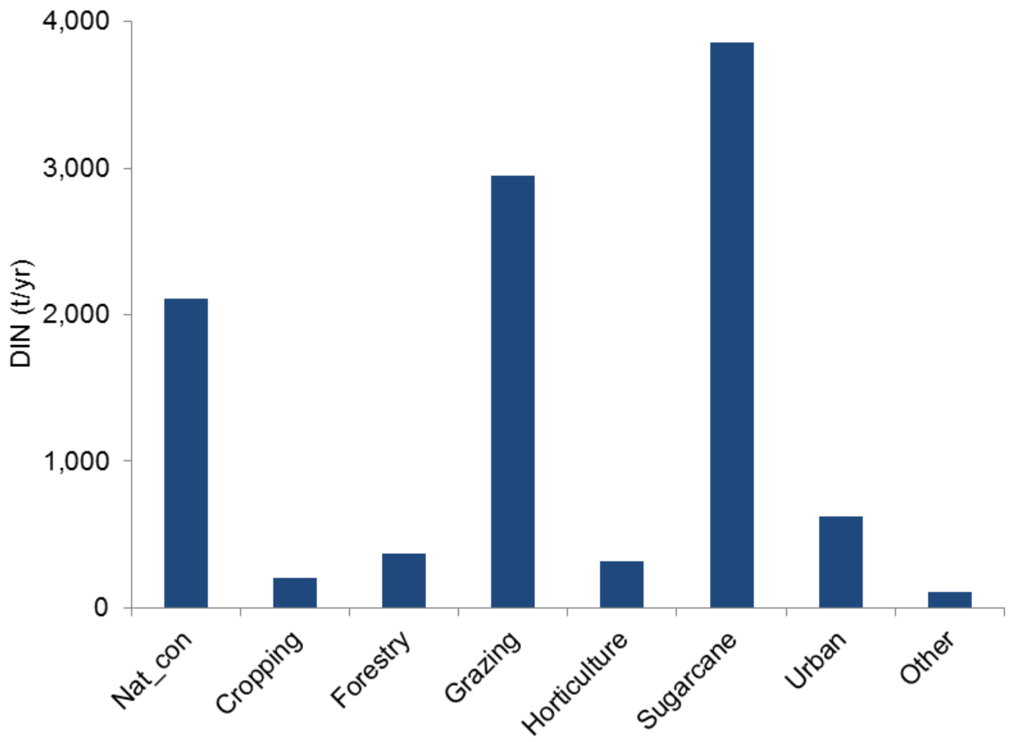


Figure 22 DIN (t/yr) total baseline load contribution by land use

On a per unit area basis, sugarcane was the highest contributor of TSS at 1 t/ha/yr with horticulture 0.71 t/ha/yr and the remaining land uses less than 0.5 t/ha/yr (Figure 23). For DIN contribution per unit area, the two highest contributors were sugarcane at 7.2 kg/ha/yr and horticulture at 4.2 kg/ha/yr (Figure 24).

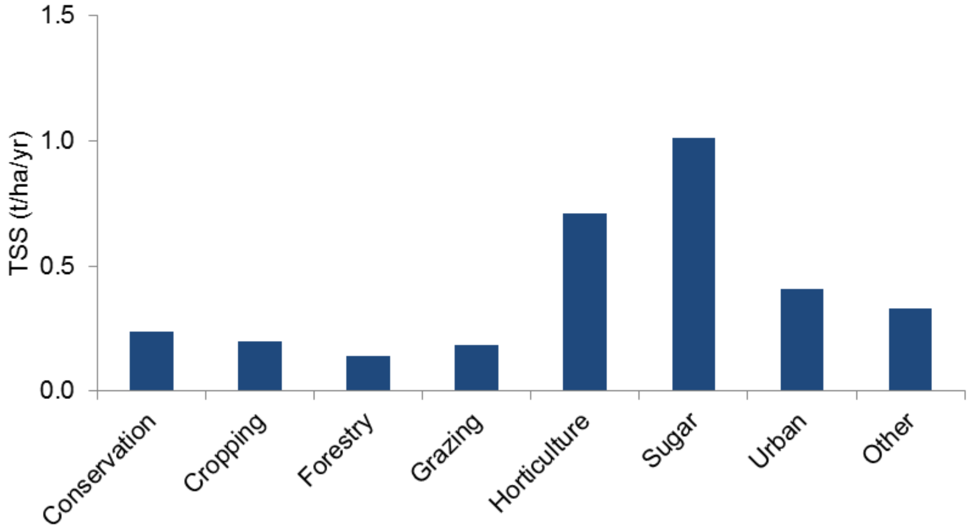


Figure 23 TSS (t/ha/yr) baseline load per unit area contribution by land use

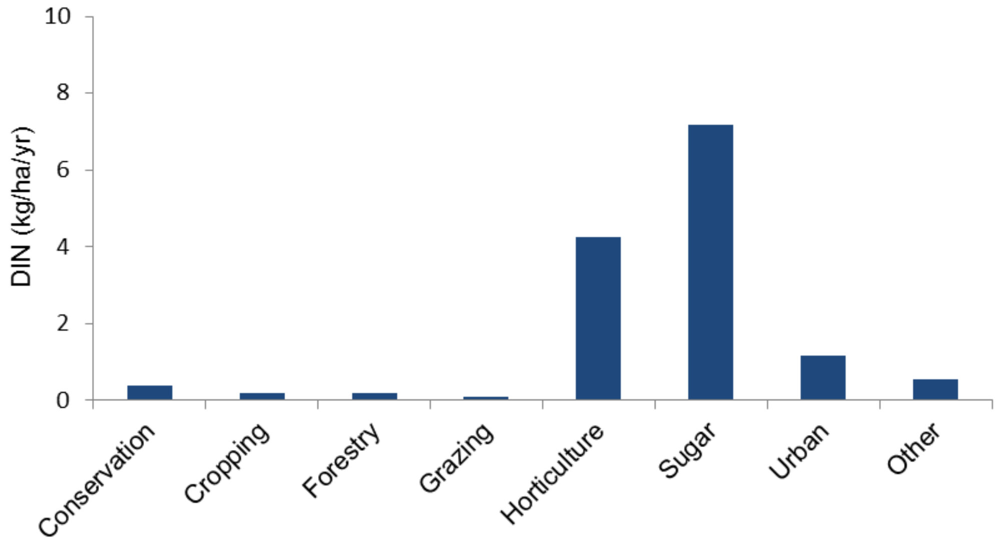


Figure 24 DIN (t/ha/yr) baseline load per unit area contribution by land use

4.3.3 Erosion processes

The contribution to total export can be separated into hillslope, gully and streambank erosion in the model. The modelled contribution from different sources of erosion was highly variable across the GBR. For the whole of GBR streambank and gully erosion accounted for just over half of the total erosion (Figure 25). The model results suggest that the three regions with the highest gully erosion were the Fitzroy, Burdekin and Cape York. Streambank erosion in the Burnett Mary accounted for just over half of the total sediment budget. Detailed analysis of sediment budgets for each region is provided in the regional technical reports (regional report references are listed in the front of this document).

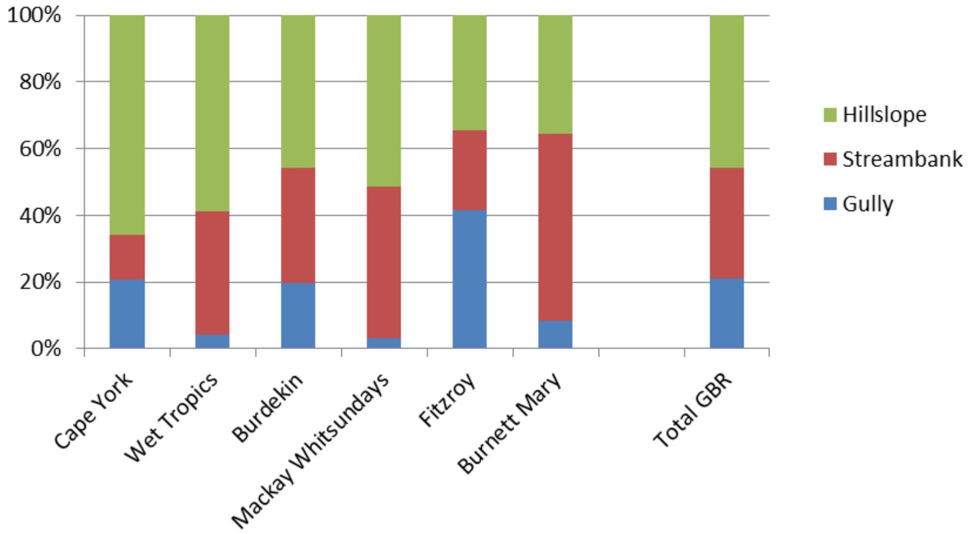


Figure 25 Relative contribution for total baseline loads from hillslope, gully and streambank erosion for the six regions and whole of GBR

4.4 Progress towards Reef Plan 2009 targets

For the whole of GBR region, there has been mixed progress towards the Reef Plan 2009 targets of 20% for TSS by 2020 and 50% reduction for nutrients and pesticides by 2013 after five years of adoption of improved land management practices (Figure 26).

There has been very good progress towards the sediment target with a reduction of 11%. The greatest sediment reduction was seen in the Burdekin region at 16% (Figure 27). Over the five years of adoption approximately half of the load reductions in the Burdekin region are attributable to riparian fencing projects with 1,291 km of works carried out (refer Appendix B for full list of riparian fencing investment by region).

Moderate progress has been made towards the pesticide target with a reduction of 28%. The greatest reduction was achieved in the Mackay Whitsunday region at 42% for Report Card 2013 (Figure 27).

There has been poor progress towards the TP target with a 13% reduction overall. The greatest reduction was achieved in the Wet Tropics region at 19%. Progress towards the nitrogen target was very poor with a 10% reduction overall. The greatest reduction was achieved in the Mackay Whitsunday region at 17%.

TN load reductions were achieved mostly through a combination of managing dissolved nitrogen from sugarcane and reducing particulate nitrogen export from grazing. The GBR DIN load reduction was 16%, with the WT and Burdekin regions responsible for 60% of the load reduction, almost equally shared between the two regions.

The GBR TP average annual load reductions were 13%. These reductions were predominately achieved through improved grazing management practices and the Burdekin and Wet Tropics NRM regions accounted for 76% of the reduction. The average annual PSII herbicide load leaving the GBR basins reduced by 28%. Over 80% of the reduction in the PSII load occurred in the sugarcane areas of Wet Tropics and Mackay Whitsunday NRM regions (Figure 27).

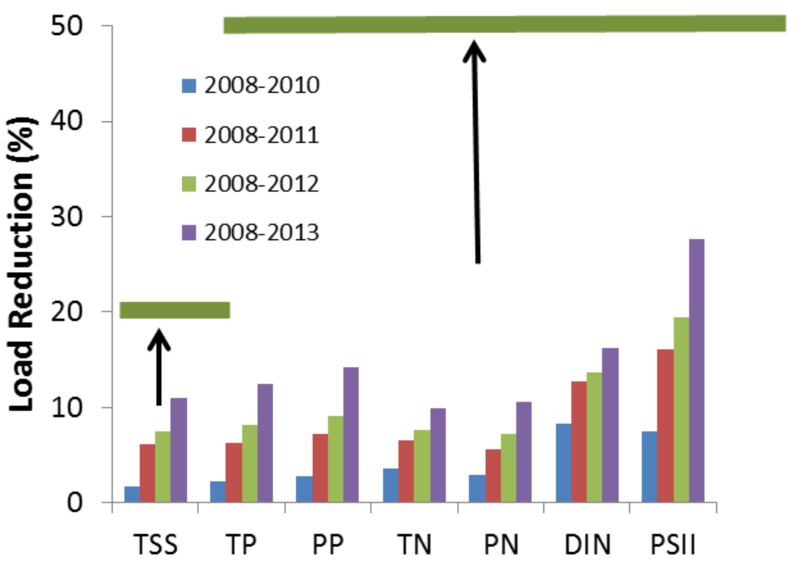


Figure 26 GBR wide modelled cumulative load reductions from Report Card 2010 to Report Card 2013

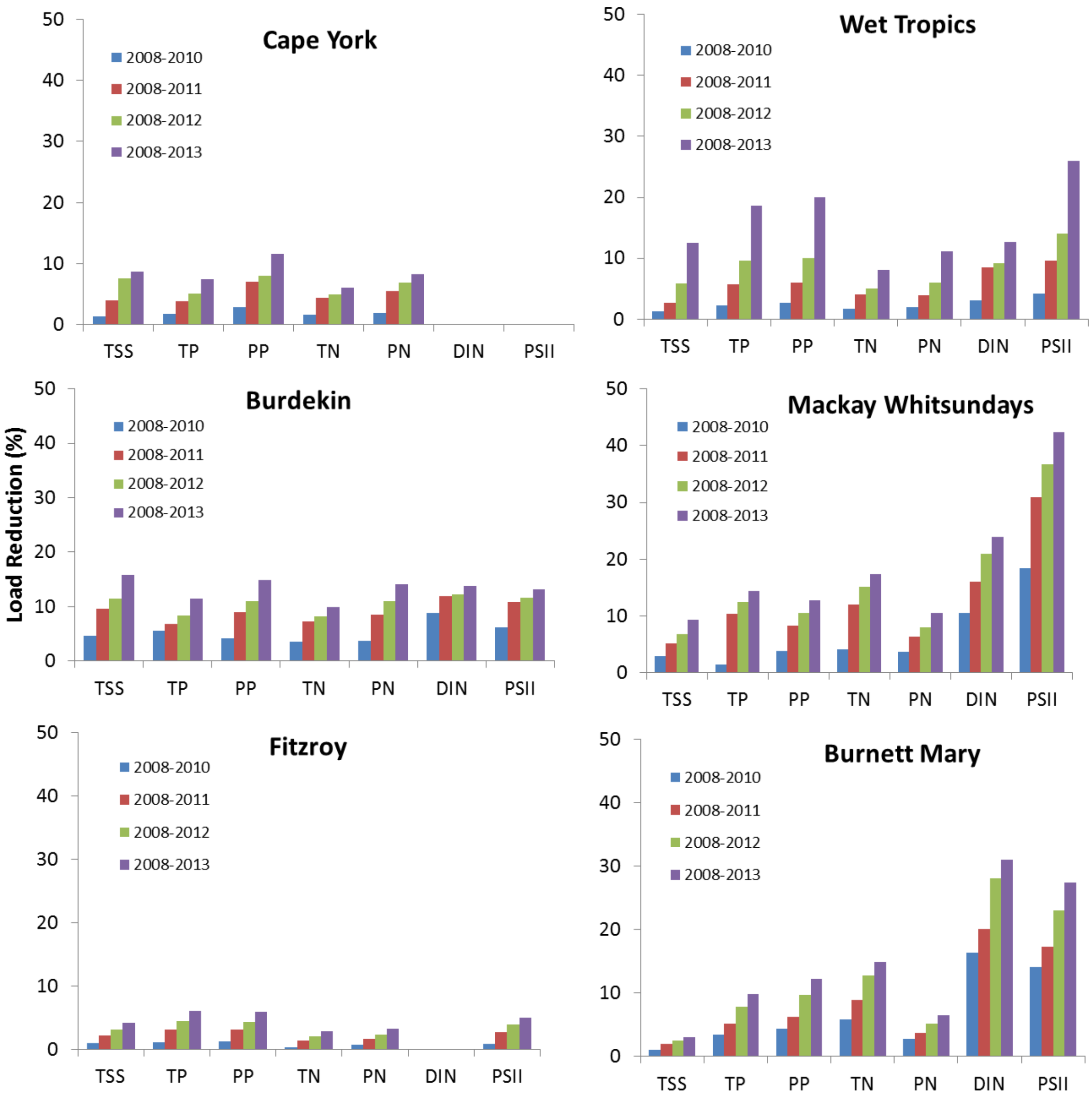


Figure 27 Modelled cumulative load reductions from Report Card 2010 to Report Card 2013

4.4.1 Potential to achieve the targets

The additional “All A” through to “All D” scenarios were undertaken for the Department of the Premier and Cabinet to look at the feasibility of achieving the Reef Plan 2009 targets (Appendix C, a-e). The results show that the TSS target could be met if a 50% adoption of A class practices and 50% B class practices were adopted. It is also worth noting that these estimates did not include riparian fencing as a management strategy which would further improve the result. The PSII target of 50% was achievable under an “All B” practice adoption. An “All A” scenario would not achieve the 50% target for nutrients.

5 Discussion

In the Paddock to Reef program, a consistent modelling approach was used to report on water quality targets. The CRC eWater Source Catchments modelling framework was used to generate predevelopment, total loads and subsequent anthropogenic baseline loads for key constituent for the 35 reef catchments for the six NRM regions. All load contributions from small coastal catchments were included in the GBR loads modelling, in contrast to previous catchment modelling where a simple area correction factor was used (Kroon et al. 2012, Wallace et al. 2012). The incorporation of a broad range of model enhancements have been undertaken to meet the objectives of the P2R modelling. These include the incorporation of SedNet/ANNEX modelling functionality to provide estimates of gully and streambank erosion, daily time-step hydrology, spatial and temporal representation of ground cover, inclusion of detailed soils information and point scale modelling of land management practices and the use of water quality monitoring data to validate model outputs. These collective enhancements have resulted in a comprehensive modelling framework developed for reporting on the impact of changes in land management and their associated load reductions discharging from GBR catchments to the reef lagoon.

5.1 Hydrology and load performance

The following section provides an overview of the hydrology calibration performance and load validation against the four data sources with some future improvement outlined.

5.1.1 Hydrology calibration

An improved spatial and temporal representation of hydrology has been a critical enhancement of the catchment modelling. Overall the hydrology calibration for the six NRM regions was Very Good for the three performance criteria: daily and monthly NSE and total modelled volume difference. Having three of the NRM regions with over 80% of the gauges meeting the three performance criteria and the remaining three having 60% of gauges meeting two of the performance criteria can be regarded as an extremely good calibration result. Mackay Whitsunday and Wet Tropics regions achieved extremely good calibration statics with over 85% of gauges in each region achieving an NSE >0.85. Moriasi et al. (2007) in a global review of hydrology calibrations rated monthly NSE values >0.75 as ‘Very Good’. The three, higher rainfall catchments namely Cape York, Wet Tropics and Mackay Whitsunday achieved the best calibration performance due to the greater rain gauge density and number of flow days available to calibrate the models.

Whilst calibration performance statistics extremely good for the average annual time-step, at the sub annual time-step peak flows were generally under-predicted in wetter years and over-predicted in drier years as highlighted for the Wet Tropics. In the Burdekin the hydrology modelling had good agreement with measured flow volumes particularly at the larger spatial and temporal scales, but less so at smaller scales; such as the Ross catchment attributed to the complex drainage network in the area including the township of Townsville.

Variable rain gauge density appears to be the greatest limiting factor to achieving significant improvements in runoff estimates. Bureau of Meteorology rain gauges used to generate daily rainfall surfaces for runoff calibration tend to be more clustered around major centres. For example in the Mackay Whitsunday region there are almost 60 rain gauge stations, however the majority of them clustered around the more populated areas like Mackay, Proserpine and Airlie Beach, Plain Creek and O’Connell catchments having the lowest density of rain gauges and poorer calibration

(Packett et al. 2014). This is an even greater issue in the larger catchments and partly explains why the three wetter regions achieved the best calibration statistics.

Despite the challenges of variable gauge density, the current hydrology calibration results provide a very good estimate of annual and long-term average annual flows.

One area that will be explored further is to examine the current objective functions used to optimise flow. Future hydrology modelling will revisit the objective functions used in the calibration and reconsidered the weighting of each objective function (weighted equally in this project), with the aim to improve runoff predictions.

An area where further improvements may be achieved is in the choice of rainfall runoff models. An investigation into the performance of a number of other models available in Source Catchments was undertaken (Zhang et al. 2013) following the release of Report Card 2010. As a result of this work, Sacramento model will be applied in future model due to its improvement in runoff predictions and better representation of groundwater losses compared to Simhyd. Sacramento is used by the Queensland hydrology group (DSITIA 2013) in the Integrated Quantity Quality Model (IQQM) for water planning purposes, which will ensure consistency across agencies.

5.1.2 Load validation

An important attribute of the GBR Source Catchments framework is that model outputs can be compare to loads derived from disparate water quality datasets collected at different locations and time periods within the model run period. This feature allowed for a range of validation approaches over various time-steps to be used. The first, the short-term catchment monitoring data for the 2006 to 2010 period (Turner et al. 2012) was compared to the equivalent four year modelled loads discharged from end of system catchments. The second, a ratio approach was used to derive loads from measured water quality data. These loads were then compared to modelled annual and average annual loads for the 23 year model period Joo et al. (2014). The third, Source Catchments loads were compared to a variety of regional data sets and fourthly, modelled loads were compared with previous estimates reported by Kroon et al. (2012). The four validations are discussed below.

5.1.2.1 Short-term comparison – GBR Catchment Loads Monitoring Program (2006–2010)

The GBR Source Catchments modelled average annual loads compared favourably to the estimates derived from short-term (2006–2010) catchment loads at key monitoring sites. Across all constituents at the 10 sites, 90% of modelled loads were within ±50% of GBRCLMP load estimates for the short four year period.

In the Cape York region, the Source Catchments modelled loads and average concentrations showed good agreement with the four year catchment monitoring period at the Kalpowar gauging station, with the average sediment concentration similar (51 mg/L and 45 mg/L) for the respective modelled and monitored period (McCloskey et al. 2014). In the three largest GBR catchments, Burdekin, Fitzroy and the Burnett, the modelled TSS, TN and TP loads showed good agreement to GBRCLMP load estimates, in the order of 25% lower than the estimated measured loads (Dougall et al. 2014a, Dougall et al. 2014b, Fentie et al. 2014). The lower erosion and particulate nutrients predictions across the three regions are thought to be related to high ground cover estimates generated from the remotely sensed data compared to the traditional static estimates. Trevithick & Scarth (2013) have correlated cover estimates derived from remotely sensed data and traditional visual estimates of cover. As a result this correlation will be applied to the remotely sensed data in subsequent model runs.

In the Wet Tropics, TSS loads at three of the five monitoring sites were rated very good, modelled loads were within ± 12% of the measured loads, with the Barron and South Johnstone gauges within 50% and 58% respectively (Hateley et al. 2014). For the Pioneer River Gauge in Mackay Whitsunday region, modelled loads were generally lower than GBRCLMP load estimates although within the acceptable range. All modelled load were within 30% of GBRCLMP load estimates. Moriasi et al. (2007) in a global review of calibrations rated loads within ± 40% (PBIAS) as a 'Good' performance. The hydrology performance was extremely good in both regions.

It is important to note when comparing such a short validation period that the modelled loads are only indicative of actual measured loads. The measured water quality data captures the seasonal and annual variability within the landscape. The catchment model loads represent a particular set of land use and land management conditions at a particular moment in time. Therefore model validation aims to demonstrate that the models are achieving a reasonable approximation of the loads derived from measured water quality data. Validation therefore, is more appropriate at an average annual to annual timescale and any comparisons made at smaller time-steps should be treated cautiously and be considered to have a higher degree of uncertainty. On the whole the modelling results are extremely promising when compared to the short-term monitored estimates. As further catchment monitoring data becomes available, greater confidence in modelled estimates will be achieved.

5.1.2.2 Long-term comparison – FRCE load estimates (1986–2009)

Modelled load estimates, were within the likely range estimated by Joo et al. (2014) for nine of the 10 EOS sites across all constituents (Figure 11–13). The exception being the Burnett River site where modelled loads were just outside of the lower range for TSS and TP.

Modelled load estimates were generally rated as satisfactory to very good for all constituents using the three modelling performance criteria from Moriasi et al. (2007): RSR, NSE and PBIAS.

RSR values ranged from 0.27 to 0.87, PBIAS were rated as good for TSS and TP at all sites, with just one site classified as poor for TN. For NSE the majority of the ten sites were rated satisfactory to very good for TSS, TP, TN (NSE values 0.5 to 0.91). At a regional level TSS for the Normanby, Tully, Herbert and Pioneer Catchments showed good to very good agreement with Joo et al. (2014) load estimates for all three performance criteria. The Barron, North and South Johnstone and Burdekin catchments had a satisfactory rating with all criteria satisfactory or better for the performance criteria. The Fitzroy and Burnett Mary catchments had a number of the ratings as unsatisfactory. The poorest statics occurred in the Burnett Mary region with modelled loads consistently lower than loads estimated are the limited validation data available to assess modelled loads against, thus increasing the uncertainty in loads estimated from measured data. Secondly the higher than expected cover estimates derived from the satellite imagery are resulting in low TSS and particulate nutrient estimates. The adjustment to cover and inclusion of the 2009–2013 monitoring data will greatly improve load estimates for the next reporting period.

For TP, the Normanby, Barron, Tully and Herbert Catchments showed good to very good agreement with the estimated loads for all three performance criteria, with satisfactory or better ratings for the North Johnstone, Burdekin and Pioneer catchments. Fitzroy and Burnett Mary catchments had unsatisfactory ratings for at least two of the criteria.

The model performance was also encouraging for TN load estimates with seven of the 10 sites achieving a rating of good or very good for all three criteria. The South Johnstone and Fitzroy catchments achieved two very good and a satisfactory criteria rating. On the whole, the model validation performance ratings for TN were higher than TSS and TP in particular for the Wet Tropics and Mackay regions.

Overall, the wetter catchments, Cape York, Wet Tropics and Mackay Whitsunday showed good agreement to Joo et al. (2104) load estimates. The Burnett Mary catchment had the poorest model performance, although having the least amount of water quality data available to assess model performance. Highlighting the importance of long-term catchment water quality data to both validate and assess the performance of the catchment models.

5.1.2.3 Other specific load estimates

In the Wet Tropics the Source Catchments model produced a favourable comparison with the AIMS load estimates for a 13 year period (1988–2000) at Tully EOS gauge (Hateley et al. 2014). The majority of loads were within 50% of AIMS load estimates. Similarly, in the Burdekin basin, modelled trapping efficiency estimates were in agreement with those estimated by Lewis et al. (2011). These examples again highlight the value of the detailed spatial and temporal structure of the GBR Source Catchments models. Generating daily outputs for discrete periods and locations thus facilitates aggregation of the disparate monitoring data for use in model validation.

5.1.2.4 Previous estimates

Source Catchments modelled loads were approximately half of previous estimates reported in Kroon et al. (2012). The addition of the range of improvements in modelling functionality has resulted in an improved estimate of catchment loads across the GBR.

Previous modelling had limited functionality to represent consistent generation for specific management practices, with the result higher nutrient estimates reported in Kroon et al. (2010) and Kroon et al. (2012). The high nutrient generation estimates are in part due to over-estimation of particulate nutrient loads in a number of previous SedNet/ANNEX modelling studies (Cogle et al. 2006, Sherman & Read 2008).

In summary the GBR Source Catchments constituent modelled loads compared favourably with three different sets of load estimates generated from monitored data and for a diverse range of reporting periods. The difference between previous collated modelled load estimates can be explained by the incorporation of enhanced hydrology modelling and improved representation of hillslope generation rates for the key management practices occurring across the GBR regions.

5.2 Regional discharge

Average annual discharge across the GBR is amongst the most variable in the world (Finlayson & McMahon 1988). This variability is attributed to a range of factors including the spatial distribution of mean annual rainfall, seasonal variations in rainfall due to monsoonal climate influences, inter-annual fluctuations in rainfall associated with global climate variability (e.g. ENSO) and the unpredictable movement of tropical cyclones (Furnas et al. 2003). Each of these factors contributes to the high degree of variability in runoff and constituent export to the GBR.

The Wet Tropics region generates the highest runoff contributing one third of the average annual runoff for the modelling period yet only covers 5% of the GBR contributing land area. Runoff is greater than 50% of rainfall for the majority of the region. This is contrast to the most southern region for example, the Burnett Mary, with runoff between 10-15% of annual rainfall.

Groundwater contributions to total flow are significant in the Wet Tropics and Mackay Whitsundays regions with many rivers flowing all year round. This baseflow is an important source of runoff and dissolve nutrients and pesticide loads to the GBR. By comparison, the larger catchments, the Normanby, Burdekin and Fitzroy Rivers are more ephemeral with little to no baseflow and events being more episodic in nature.

5.3 Regional loads

5.3.1 Anthropogenic baseline and predevelopment loads

Reef Plan 2009 water quality targets look to reduce the anthropogenic baseline load, which is the loads contribution caused by human induced development and management practice activities. Therefore, the anthropogenic load is determined by the difference between the total baseline load and predevelopment load. Although the total constituent load discharged to GBR lagoon is important to the overall marine water quality, it is acknowledged that improved land management aspires to reduce the anthropogenic load contribution from the particular land uses.

The increase factor across all constituents ranged from 1–3 for the majority of the NRM regions. Increase factors up to 5 were estimated for DIN in a number of the basins where cane was present. The estimated increase in loads is much smaller than previously reported (McKergow et al. 2005b, Kroon et al. 2012) where estimated increases were 5.4, 4.0 and 4.0 fold for TSS, TN and TP respectively. The reason for the differences between previous and Source Catchments load estimates include the use of a spatially and temporally variable cover factor in the estimation of hillslope erosion in Source Catchments. McKergow et al. (2005a) used a generic low ground cover value for their current condition (total baseline) scenario, with a static higher value (95%) for the predevelopment scenario. Average cover figures for the baseline scenarios are 10-20% higher than previous models, leading to a smaller increase in anthropogenic baseline loads than previously reported.

The Burdekin and Fitzroy regions contribute over 70% of the anthropogenic TSS load predominately from grazing lands. This is consistent with previous findings by Kroon et al. (2012).

Given that the grazing occupies 75% of the GBR area it will generally contribute the highest load. However on a per unit area basis relative to other industries grazing contribution is low. It is a similar result for particulate nutrients, with the majority of the particulate nutrients coming from the Burdekin and Wet Tropics regions followed by the Fitzroy although per unit area grazing is low compared to other industries. The Wet Tropics and Burdekin regions contribute over 70% of the anthropogenic DIN load to the GBR predominantly from cane areas. The Wet Tropics, Burdekin and Mackay Whitsunday catchments contribute over 80% to the total photosystem-II inhibiting herbicides load to the GBR lagoon, with sugarcane being the main source (94%). These findings are consistent with previous findings and provide clear indications of which regions should be targeted as a priority to achieve load reduction targets.

5.3.2 Contribution by land use

Hillslope erosion from grazing lands contributes close to half of the average annual baseline (Figure 21) and anthropogenic loads of TSS, PP and PN (48%, 47% and 50% respectively) delivered to the lagoon. If the assumption were made that streambank erosion could be uniformly distributed across the grazing areas then as a proportion of land use area, then the average annual anthropogenic loads of TSS, PP, PN from grazing areas (hillslope plus streambank erosion) to increase to 77%, 66% and 65% of the total load respectively. Sugarcane and cropping contribute less than 10% of the TSS load. The Burdekin and Fitzroy regions are the dominant sources of sediment export which has been reported previously by Greiner et al. (2005), McKergow et al. (2005), Kroon et al. (2012) and the Scientific Consensus statement (Brodie et al. 2013).These two large grazing catchments contain 78% of the total grazing area of the GBR. In the Burdekin region, both the modelling and tracer studies suggest areas within the Upper Burdekin, below the Burdekin Dam and the Bowen Bogie subcatchments are the main sources of sediment (Dougall et al. 2013, Bartley, 2013). In the Fitzroy region, the main TSS export areas are the Isaacs, Dawson, Mackenzie and Nogoa subcatchments (Dougall et al. 2014b).

The modelling suggests that the majority of particulate phosphorus and nitrogen (PP and PN) comes from hillslope and gully erosion in grazing land (41% and 44% respectively), with streambank erosion estimated to contribute 28 and 21% of the PP and PN respectively. Cane lands are the other main contributor of PP and PN with (17% and 18%), with grains a minor contributor to the average annual anthropogenic loads.

The cane industry occupies just 1.3% of the total GBR catchment area and contributes over 70% of the anthropogenic DIN load and 94% of the pesticide load. The three biggest cane growing regions, Wet Tropics, Mackay Whitsunday and Burdekin contribute over 90% of the total anthropogenic DIN load exported to the GBR lagoon. At the subcatchment level, the largest contributors to anthropogenic DIN load are the Johnstone Burdekin and Haughton basins.

At the basin scale, the largest contributors to PSII load from cane areas are the Herbert and Johnstone basins.

On a per unit area basis whilst the large grazing areas contribute the majority of TSS and particulate nutrients, sugarcane and horticulture contribute four to five times more than grazing. Similarly, for DIN sugarcane and horticulture are the two dominant land uses. The per unit are contribution is an important consideration for regional NRM groups when prioritising investment in catchments where similar proportions of major land uses are present.

Whilst land use area is an important consideration when looking at pollutant load contribution, movement of sediment, nutrients and herbicides is largely controlled by the volume, intensity and distribution of rainfall (Furnas 2003). For example the Wet Tropics is unique compared to the other GBR regions as it has the highest annual flow volume with 33% of the flow to the GBR from only 5% of the GBR contributing land area (Hateley et al. 2014). Proximity to the coast can also have a major influence on loads exported. Small coastal regions close to the coast where the majority of cane is grown, have the potential to export dissolved nutrients and herbicides with limited losses due by in-stream or floodplain processes from paddock to the GBR lagoon in floods (Hateley et al. 2014). This is in contrast to the larger grazing basins such as the Fitzroy and Burdekin.

5.3.3 Erosion processes

The modelled sediment sources for the whole of GBR comprise gully (21%) and streambank (33%) and hillslope (46%) with streambank and gully erosion accounting for over half the current TSS load. This is highly variable across regions for example in the Burnett Mary catchment modelled estimates indicate over half the total load exported to the GBR is streambank erosion particularly in the Mary catchment. In Cape York alluvial gullies have been identified as a potential major source of sediment in the Normanby basin in Cape York (Brooks et al. 2013). Alluvial gullies have also been identified as a major source of sediment in a number of other northern Australian rivers, including the Mitchell catchment in Queensland (Brooks et al. 2009, Shellberg 2011) and in the Victoria River, Northern Territory (McCloskey 2010). Sediment supply from alluvial gully erosion is likely to be accounted for in hillslope erosion estimates in the current modelling framework. Therefore, the simplistic interpretation that modelled hillslope contribution represents surface sediment, and vice versa for gullies, could lead to a perception that alluvial gully contribution is underestimated and hillslope sources overestimated in parts of the GBR catchments.

Recent radionuclide sediment sourcing studies in northern Australia indicate that rilled and scalded hillslopes may be contributing almost as much erosion as vertical channel banks (Hancock et al. 2013, Wilkinson et al. 2013), implying that some of the 46% of hillslope erosion estimated across the GBR as represented in the modelling framework, is made up of both surface and sub-surface derived sediments.

The current structure of the GBR Source Catchments hillslope process component does not differentiate between the erosion of surface and or subsurface erosion from hillslopes. Therefore this should be taken into account when comparisons are made between sediment tracing results and Source catchments modelled hillslope and gully estimates. Future model iterations will attempt to partition hillslope derived sediment loads into an estimated surface and sub-surface component for reporting, allowing better comparison with sediment tracing projects. This comparison, however, should be conducted in a conservative way that recognises that neither the tracing models nor the GBR Source Catchments models are a direct measure of ‘reality’.

5.4 Progress towards Reef Plan 2009 targets

Investments in improved land management practices during the life of Reef Plan 2009 are estimated to have reduced loads of TSS, TP, TN and PSII herbicides to the reef lagoon by 11%, 13%, 10% and 28% respectively.

Modelled reductions in TSS ranged from 3% from the Burnett Mary to 16% from the Burdekin region, with approximately half of the reduction in the Burdekin region attributable to investment in improved riparian area management. The exception was the Burnett Mary where no investment in riparian fencing was reported and therefore was not modelled as a load reduction. Future modelling in the region should include investment in riparian fencing to determine the full load reduction estimates. Based on the assumptions applied in the model the results for the Burdekin region are encouraging and highlight the potential value of riparian fencing as a management tool to reduce erosion. Given the significant investment in riparian fencing to improve water quality the modelling results do highlight the importance of further research in this area to improve our understanding of the water quality improvements associated with riparian fencing activities and quantify the uncertainty in the estimates. As a result of large shifts from C class to B and A class nutrient management practices in cane areas of the Mackay Whitsunday and Burnett Mary regions, both regions achieved over 15% reduction in TN and 24% and 31% reduction in DIN respectively. Similarly, a large movement from C to B and A class management in cane systems caused a very large reduction in PSII herbicide loads from the Wet Tropics (26%), Burnett Mary (28%) and Mackay Whitsunday (42%) regions. The large reductions in PSII loads are due to the reporting of significant adoption of improved practices out of C to A and B class practices. The large reductions in pesticides when shifting out of C class practices for pesticide management are a function of the assumption used in the models based on regional consultation. A typical set of pesticide products, rates and timing of applications were determined through regional consultation and used to represent ABCD practices in each cane region. For example, when there is a shift from a C to B class cane management system, pesticide rates are assumed to reduce by half in the cane ratoon phase and when there is a move from B to A, no pesticides are assumed to be applied during the ratoon phase resulting in large reductions in PSII loads generated in the model. In line with the adaptive approach of the P2R program, the regional ABCD management practice descriptions and the modelled assumptions will be revisited through a series of regional forums with local experts to refine the ABCD framework prior to Reef Plan 2013 reporting. Improvements to the framework will include a wider range of management practice options represented in the models. A number of these practices will need to be implemented by a farmer before a management class change (e.g. C to B) will be reported and hence reflected in the models. This will avoid large step changes in improved management practice currently represented in paddock modelling.

In relation to the potential to achieve the targets, the model results suggest that the TSS target could be met if a 50% adoption of A class practices and 50% B class practices were adopted. This is despite the fact that no riparian investment data was modelled for Report Card 2010 and therefore did not contribute to these load reduction estimates. The PSII target of 50% could be achieved under an “All B” class practice adoption. Achieving the 50% TN and DIN reduction is more challenging. The modelled results suggest that an all A management adoption scenario would not achieve the target. Thorburn and Wilkinson (2012) believe the greatest reductions in nitrogen DIN exports will be achieved by reducing the total amount of nitrogen applied to crops, rather than changing management of current application regimes to improve nitrogen use efficiency. It is clear therefore that alternative nutrient management strategies need to be considered if current and future targets are to be achieved. It is important to acknowledge at the baseline year (2009), industry were already classed as being better than an “All C” level of adoption.

6 Conclusions

This work demonstrates the significant progress made over the past five years in model development to meet the objectives for reporting under Reef Plan. The model was applied to report on progress towards reef water quality targets for whole-of-reef and for the six NRM regions. A consistent modelling approach was used to estimate pre development loads. Industry specific paddock scale models were used to represent a change in contemporary land management practices. The modelling results provide one line of evidence for regional bodies to assist with prioritisation of future on ground works. The modelling provides insights into the potential load reductions that may be achieved through the various improved management practices.

Consistent with the P2R program's continual improvement process, a number of updated input data layers will be included prior to delivery of model results for Report Card 2014 including:

- The use of the Sacramento hydrology model to better match to observed and modelled flows
- Incorporation of seasonal rather than annual dry season cover
- Improved spatial allocation of specific management practice information
- Updated ABCD management framework that requires more defined management practice changes before a whole system change is acknowledged and modelled extension of the model climate period by five years to include the recent extreme events
- The collection of additional soil erodibility data (K factor layer in RUSLE) for specific soil types where data is lacking particularly in grazing lands. Parameters will be derived from rainfall simulation study and WEPP modelling
- Incorporation of updated gully maps where available
- Refinement of sediment budgets where appropriate data is available to justify changes to current models

These changes will improve estimates of catchment loads and load reductions. It should be noted that, due to the proposed model changes, the modelled results for the Reef Plan 2013 reporting period should not be directly related to the outcomes reported in Reef Plan 2009.

7 References

Agriculture & Environment Research Unit (AERU) 2006–2013, *The Pesticide Properties Database (PPDB)*, University of Hertfordshire, UK.

ANRA 2002, *User guide: Australian Natural Resources Atlas,* URL: http://nrmonline.nrm.gov.au/catalog/mql:2479, viewed 28 May 2011.

Bartley, R, Speirs, WJ, Ellis, TW, Waters, DK 2012, A review of sediment and nutrient concentration data from Australia for use in catchment water quality models, *Marine Pollution Bulletin* 65 (4–9), 101–16.

Bartley, R, Bainbridge, ZT, Lewis, SE, Kroon, FJ, Wilkinson, SN, Brodie, JE, Silburn, DM 2013, Relating sediment impacts on coral reefs to watershed sources, processes and management: a review, *Science of the Total Environment* 468–469, 1138–1153.

Beale, EML 1962, Some uses of computers in operational research, *Industrielle Organisation* 31, 51–52.

Belperio, AP 1979, The combined use of wash load and bed material load rating curves for the calculation of total load: an example from the Burdekin River, Australia, *Catena* 6 (3–4), 317–29.

Brodie, J, McKergow, LA, Prosser, IP, Furnas, M, Hughes, AO, Hunter, H 2003, *Sources of sediment and nutrient exports to the Great Barrier Reef World Heritage Area*, Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Brodie, J, Waterhouse, J, Lewis, S, Bainbridge, Z, Johnson, J 2009, *Current loads of priority pollutants discharged from Great Barrier Reef Catchments to the Great Barrier Reef*, ACTFR Report 09/02, Townsville.

Brodie, JE, Mitchell, A, Waterhouse, J 2009, *Regional Assessment of the Relative Risk of the Impacts of Broad-Scale Agriculture on the Great Barrier Reef and Priorities for Investment under the Reef Protection Package, Stage 2 Report*, ACTFR Technical Report 09/30, Australian Centre for Tropical Freshwater Research, Townsville.

Brodie, J, Waterhouse, J, Schaffelke, B, Kroon, F, Thorburn, P, Rolfe, J, Johnson, J, Fabricius, K, Lewis, S, Devlin, M, Warne, M, McKenzie, L 2013, *2013 Reef scientific consensus statement, Land use impacts on Great Barrier Reef water quality and ecosystem condition* , Reef Water Quality Protection Plan Secretariat, Brisbane.

Brooks, A, Spencer, J, Olley, J, Pietsch, T, Borombovits, D, Curwen, G, Shellberg, J, Howley, C, Gleeson, A, Simon, A, Bankhead, N, Klimetz, D, Eslami-Endargoli, L, Bourgeault, A 2013, *An empirically-based sediment budget for the Normanby Basin: sediment sources, sinks, and drivers on the Cape York Savannah*, Australian Rivers Institute, Griffith University.

Brooks, AP, Shellberg, JG, Knight, J, Spencer, J 2009, Alluvial gully erosion: An example from the Mitchell fluvial megafan, Queensland, Australia, *Earth Surface Processes and Landforms* 34 (14), 1951–69.

Brough, DM, Claridge, J, Grundy, MJ 2006, *Soil and landscape attributes: a report on the creation of a soil and landscape information system for Queensland*, Department of Natural Resources, Mines and Water, Brisbane.

Carroll, C, Waters, D, Vardy, S, Silburn, DM, Attard, S, Thorburn, PJ, Davis, AM, Halpin, N, Schmidt, M, Wilson, B, Clark, A 2012, A paddock to reef monitoring and modelling framework for the Great Barrier Reef: paddock and catchment component, *Marine Pollution Bulletin* 65 (4–9), 136–49.

Chapman, PJ, Edwards, AC, Shand, CA 1997, The phosphorus composition of soil solutions and soil leachates: influence of soil:solution ratio, *European Journal of Soil Science* 48 (4) 703–10.

Chiew, FHS, McMahon, TA 1993, Assessing the adequacy of catchment streamflow yield estimates, *Australian Journal of Soil Research* 31 (5), 665–80.

Chiew, FHS, Peel, MC, Western, AW 2002, 'Application and testing of the simple rainfall-runoff model SIMHYD' in *Mathematical models of small watershed hydrology and applications*, VP Singh & DK Frevert (eds), Water Resources Publication, Littleton, Colorado, pp. 335–67.

Chiew, FHS, Siriwardena, L 2005, 'Estimation of SIMHYD parameter values for application in ungauged catchments' in *MODSIM 2005 International Congress on Modelling and Simulation: Advances and applications for management and decision making*, A Zerger & RM Argent (eds), Modelling and Simulation Society of Australia and New Zealand, Melbourne, December 2005, pp. 2883–89.

Cogle, AL, Carroll, C, Sherman, BS 2006, *The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting*, Department of Natural Resources, Mines and Water, Brisbane.

Department of the Premier and Cabinet 2009, *Reef Water Quality Protection Plan 2009. For the Great Barrier Reef World Heritage Area and adjacent catchments*, Reef Water Quality Protection Plan Secretariat, Brisbane. URL: www.reefplan.qld.gov.au.

Department of the Premier and Cabinet 2013, *Reef Water Quality Protection Plan 2013, Securing the health and resilience of the Great Barrier Reef World Heritage Area and adjacent catchments*, Reef Water Quality Protection Plan Secretariat, Brisbane. URL: www.reefplan.qld.gov.au.

Doherty, J 2005, *PEST: Model-Independent Parameter Estimation, User Manual*, (5th edition), Watermark Numerical Computing, Brisbane.

Dougall, C, Carroll, C 2013, 'Great Barrier Reef Source Catchment's modeling: better targeting through event based water quality assessment' in *MODSIM2013, 20th International Congress on Modelling and Simulation,* J Piantadosi, RS Anderssen & J Boland (eds), Modelling and Simulation Society of Australia and New Zealand, Adelaide, South Australia, December 2013.

Dougall, C, Carroll, C, Herring, M, Trevithick, R, Neilsen, S, Burger, P 2009, *Enhanced sediment and nutrient modelling and target setting in the Fitzroy Basin*, Department of Environment and Resource Management, Emerald, Queensland.

Dougall, C, Ellis, R, Waters, DK, Carroll, C 2014a, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef Catchments – Burdekin NRM region, Technical Report, Volume 4*, Queensland Department of Natural Resources and Mines, Rockhampton, Queensland.

Dougall, C, McCloskey, GL, Ellis, R, Waters, DK, Carroll, C 2014b, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef Catchments – Fitzroy NRM region, Technical Report, Volume 6*, Queensland Department of Natural Resources and Mines, Rockhampton, Queensland.

Drewry, J, Higham, W, Mitchell, C 2008, *Water quality improvement plan: final report for Mackay Whitsunday region*, Mackay Whitsunday Natural Resource Management Group, Mackay, Australia.

DSITIA 2012, *Land use summary 1999–2009: Great Barrier Reef catchments*, Queensland Department of Science, Information Technology, Innovation and The Arts, Brisbane.

DSITIA 2013, *Wet Tropics water resource plan. Calibration of Sacramento and IQQM models for the Tully and Murray River Basins*, Queensland Department of Science, Information

Technology, Innovation and the Arts, Brisbane.

Ellis, R, Doherty, J, Searle, R, Moodie, KB 2009, Applying PEST (Parameter ESTimation) to improve parameter estimation and uncertainty analysis in WaterCAST models, in *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation, Interfacing modelling and simulation with mathematical and computational sciences*, RS Anderssen, RD Braddock & LTH. Newham (eds), Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics, Cairns, July 2009.

Ellis, R, Searle, R 2013, An integrated water quality modelling framework for reporting on Great Barrier Reef catchments, in *MODSIM2013 20th International Congress on Modelling and Simulation*, J Piantadosi, RS Anderssen & J Boland (eds), Modelling and Simulation Society of Australia and New Zealand, Adelaide, South Australia, December 2013.

Ellis, R, Searle, R 2014, *Dynamic SedNet component model reference guide*, Queensland Department of Science, Information Technology, Innovation and the Arts, Bundaberg, Queensland.

eWater Ltd 2012*, Source Catchments product information,* URL: www.eWater.com.au/products/ewater-source/for-catchments/, viewed May 2011.

eWater Ltd 2013, *Source scientific reference guide (v3.5.0)*, eWater Ltd, Canberra.

Fentie, B, Ellis, R, Waters, DK, Carroll, C 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef Catchments – Burnett Mary NRM region, Technical Report, Volume 7*, Queensland Department of Natural Resources and Mines, Cairns.

Finlayson, B.L. and T.A. McMahon 1988 Australia v. the World: A Comparative Analysis of Streamflow Characteristics, Academic Press, Sydney

Freebairn, DM, Wockner, GH 1986, A study of soil erosion on Vertisols of the eastern Darling Downs, Queensland. I. Effects of surface conditions on soil movement within contour bay catchments, *Australian Journal of Soil Research* 24 (2), 135–58.

Furnas, MJ 2003, *Catchment and corals: terrestrial runoff to the Great Barrier Reef,* Australian Institute of Marine Science, Townsville.

Greiner, R, Herr, A, Brodie, J, Haynes, D 2005, A multi-criteria approach to Great Barrier Reef catchment (Queensland, Australia) diffuse-source pollution problem, *Marine Pollution Bulletin* 51 (1–4), 128–37.

Hancock, GJ, Wilkinson, SN, Hawdon, AA & Keen, RJ 2013, 'Use of fallout tracers 7Be, 210Pb and 137Cs to distinguish the form of sub-surface soil erosion delivering sediment to rivers in large catchments', Hydrological Processes.

Hateley, LR, Ellis, R, Shaw, M, Waters, DK, Carroll, C 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef Catchments – Wet Tropics NRM region, Technical Report, Volume 3*, Queensland Department of Natural Resources and Mines, Cairns.

Hateley, L, Armour, A, Pitt, G, Cogle, L 2005, 'Use of SedNet model to establish sediment export targets for catchments of the Wet Tropics draining to the Great Barrier Reef', in *MODSIM 2005 International Congress on Modelling and Simulation*, A Zerger & RM Argent (eds), Modelling and Simulation Society of Australia and New Zealand, Melbourne, December 2005, pp. 290.

Hughes, AO, Croke, JC, Pietsch, TJ, Olley, JM 2010, Changes in the rates of floodplain and in-channel bench accretion in response to catchment disturbance, central Queensland, Australia, *Geomorphology* 114 (3), 338–47.

Joo, M, McNeil, V, Carroll, C, Waters, D, Choy, S 2014, *Sediment and nutrient load estimates for major Great Barrier Reef catchments (1987–2009) for Source Catchments model validation*, Department of Science, Information Technology, Innovation, and the Arts, (unpublished report), Brisbane.

Joo, M, Raymond, MAA, McNeil, VH, Huggins, R, Turner, RDR, Choy, S 2012, Estimates of sediment and nutrient loads in 10 major catchments draining to the Great Barrier Reef during 2006–2009, *Marine Pollution Bulletin* 65 (4–9), 150–66.

Keating, BA, Carberry, PS, Hammer, GL, Probert, ME, Robertson, MJ, Holzworth, D, Huth, NI, Hargreaves, JNG, Meinke, H, Hochman, Z, McLean, G, Verburg, K, Snow, V, Dimes, JP, Silburn, M, Wang, E, Brown, S, Bristow, KL, Asseng, S, Chapman, S, McCown, RL, Freebairn, DM & Smith, CJ 2003, 'An overview of APSIM, a model designed for farming systems simulation', European Journal of Agronomy, vol. 18, no. 3-4, pp. 267-288.

Kroon, F, Kunhert, K, Henderson, A, Turner, R, Huggins, R, Wilkinson, S, Abbott, B, Brodie, J, Joo, M 2010, *Baseline pollutant loads to the Great Barrier Reef*, CSIRO: Water for a Healthy Country Flagship report series ISSN: 1835-095X. 41 pp.

Kroon, FJ, Kuhnert, PM, Henderson, BL, Wilkinson, SN, Kinsey-Henderson, A, Abbott, B, Brodie, JE, Turner, RDR 2012, River loads of suspended solids, nitrogen, phosphorus and herbicides delivered to the Great Barrier Reef lagoon, *Marine Pollution Bulletin* 65 (4–9), 167–81.

Lewis, SE, Bainbridge, ZT, Kuhnert, PM, Sherman, BS, Henderson, B, Dougall, C, Cooper, M, Brodie, JE 2013, Calculating sediment trapping efficiencies for reservoirs in tropical settings: A case study from the Burdekin Falls Dam, NE Australia, *Water Resources Research* 49, 1017.

Lewis, SE, Brodie, JE, Bainbridge, ZT, Rohde, KW, Davis, AM, Masters, BL, Maughan, M, Devlin, MJ, Mueller, JF, Schaffelke, B 2009, Herbicides: a new threat to the Great Barrier Reef, *Environmental Pollution* 157 (8–9), 2470–484.

Littleboy, M, Silburn, MD, Freebairn, DM, Woodruff, DR, Hammer, GL 1989, *PERFECT: a computer simulation model of Productivity Erosion Runoff Functions to Evaluate Conservation Techniques*, Soil Conservation Research and Agriculture Branch, Queensland Department of Primary Industries, Brisbane.

Lu, H, Gallant, J, Prosser, IP, Moran, CJ, Priestley, G 2001, *Prediction of sheet and rill erosion over the Australian continent, incorporating monthly soil loss distribution*, CSIRO Land and Water, Canberra.

McCloskey, GL, Ellis, R, Waters, DK, Carroll, C 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef Catchments – Cape York NRM region, Technical Report, Volume 2*, Queensland Department of Natural Resources and Mines, Cairns.

McCloskey, GL 2010, *Riparian erosion morphology, processes and causes along the Victoria River, Northern Territory, Australia*, PhD thesis, Charles Darwin University.

McKeon, G, Day, K, Howden, S, Mott, J, Orr, D, Scattini, W, Weston, E 1990, Northern Australian savannas: management for pastoral production, *Journal of Biogeography* 17 (4–5), 355–72.

McKergow, LA, Prosser, IP, Hughes, AO, Brodie, J 2005a, Regional scale nutrient modelling: exports to the Great Barrier Reef World Heritage Area, *Marine Pollution Bulletin* 51 (1–4), 186–99.

McKergow, LA, Prosser, IP, Hughes, AO, Brodie, J 2005b, Sources of sediment to the Great Barrier Reef World Heritage Area, *Marine Pollution Bulletin* 51 (1–4), 200–11.

Mitchell, AW, Reghenzani, JR, Furnas, M, De'ath, G, Brodie, J, Lewis, S 2007, *Nutrients and suspended sediments in the Tully River: spatial and temporal trends*, Australian Centre for Tropical Freshwater Research, Townsville, Queensland.

Mitchell, AW, Bramley, RGV, Johnson, AKL 1997, Export of nutrients and suspended sediment during a cyclone-mediated flood event in the Herbert River Catchment, Australia, *Marine and Freshwater Research* 48 (1), 79–88.

Moriasi, DN, Arnold, JG, Van Liew, MW, Bingner, RL, Harmel, RD, Veith, TL 2007, Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, *Transactions of the ASABE* 50 (3), 885–900.

Moss, AJ, Rayment, GE, Reilly, N, Best, EK 1992, A preliminary assessment of sediment and nutrient exports from Queensland coastal catchments, Queensland Department of Environment and Heritage, Brisbane.

National Committee on Soil and Terrain 2009, *Australian Soil and Land Survey Field Handbook,* (3rd edition), CSIRO Publishing, Collingwood, Victoria.

Neil, DT, Yu, B 1996, 'Fluvial sediment yield to the Great Barrier Reef lagoon: spatial patterns and the effect of land use', in *Downstream effects of land use change*, HM Hunter, AG Eyles & GE Rayment (eds), Department of Natural Resources, Rockhampton, 26–28 April, pp. 281–86.

Packett, R, Ellis, R, Waters, DK, Carroll, C 2014, *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef Catchments – Mackay Whitsunday NRM region, Technical Report, Volume 5*, Queensland Department of Natural Resources and Mines, Cairns.

Packett, R, Dougall, C, Rohde, K, Noble, R 2009, Agricultural lands are hot-spots for annual runoff polluting the southern Great Barrier Reef lagoon, *Marine Pollution Bulletin* 58 (7), 976–86.

Prosser, IP, Rustomji, P, Young, WJ, Moran, CJ, Hughes, A 2001, *Constructing river basin sediment budgets for the National Land and Water Resources Audit*, CSIRO Land and Water, Canberra.

Queensland Government 2011, *SILO Climate Data* URL: www.longpaddock.qld.gov.au, viewed 22 Feb 2012.

Rattray, DJ, Freebairn, DM, McClymont, D, Silburn, DM, Owens, JS, Robinson, JB 2004, 'HOWLEAKY? The journey to demystifying 'simple' technology', in *Conserving soil and water for society: sharing solutions, The 13th International Soil Conservation Organization Conference*, SR Raine, AJW. Biggs, NW Menzies, DM Freebairn & PE Tolmie (eds), ISCO, Brisbane, July 2004.

Renard, KG, Ferreira, VA 1993, RUSLE model description and database sensitivity, *Journal of Environmental Quality* 22 (3), 458–66.

Renard, KG, Foster, GA, Weiss, DK, Mcool, DK, Yoder, DC 1997, *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation*, United States Department of Agriculture, Agriculture handbook no 73, 404 pp.

Robinson, JB, Silburn, DM, Rattray, D, Freebairn, DM, Biggs, A, McClymont, D, Christodoulou, N 2010, Modelling shows that the high rates of deep drainage in parts of the Goondoola Basin in semi-arid Queensland can be reduced with changes to the farming systems, *Australian Journal of Soil Research* 48 (1), 58–68.

Rohde, K, Masters, B, Fries, N, Noble, R, Carroll, C 2008, *Fresh and marine water quality in the Mackay Whitsunday region 2004/05 to 2006/07*, Queensland Department of Natural Resources and Water for the Mackay Whitsunday Natural Resource Management Group, Australia.

Scarth, P, Byrne, M, Danaher, T, Henry, B, Hassett, R, Carter, J, Timmers, P 2006, 'State of the paddock: monitoring condition and trend in groundcover across Queensland', in *Proceedings of the 13th Australasian Remote Sensing Conference, Earth observation: from science to solutions*, Spatial Sciences Institute (Australia), Canberra, 21–24 November 2006.

Shaw, M, Furnas, MJ, Fabricius, K, Haynes, D, Carter, S, Eaglesham, G, Mueller, JF 2010, Monitoring pesticides in the Great Barrier Reef, *Marine Pollution Bulletin* 60 (1), 113–22.

Shaw, M, Silburn, DM, Thornton, CM, Robinson, B, McClymont, D 2011, 'Modelling pesticide runoff from paddocks in the Great Barrier Reef with HowLeaky', in *MODSIM2011 19th International Congress on Modelling and Simulation, Sustaining our future: understanding and living with uncertainty*, F Chan, D Marinova & RS Anderssen (eds), Modelling and Simulation Society of Australia and New Zealand, Perth, December 2011, pp. 2057.

Shaw, M, Silburn, DM 2014, *Paddock to Reef integrated monitoring, modelling and reporting program, Paddock scale modelling technical report*, Queensland Department of Natural Resources and Mines, Brisbane.

Shellberg, JG 2011, *Alluvial gully erosion rates and processes across the Mitchell River fluvial megafan in Northern Queensland, Australia*, PhD thesis, Griffith University.

Sherman, BS, Read, AM, 2008, 'Uncertainty in Great Barrier Reef Catchment soil nutrient data – implications for land use management', in *International Congress on Environmental Modelling and Software (iEMSs 2008),* M Sanchez-Marre, J Bejar, J Comas, A Rizzoli, & G Guariso (eds), International Environmental Modelling and Software Society, Barcelona, Catalonia, July 2008, p. 8.

Smith, R, Middlebrook, R, Turner, R, Huggins, R, Vardy, S, Warne, M 2012, Large-scale pesticide monitoring across Great Barrier Reef catchments—Paddock to Reef integrated monitoring, modelling and reporting program, *Marine Pollution Bulletin* 65 (4–9), 117–27.

Stewart, J 2011, *Great Barrier Reef Catchment modelling: parameter sensitivity and uncertainty analysis and hydrologic model parameterisation methodology.* Prepared for the Queensland Department of Environment and Resource Management, BMT WBM Pty Ltd, Leichardt, NSW, Australia.

Thorburn, PJ, Wilkinson, SN 2012, Conceptual frameworks for estimating the water quality benefits of improved agricultural management practices in large catchments, *Agriculture, Ecosystems and Environment* 180, 1–3.

Thornton, CM, Cowie, BA, Freebairn, DM, Playford, CL 2007, The Brigalow Catchment study. II. Clearing brigalow (Acacia harpophylla) for cropping or pasture increases runoff, *Australian Journal of Soil Research* 45 (7), 496–511.

Trevithick, R, Scarth, P 2013, 'Estimating RUSLE C-factor values for Great Barrier Reef catchments using satellite derived ground cover estimates', in *MODSIM2013 20th International Congress on Modelling and Simulation*, J Piantadosi, RS Anderssen, & J Boland (eds), Modelling and Simulation Society of Australia and New Zealand, Adelaide, South Australia, December 2013, pp. 3246–252. ISBN: 978-0-9872143-3-1.

Turner, R, Huggins, R, Wallace, R, Smith, R, Vardy, S, Warne, MSJ 2012, *Sediment, nutrient and pesticide loads: Great Barrier Reef Catchment loads monitoring 2009–2010*, Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Turner, RF, Smith, R, Huggins, R, Wallace, R, Warne, M, Waters, D 2013, 'Monitoring to enhance modelling – a loads monitoring program for validation of catchment models', in *MODSIM2013 20th International Congress on Modelling and Simulation,* J Piantadosi, RS

Anderssen & J Boland (eds), Modelling and Simulation Society of Australia and New Zealand, Adelaide, December 2013, pp. 3253–259. ISBN: 978-0-9872143-3-1, URL: www.mssanz.org.au/modsim2013/L22/turner.pdf

Vaze, J, Perraud, J-, Teng, J, Chiew, F, Wang, B 2011, 'Estimating regional model parameters using spatial land cover information—Implications for predictions in ungauged basins', in *MODSIM2011 19th International Congress on Modelling and Simulation, Sustaining our future: understanding and living with uncertainty*, F Chan, D Marinova & RS Anderssen (eds), Modelling and Simulation Society of Australia and New Zealand, Perth, December 2011, pp. 3433.

Wallace, J, Karim, F, Wilkinson, S 2012, Assessing the potential underestimation of sediment and nutrient loads to the Great Barrier Reef lagoon during floods, *Marine Pollution Bulletin* 65 (4–9), 194–202.

Waterhouse, J, Brodie, J, Maynard, J 2013, 'Assessing the relative risk of land based pollutants to the Great Barrier Reef', in *MODSIM2013 20th International Congress on Modelling and Simulation,* J Piantadosi, RS Anderssen & J Boland (eds), Modelling and Simulation Society of Australia and New Zealand, Adelaide, December 2013, pp. 3204–210. ISBN: 978-0-9872143-3-1, URL: www.mssanz.org.au/modsim2013/L21/waterhouse.pdf

Waters, D, Packett, R 2007, 'Sediment and nutrient generation rates for Queensland rural catchments—an event monitoring program to improve water quality modelling', in *Proceedings of the 5th Australian Stream Management Conference, Australian rivers: making a difference*, AL Wilson, RL Dehaan, RJ Watts, KJ Page, KH Bowmer & A Curtis (eds), Charles Sturt University, Thurgoona, NSW, 21–25 May 2007.

Waters, D, Carroll, C, Ellis, R, McCloskey, GL, Hateley, L, Packett, R, Dougall, C, Fentie, B 2013, 'Will we meet our reef water quality targets? Catchment modelling results', in *MODSIM2013, 20th International Conference on Modelling and Simulation*, J Piantadosi, RS Anderssen & J Boland (eds), Modelling and Simulation Society of Australia and New Zealand, Adelaide, South Australia, December 2013.

Wilkinson, S, Cook, F, Bartley, R, Henderson, A, Searle, R, Ellis, T, Jordan, P, Miller, A 2010, *Specification for sediment, nutrient and pesticide generation and transport modules in Source Catchments*, eWater Cooperative Research Centre, Canberra.

Wilkinson, SN, Dougall, C, Kinsey-Henderson, AE, Searle, RD, Ellis, RJ, Bartley, R 2014, Development of a time-stepping sediment budget model for assessing land use impacts in large river basins, *Science of the Total Environment* 468-469, 1210.

Wilkinson, SN, Hancock, GJ, Bartley, R, Hawdon, AA, Keen, RJ 2013, Using sediment tracing to assess processes and spatial patterns of erosion in grazed rangelands, Burdekin River basin, Australia, *Agriculture, Ecosystems and Environment* 180, 90–102.

Wilkinson, S, Henderson, A, Chen, Y 2004, *SedNet User Guide. Client report for the Cooperative Research Centre for Catchment Hydrology*, CSIRO Land and Water, Canberra.

Wilkinson, SN, Olley, JM, Prosser, IP, Read, AM 2005, Targeting erosion control in large river systems using spatially distributed sediment budgets, *IAHS-AISH Publication*, no. 299, 56–64.

Yee Yet, J, Silburn, DM 2003, *Deep drainage estimates under a range of land uses in the QMDB using water balance modelling*, Queensland Department of Natural Resources and Mines, Toowoomba, Queensland QNRM03021.

Young, WJ, Prosser, IP, Hughes, AO 2001, *Modelling nutrient loads in large-scale river networks for the National Land and Water Resources Audit*, CSIRO, Canberra.

Zhang, X, Waters, D, Ellis, R 2013, 'Evaluation of Simhyd, Sacramento and GR4J rainfall runoff models in two contrasting Great Barrier Reef catchments', in *MODSIM2013, 20th International Congress on Modelling and Simulation,* J Piantadosi, RS Anderssen & J Boland (eds), Modelling and Simulation Society of Australia and New Zealand, Adelaide, South Australia, December 2013, pp. 3260–3266. ISBN: 978-0-9872143-3-1 URL: www.mssanz.org.au/modsim2013/L22/zhang.pdf

Zhang, YQ, Chiew, FHS 2009, 'Evaluation of regionalisation methods for predicting runoff in ungauged catchments in southeast Australia', in *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation*, RS Anderssen, RD Braddock & LTH Newham (eds), Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics, Cairns, July 2009.

Appendix A – Typical management practices targeted

Table 20 A list of typical improved management practices targeted through Reef Plan 2009 (including Reef Rescue) investments (McCosker pers.comm. 2014). Note: the list is not comprehensive

Targets for management change	What is involved
Grazing	
Land type fencing	New fencing that delineates significantly different land types, where practical. This enables land types of varying quality (and vulnerability) to be managed differently.
Gully remediation	Often involves fencing to exclude stock from gullied area and from portion of the catchment above it. May also involve engineering works to rehabilitate degraded areas (e.g. rebattering gully sidewalls, installation of check dams to slow runoff and capture sediment).
Erosion prevention	Capacity building to acquire skills around appropriate construction and maintenance of roads, firebreaks and other linear features with high risk of initiating erosion. Often also involves co-investment for works, such as installing whoa-boys on roads/firebreaks and constructing stable stream crossings.
Riparian or frontage country fencing	Enables management of vulnerable areas – the ability to control grazing pressure. Usually requires investment in off stream watering points.
Off stream watering points	Installation of pumps, pipelines, tanks and troughs to allow stock to water away from natural streams. Enables careful management of vulnerable streambanks and also allows grazing pressure to be evenly distributed in large paddocks.
Capacity building—Grazing land management	Extension/training/consultancy to acquire improved skills in managing pastures (and livestock management that changes as a result). Critical in terms of achieving more even grazing pressure and reducing incidences of sustained low ground cover.
Voluntary Land Management Agreement	An agreement a grazier enters into with an NRM organisation which usually includes payments for achieving improved resource condition targets, e.g. areas of degraded land rehabilitated, achievement of a certain level of pasture cover at the end of the dry season.
Sugarcane	
Subsurface application of fertilisers	Changing from dropping fertiliser on the soil surface, to incorporating 10–15cm below the surface with non-aggressive narrow tillage equipment
Controlled traffic farming	Major farming system change. Changes required to achieve CTF include altering wheelbases on all farm machinery, wider row widths, retooling all implements to operate on wider row

	widths, use of GPS guidance
Nutrient management planning	Capacity building to improve skills in determining appropriate fertiliser rates
Recycling pits	Structure to capture irrigation runoff water on-farm. Also includes sufficient pumping capacity to allow timely reuse of this water, maintaining the pit at low storage level
Shielded/directed sprayers	Equipment that allows more targeted herbicide application. Critical in increasing the use of knockdown herbicides in preference to residual herbicides.
Reduced and/or zonal tillage	New or modified equipment that either reduces the frequency and aggressiveness of tillage and/or tills only a certain area of the paddock (e.g. only the portion of the row that is to be planted).
High-clearance boom sprays	Important in extending the usage window for knockdown herbicides (i.e. longer period of in-crop use)
Sediment traps	Structures that slow runoff transport sufficiently to allow retention of sediments
Variable rate fertiliser application equipment	Equipment that enables greater control of fertiliser rate (kg/ha) within blocks or between blocks
Zero tillage planting equipment	Planting equipment for sugarcane and/or fallow crops that reduce or negate the need for tillage to prepare a seedbed.
Laser levelling	Associated with improvements in farm drainage and runoff control and with achieving improved irrigation efficiency.
Irrigation scheduling tools	Equipment and capacity building to optimise irrigation efficiency. Matching water applications to crop demand minimises potential for excess water to transport pollutants such as nutrients and pesticides.

Appendix B – Reported riparian fencing

Table 21 Reported riparian fencing investment (km) from 2008–2013

Region	Burnett Mary	Burdekin	Cape York	Fitzroy	Mackay Whitsunday	Wet Tropics
2008–2010	0	1,011	0	0	60	0
2010–2011	0	27	0	288	68	0
2011–2012	0	70	36	399	43	53
2012–2013	0	183	167	739	119	127

Appendix C – Potential to achieve target scenarios

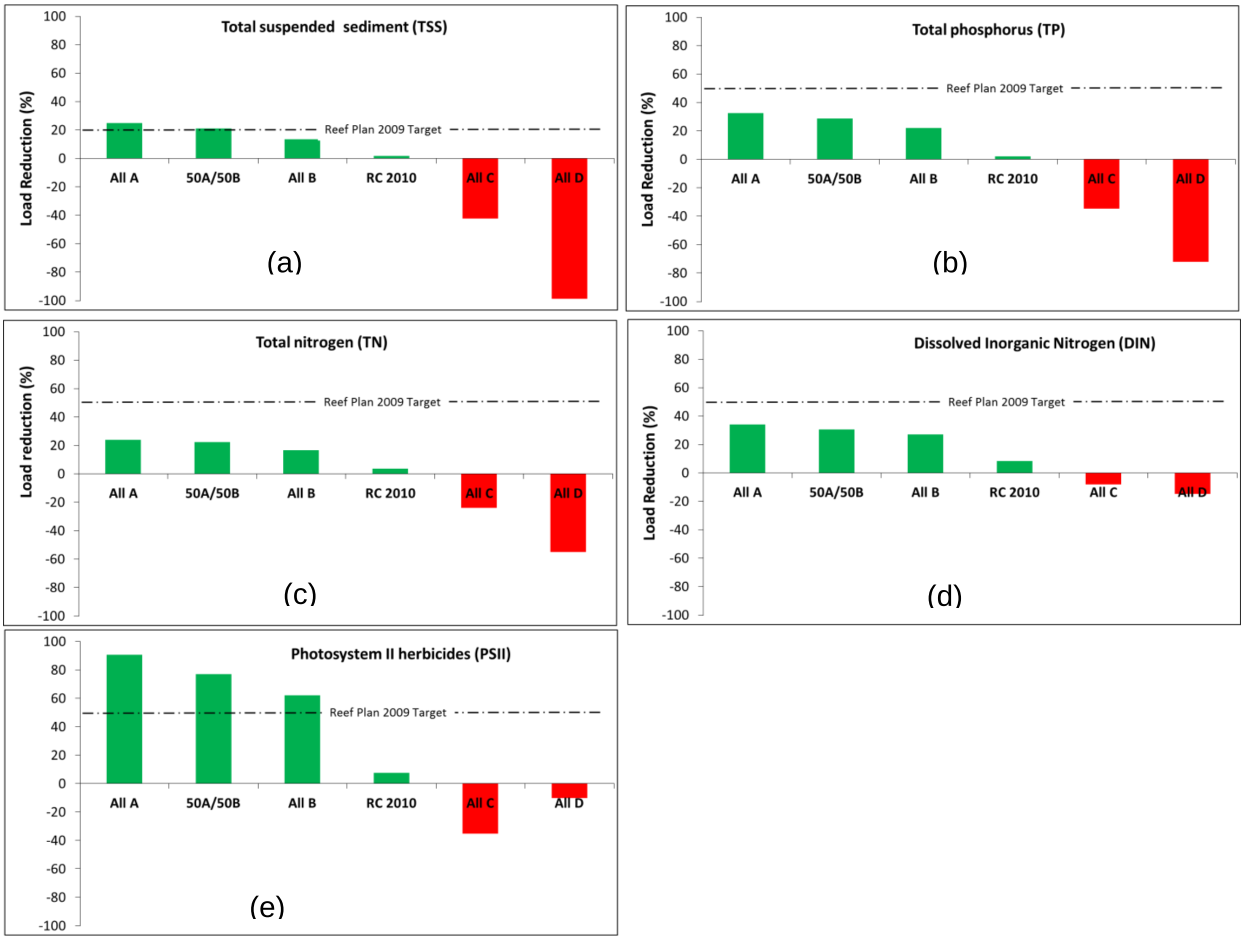


Figure 28 Modelled load reductions for Report Card 2010 and “All A” through to “All D” practice adoption scenarios, for (a) TSS, (b) TP, (c) TN), (d) DIN, (e) PSII herbicides

(NOTE: riparian investments were not modelled as part of Report Card 2010 and are therefore not part of these load reduction estimates). The results show that the 20% TSS target could be achieved with “50A” and “50B”practice adoption. The 50% PSII target could also be achieved with an All B adoption whilst the 50% nutrient target many be more challenging to achieve.

Appendix D – Predevelopment, total & anthropogenic baseline, increase factor and load reductions (2008–2013)

Table 22 Total suspended sediment loads – Report Card 2013

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Total suspended sediment					
				Predevelopment (kt/yr)	Total baseline (kt/yr)	Increase factor	Report Card 2013 (kt/yr)	Anthropogenic baseline (kt/yr)	Total change (%)
Cape York	Jacky Jacky Creek	2,963	2,830,817	43	44	1.0	44	1	0.0
	Olive Pascoe River	4,180	3,575,881	58	60	1.0	60	3	0.0
	Lockhart River	2,883	2,213,964	38	39	1.0	39	1	0.0
	Stewart River	2,743	1,325,365	19	29	1.5	29	10	0.0
	Normanby River	24,399	4,692,715	53	188	3.6	173	135	11.5
	Jeannie River	3,638	1,309,193	18	27	1.5	27	9	0.0
	Endeavour River	2,182	1,588,862	21	42	2.0	42	21	0.0
	Regional total	**42,988**	**17,536,797**	**249**	**429**	**1.7**	**413**	**180**	**8.6**
Wet Tropics	Daintree River	2,107	2,639,319	44	62	1.4	61	19	5.4
	Mossman River	473	507,886	7	14	2.0	14	7	9.9
	Barron River	2,188	793,802	42	92	2.2	82	50	19.8
	Mulgrave-Russell River	1,983	3,684,046	67	168	2.5	150	101	17.9
	Johnstone River	2,325	4,559,029	88	265	3.0	236	178	16.5
	Tully River	1,683	3,488,088	46	110	2.4	104	64	9.0
	Murray River	1,107	1,290,985	21	43	2.1	40	22	13.3
	Herbert River	9,844	4,273,490	130	463	3.6	434	333	8.6
	Regional total	**21,710**	**21,236,645**	**445**	**1,219**	**2.7**	**1,122**	**773**	**12.5**
Burdekin	Black River	1,057	620,226	82	107	1.3	106	25	4.9
	Ross River	1,707	573,747	84	110	1.3	109	26	5.3
	Haughton River	4,051	1,045,169	104	261	2.5	251	157	6.2
	Burdekin River	130,120	8,913,702	1027	3173	3.1	2813	2,146	16.8
	Don River	3,736	846,600	153	325	2.1	298	171	15.5
	Regional total	**140,671**	**11,999,444**	**1,451**	**3,976**	**2.7**	**3,577**	**2,525**	**15.8**

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Total suspended sediment					
				Predevelopment (kt/yr)	Total baseline (kt/yr)	Increase factor	Report Card 2013 (kt/yr)	Anthropogenic baseline (kt/yr)	Total change (%)
Mackay Whitsunday	Proserpine River	2,494	1,346,466	29	66	2.3	63	37	9.1
	O'Connell River	2,387	1,566,516	48	156	3.3	145	108	10.2
	Pioneer River	1,572	866,019	40	203	5.0	195	163	4.9
	Plane Creek	2,539	1,324,152	34	85	2.5	74	51	21.9
	Regional total	**8,992**	**5,103,153**	**151**	**511**	**3.4**	**477**	**360**	**9.3**
Fitzroy	Styx River	3,013	271,616	28	68	2.4	68	40	0.6
	Shoalwater Creek	3,601	387,422	27	53	2.0	53	26	1.1
	Water Park Creek	1,836	391,686	27	32	1.2	32	5	0.9
	Fitzroy River	142,552	4,659,346	440	1,740	4.0	1,681	1,300	4.5
	Calliope River	2,241	117,034	16	44	2.8	44	28	0.7
	Boyne River	2,496	40,307	3	11	3.7	11	8	1.9
	Regional total	**155,740**	**5,867,411**	**542**	**1,948**	**3.6**	**1,889**	**1,407**	**4.2**
Burnett Mary	Baffle Creek	4,085	491,201	20	50	2.5	49	30	2.5
	Kolan River	2,901	74,321	2	11	4.8	10	9	12.5
	Burnett River	33,207	193,141	3	24	7.6	23	21	8.2
	Burrum River	3,362	258,813	7	24	3.6	21	17	16.1
	Mary River	9,466	1,400,239	61	352	5.8	347	291	1.5
	Regional total	**53,021**	**2,417,715**	**93**	**462**	**5.0**	**451**	**369**	**2.9**
	GBR TOTAL	**423,122**	**64,161,165**	**2,931**	**8,545**	**2.9**	**7,930**	**5,613**	**11.0**

Table 23 Total phosphorus loads – Report Card 2013

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Total phosphorous					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Cape York	Jacky Jacky Creek	2,963	2,830,817	56	58	1.0	58	3	0.0
	Olive Pascoe River	4,180	3,575,881	76	83	1.1	83	7	0.0
	Lockhart River	2,883	2,213,964	46	46	1.0	46	0	0.0
	Stewart River	2,743	1,325,365	25	40	1.6	40	15	0.0
	Normanby River	24,399	4,692,715	93	205	2.2	192	113	11.6
	Jeannie River	3,638	1,309,193	26	35	1.4	35	10	0.0
	Endeavour River	2,182	1,588,862	33	63	1.9	63	31	0.0
	Regional total	**42,988**	**17,536,797**	**353**	**531**	**1.5**	**518**	**178**	**7.3**
Wet Tropics	Daintree River	2,107	2,639,319	73	95	1.3	92	22	13.7
	Mossman River	473	507,886	12	22	1.7	19	9	25.8
	Barron River	2,188	793,802	33	85	2.6	77	53	15.0
	Mulgrave-Russell River	1,983	3,684,046	108	238	2.2	213	129	19.0
	Johnstone River	2,325	4,559,029	153	530	3.5	428	377	27.3
	Tully River	1,683	3,488,088	77	160	2.1	146	83	16.5
	Murray River	1,107	1,290,985	36	71	2.0	63	35	23.4
	Herbert River	9,844	4,273,490	150	454	3.0	427	304	8.8
	Regional total	**21,710**	**21,236,645**	**643**	**1,656**	**2.6**	**1,466**	**1,013**	**18.7**
Burdekin	Black River	1,057	620,226	53	69	1.3	69	16	2.0
	Ross River	1,707	573,747	31	81	2.6	81	50	0.7
	Haughton River	4,051	1,045,169	62	256	4.1	249	194	3.6
	Burdekin River	130,120	8,913,702	658	1603	2.4	1477	945	13.3
	Don River	3,736	846,600	86	174	2.0	160	88	15.9
	Regional total	**140,671**	**11,999,444**	**891**	**2,184**	**2.5**	**2,036**	**1,293**	**11.4**

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Total phosphorous					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Mackay Whitsunday	Proserpine River	2,494	1,346,466	44	90	2.0	82	46	18.3
	O'Connell River	2,387	1,566,516	57	129	2.3	119	72	12.6
	Pioneer River	1,572	866,019	38	115	3.1	111	77	5.2
	Plane Creek	2,539	1,324,152	53	105	2.0	91	52	26.7
	Regional total	**8,992**	**5,103,153**	**191**	**439**	**2.3**	**403**	**247**	**14.3**
Fitzroy	Styx River	3,013	271,616	21	38	1.8	38	17	0.6
	Shoalwater Creek	3,601	387,422	14	21	1.5	21	7	0.5
	Water Park Creek	1,836	391,686	16	19	1.1	19	2	1.2
	Fitzroy River	142,552	4,659,346	414	983	2.4	946	569	6.5
	Calliope River	2,241	117,034	13	27	2.0	26	13	0.5
	Boyne River	2,496	40,307	2	6	2.6	6	4	1.0
	Regional total	**155,740**	**5,867,411**	**481**	**1,093**	**2.3**	**1,056**	**612**	**6.0**
Burnett Mary	Baffle Creek	4,085	491,201	30	55	1.8	55	25	2.6
	Kolan River	2,901	74,321	4	14	3.5	12	10	24.3
	Burnett River	33,207	193,141	21	37	1.8	33	16	27.8
	Burrum River	3,362	258,813	15	43	2.8	35	28	27.3
	Mary River	9,466	1,400,239	98	242	2.5	235	145	4.7
	Regional total	**53,021**	**2,417,715**	**168**	**392**	**2.3**	**370**	**224**	**9.8**
	GBR TOTAL	**423,122**	**64,161,165**	**2,727**	**6,294**	**2.3**	**5,849**	**3,567**	**12.5**

Table 24 Particulate phosphorus loads – Report Card 2013

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Particulate phosphorous					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Cape York	Jacky Jacky Creek	2,963	2,830,817	21	22	1.0	22	1	0.0
	Olive Pascoe River	4,180	3,575,881	28	31	1.1	31	3	0.0
	Lockhart River	2,883	2,213,964	18	18	1.0	18	0	0.0
	Stewart River	2,743	1,325,365	8	17	2.0	17	9	0.0
	Normanby River	24,399	4,692,715	28	105	3.7	91	76	17.1
	Jeannie River	3,638	1,309,193	10	16	1.6	16	6	0.0
	Endeavour River	2,182	1,588,862	11	29	2.6	29	18	0.0
	Regional total	**42,988**	**17,536,797**	**125**	**238**	**1.9**	**225**	**113**	**11.6**
Wet Tropics	Daintree River	2,107	2,639,319	41	57	1.4	54	16	15.3
	Mossman River	473	507,886	7	14	2.0	12	7	27.3
	Barron River	2,188	793,802	23	67	2.8	59	43	18.3
	Mulgrave-Russell River	1,983	3,684,046	65	175	2.7	152	110	21.1
	Johnstone River	2,325	4,559,029	104	453	4.4	352	349	28.7
	Tully River	1,683	3,488,088	44	110	2.5	98	66	18.5
	Murray River	1,107	1,290,985	20	46	2.3	39	26	26.1
	Herbert River	9,844	4,273,490	97	377	3.9	353	280	8.8
	Regional total	**21,710**	**21,236,645**	**401**	**1,297**	**3.2**	**1,118**	**896**	**20.0**
Burdekin	Black River	1,057	620,226	43	50	1.2	50	7	4.5
	Ross River	1,707	573,747	23	33	1.4	33	10	3.4
	Haughton River	4,051	1,045,169	47	159	3.4	153	113	6.1
	Burdekin River	130,120	8,913,702	512	1300	2.5	1174	788	16.0
	Don River	3,736	846,600	73	146	2.0	132	73	19.2
	Regional total	**140,671**	**11,999,444**	**699**	**1,690**	**2.4**	**1,542**	**990**	**14.9**

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Particulate phosphorous					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Mackay Whitsunday	Proserpine River	2,494	1,346,466	28	44	1.5	42	16	14.1
	O'Connell River	2,387	1,566,516	39	84	2.2	78	45	13.8
	Pioneer River	1,572	866,019	27	93	3.4	90	66	4.8
	Plane Creek	2,539	1,324,152	30	50	1.7	43	20	35.3
	Regional total	**8,992**	**5,103,153**	**124**	**271**	**2.2**	**252**	**147**	**12.7**
Fitzroy	Styx River	3,013	271,616	12	29	2.4	29	17	0.6
	Shoalwater Creek	3,601	387,422	3	10	2.9	10	7	0.5
	Water Park Creek	1,836	391,686	4	6	1.6	6	2	1.2
	Fitzroy River	142,552	4,659,346	145	687	4.7	653	542	6.3
	Calliope River	2,241	117,034	8	21	2.7	21	13	0.5
	Boyne River	2,496	40,307	1	4	5.1	4	4	1.0
	Regional total	**155,740**	**5,867,411**	**174**	**759**	**4.4**	**724**	**585**	**5.9**
Burnett Mary	Baffle Creek	4,085	491,201	25	44	1.8	43	19	3.3
	Kolan River	2,901	74,321	3	9	3.1	7	6	32.2
	Burnett River	33,207	193,141	8	18	2.3	13	10	42.6
	Burrum River	3,362	258,813	8	27	3.3	20	19	36.2
	Mary River	9,466	1,400,239	73	181	2.5	175	108	5.6
	Regional total	**53,021**	**2,417,715**	**117**	**278**	**2.4**	**259**	**161**	**12.2**
	GBR TOTAL	**423,122**	**64,161,165**	**1,640**	**4,532**	**2.8**	**4,120**	**2,892**	**14.3**

Table 25 Dissolved inorganic phosphorus loads – Report Card 2013

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Dissolved inorganic phosphorous					
				Predevelopment (t/yr)	**Total baseline (t/yr)**	**Increase factor**	**Report Card 2013 (t/yr)**	**Anthropogenic baseline (t/yr)**	**Total change (%)**
Cape York	Jacky Jacky Creek	2,963	2,830,817	11	12	1.1	12	1	0.0
	Olive Pascoe River	4,180	3,575,881	16	17	1.1	17	1	0.0
	Lockhart River	2,883	2,213,964	9	9	1.0	9	0	0.0
	Stewart River	2,743	1,325,365	5	8	1.4	8	2	0.0
	Normanby River	24,399	4,692,715	22	34	1.6	34	12	0.0
	Jeannie River	3,638	1,309,193	5	6	1.2	6	1	0.0
	Endeavour River	2,182	1,588,862	7	11	1.6	11	4	0.0
	Regional total	**42,988**	**17,536,797**	**76**	**98**	**1.3**	**98**	**22**	**0.0**
Wet Tropics	Daintree River	2,107	2,639,319	18	24	1.3	23	6	9.9
	Mossman River	473	507,886	3	5	1.7	5	2	19.6
	Barron River	2,188	793,802	5	12	2.4	12	7	0.5
	Mulgrave-Russell River	1,983	3,684,046	25	41	1.7	40	16	6.9
	Johnstone River	2,325	4,559,029	28	49	1.7	47	21	9.8
	Tully River	1,683	3,488,088	19	33	1.7	32	13	8.4
	Murray River	1,107	1,290,985	9	17	1.9	16	8	15.0
	Herbert River	9,844	4,273,490	30	47	1.6	45	17	10.2
	Regional total	**21,710**	**21,236,645**	**138**	**228**	**1.7**	**220**	**90**	**9.1**
Burdekin	Black River	1,057	620,226	6	12	1.9	12	6	0.5
	Ross River	1,707	573,747	5	35	6.7	35	30	0.0
	Haughton River	4,051	1,045,169	10	74	7.2	74	64	0.1
	Burdekin River	130,120	8,913,702	97	201	2.1	201	105	0.0
	Don River	3,736	846,600	8	18	2.2	18	10	0.0
	Regional total	**140,671**	**11,999,444**	**127**	**341**	**2.7**	**341**	**214**	**0.0**

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Dissolved inorganic phosphorous					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Mackay Whitsunday	Proserpine River	2,494	1,346,466	12	36	2.9	31	24	20.6
	O'Connell River	2,387	1,566,516	14	35	2.5	33	21	10.5
	Pioneer River	1,572	866,019	8	17	2.1	16	9	7.5
	Plane Creek	2,539	1,324,152	18	44	2.5	38	26	21.6
	Regional total	**8,992**	**5,103,153**	**52**	**132**	**2.5**	**119**	**80**	**16.9**
Fitzroy	Styx River	3,013	271,616	7	8	1.0	8	0	1.2
	Shoalwater Creek	3,601	387,422	9	9	1.0	9	0	0.0
	Water Park Creek	1,836	391,686	10	10	1.0	10	0	0.5
	Fitzroy River	142,552	4,659,346	225	245	1.1	243	20	10.2
	Calliope River	2,241	117,034	4	4	1.0	4	0	0.8
	Boyne River	2,496	40,307	1	1	1.0	1	0	1.3
	Regional total	**155,740**	**5,867,411**	**257**	**278**	**1.1**	**276**	**21**	**10.1**
Burnett Mary	Baffle Creek	4,085	491,201	3	7	2.2	7	4	0.8
	Kolan River	2,901	74,321	1	4	5.8	3	3	12.1
	Burnett River	33,207	193,141	10	14	1.4	14	4	3.6
	Burrum River	3,362	258,813	5	12	2.4	11	7	9.8
	Mary River	9,466	1,400,239	16	41	2.6	41	25	2.4
	Regional total	**53,021**	**2,417,715**	**35**	**78**	**2.3**	**76**	**43**	**4.2**
	GBR TOTAL	**423,122**	**64,161,165**	**685**	**1,155**	**1.7**	**1,130**	**470**	**5.5**

Table 26 Dissolved organic phosphorus loads – Report Card 2013

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Dissolved organic phosphorous					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Cape York	Jacky Jacky Creek	2,963	2,830,817	23	24	1.1	24	1	0.0
	Olive Pascoe River	4,180	3,575,881	32	35	1.1	35	3	0.0
	Lockhart River	2,883	2,213,964	18	18	1.0	18	0	0.0
	Stewart River	2,743	1,325,365	11	15	1.4	15	5	0.0
	Normanby River	24,399	4,692,715	43	67	1.6	67	24	0.0
	Jeannie River	3,638	1,309,193	11	13	1.2	13	2	0.0
	Endeavour River	2,182	1,588,862	14	23	1.6	23	8	0.0
	Regional total	**42,988**	**17,536,797**	**152**	**195**	**1.3**	**195**	**43**	**0.0**
Wet Tropics	Daintree River	2,107	2,639,319	14	15	1.1	15	1	11.6
	Mossman River	473	507,886	2	3	1.1	2	0	33.2
	Barron River	2,188	793,802	4	6	1.6	6	2	0.4
	Mulgrave-Russell River	1,983	3,684,046	18	22	1.2	22	4	7.8
	Johnstone River	2,325	4,559,029	21	29	1.4	28	8	6.5
	Tully River	1,683	3,488,088	14	17	1.2	17	3	9.6
	Murray River	1,107	1,290,985	7	9	1.2	8	1	20.7
	Herbert River	9,844	4,273,490	23	30	1.3	30	7	6.0
	Regional total	**21,710**	**21,236,645**	**103**	**130**	**1.3**	**128**	**27**	**7.6**
Burdekin	Black River	1,057	620,226	3	7	2.1	7	4	0.2
	Ross River	1,707	573,747	3	13	4.9	13	10	0.0
	Haughton River	4,051	1,045,169	5	23	4.4	23	18	0.1
	Burdekin River	130,120	8,913,702	49	101	2.1	101	52	0.0
	Don River	3,736	846,600	4	9	2.2	9	5	0.0
	Regional total	**140,671**	**11,999,444**	**65**	**153**	**2.4**	**153**	**89**	**0.0**

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Dissolved organic phosphorous					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Mackay Whitsunday	Proserpine River	2,494	1,346,466	3	10	2.8	8	6	19.8
	O'Connell River	2,387	1,566,516	4	9	2.4	9	5	10.0
	Pioneer River	1,572	866,019	2	5	2.0	4	2	7.5
	Plane Creek	2,539	1,324,152	5	12	2.3	10	7	21.1
	Regional total	**8,992**	**5,103,153**	**15**	**35**	**2.4**	**32**	**21**	**16.3**
Fitzroy	Styx River	3,013	271,616	1	1	1.0	1	0	1.1
	Shoalwater Creek	3,601	387,422	2	2	1.0	2	0	0.0
	Water Park Creek	1,836	391,686	2	2	1.0	2	0	0.5
	Fitzroy River	142,552	4,659,346	44	50	1.1	50	6	8.3
	Calliope River	2,241	117,034	1	1	1.0	1	0	0.7
	Boyne River	2,496	40,307	0	0	1.0	0	0	1.4
	Regional total	**155,740**	**5,867,411**	**50**	**56**	**1.1**	**56**	**6**	**8.2**
Burnett Mary	Baffle Creek	4,085	491,201	2	4	2.0	4	2	0.4
	Kolan River	2,901	74,321	0	1	3.3	1	1	10.1
	Burnett River	33,207	193,141	3	5	1.5	5	2	2.2
	Burrum River	3,362	258,813	2	4	2.1	4	2	7.2
	Mary River	9,466	1,400,239	9	20	2.3	20	12	1.3
	Regional total	**53,021**	**2,417,715**	**17**	**35**	**2.1**	**35**	**19**	**2.4**
	GBR TOTAL	**423,122**	**64,161,165**	**401**	**606**	**1.5**	**599**	**205**	**3.1**

Table 27 Total nitrogen loads – Report Card 2013

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Total nitrogen					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Cape York	Jacky Jacky Creek	2,963	2,830,817	719	721	1.0	721	2	0.0
	Olive Pascoe River	4,180	3,575,881	1,006	1,012	1.0	1,012	5	0.0
	Lockhart River	2,883	2,213,964	575	575	1.0	575	0	0.0
	Stewart River	2,743	1,325,365	351	395	1.1	395	44	0.0
	Normanby River	24,399	4,692,715	1,438	1,559	1.1	1,543	121	13.0
	Jeannie River	3,638	1,309,193	346	359	1.0	359	13	0.0
	Endeavour River	2,182	1,588,862	475	553	1.2	553	78	0.0
	Regional total	**42,988**	**17,536,797**	**4,910**	**5,173**	**1.1**	**5,158**	**264**	**6.0**
Wet Tropics	Daintree River	2,107	2,639,319	760	1,353	1.8	1,343	594	1.8
	Mossman River	473	507,886	130	235	1.8	226	105	8.5
	Barron River	2,188	793,802	182	464	2.5	454	281	3.3
	Mulgrave-Russell River	1,983	3,684,046	1,040	1,804	1.7	1,722	764	10.8
	Johnstone River	2,325	4,559,029	1,224	3,204	2.6	3,029	1,981	8.8
	Tully River	1,683	3,488,088	810	1,566	1.9	1,529	756	4.9
	Murray River	1,107	1,290,985	387	731	1.9	706	344	7.3
	Herbert River	9,844	4,273,490	1,253	2,794	2.2	2,630	1,540	10.6
	Regional total	**21,710**	**21,236,645**	**5,786**	**12,151**	**2.1**	**11,639**	**6,365**	**8.0**
Burdekin	Black River	1,057	620,226	256	413	1.6	410	157	1.9
	Ross River	1,707	573,747	185	540	2.9	539	356	0.3
	Haughton River	4,051	1,045,169	294	1398	4.7	1204	1,104	17.6
	Burdekin River	130,120	8,913,702	3191	6979	2.2	6654	3,788	8.6
	Don River	3,736	846,600	368	779	2.1	729	411	12.1
	Regional total	**140,671**	**11,999,444**	**4,294**	**10,110**	**2.4**	**9,536**	**5,816**	**9.9**

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Total nitrogen					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Mackay Whitsunday	Proserpine River	2,494	1,346,466	266	573	2.2	499	307	24.0
	O'Connell River	2,387	1,566,516	314	774	2.5	704	460	15.1
	Pioneer River	1,572	866,019	202	686	3.4	653	484	6.9
	Plane Creek	2,539	1,324,152	296	786	2.7	661	490	25.5
	Regional total	**8,992**	**5,103,153**	**1,078**	**2,819**	**2.6**	**2,517**	**1,741**	**17.3**
Fitzroy	Styx River	3,013	271,616	119	154	1.3	153	35	0.5
	Shoalwater Creek	3,601	387,422	121	137	1.1	137	16	0.5
	Water Park Creek	1,836	391,686	140	150	1.1	150	11	0.3
	Fitzroy River	142,552	4,659,346	2,768	3,688	1.3	3,659	921	3.2
	Calliope River	2,241	117,034	67	90	1.3	90	23	0.5
	Boyne River	2,496	40,307	16	24	1.5	24	8	1.4
	Regional total	**155,740**	**5,867,411**	**3,230**	**4,244**	**1.3**	**4,214**	**1,013**	**2.9**
Burnett Mary	Baffle Creek	4,085	491,201	127	238	1.9	232	111	5.4
	Kolan River	2,901	74,321	20	83	4.1	62	63	33.0
	Burnett River	33,207	193,141	82	258	3.1	205	176	30.4
	Burrum River	3,362	258,813	82	308	3.8	254	226	23.8
	Mary River	9,466	1,400,239	468	1316	2.8	1237	848	9.2
	Regional total	**53,021**	**2,417,715**	**779**	**2,202**	**2.8**	**1,990**	**1,423**	**14.9**
	GBR TOTAL	**423,122**	**64,161,165**	**20,077**	**36,699**	**1.8**	**35,053**	**16,622**	**9.9**

Table 28 Particulate nitrogen loads – Report Card 2013

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Particulate nitrogen					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Cape York	Jacky Jacky Creek	2,963	2,830,817	169	171	1.0	171	2	0.0
	Olive Pascoe River	4,180	3,575,881	221	227	1.0	227	5	0.0
	Lockhart River	2,883	2,213,964	147	147	1.0	147	0	0.0
	Stewart River	2,743	1,325,365	61	83	1.3	83	21	0.0
	Normanby River	24,399	4,692,715	118	224	1.9	208	106	14.9
	Jeannie River	3,638	1,309,193	62	75	1.2	75	12	0.0
	Endeavour River	2,182	1,588,862	60	104	1.7	104	44	0.0
	Regional total	**42,988**	**17,536,797**	**838**	**1,030**	**1.2**	**1,014**	**191**	**8.3**
Wet Tropics	Daintree River	2,107	2,639,319	195	282	1.4	279	86	3.7
	Mossman River	473	507,886	34	59	1.7	56	25	10.2
	Barron River	2,188	793,802	66	182	2.7	173	116	7.3
	Mulgrave-Russell River	1,983	3,684,046	276	559	2.0	521	284	13.6
	Johnstone River	2,325	4,559,029	340	1,144	3.4	1,025	804	14.8
	Tully River	1,683	3,488,088	210	421	2.0	400	211	10.3
	Murray River	1,107	1,290,985	97	159	1.6	149	62	16.4
	Herbert River	9,844	4,273,490	319	1,038	3.3	987	719	7.2
	Regional total	**21,710**	**21,236,645**	**1,537**	**3,844**	**2.5**	**3,589**	**2,307**	**11.1**
Burdekin	Black River	1,057	620,226	146	177	1.2	176	31	3.0
	Ross River	1,707	573,747	93	142	1.5	141	49	2.5
	Haughton River	4,051	1,045,169	113	294	2.6	283	181	6.0
	Burdekin River	130,120	8,913,702	1482	3224	2.2	2968	1,742	14.7
	Don River	3,736	846,600	222	441	2.0	397	219	20.2
	Regional total	**140,671**	**11,999,444**	**2,056**	**4,278**	**2.1**	**3,964**	**2,222**	**14.1**

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Particulate nitrogen					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Mackay Whitsunday	Proserpine River	2,494	1,346,466	97	130	1.3	126	33	13.5
	O'Connell River	2,387	1,566,516	119	186	1.6	176	67	14.5
	Pioneer River	1,572	866,019	90	298	3.3	291	208	3.7
	Plane Creek	2,539	1,324,152	99	124	1.3	111	25	51.5
	Regional total	**8,992**	**5,103,153**	**406**	**739**	**1.8**	**704**	**333**	**10.5**
Fitzroy	Styx River	3,013	271,616	25	60	2.4	59	35	0.5
	Shoalwater Creek	3,601	387,422	9	25	2.8	25	16	0.5
	Water Park Creek	1,836	391,686	8	18	2.3	17	10	0.4
	Fitzroy River	142,552	4,659,346	233	1,035	4.4	1,006	802	3.6
	Calliope River	2,241	117,034	11	34	3.1	34	23	0.5
	Boyne River	2,496	40,307	2	10	5.8	10	8	1.4
	Regional total	**155,740**	**5,867,411**	**288**	**1,181**	**4.1**	**1,152**	**893**	**3.3**
Burnett Mary	Baffle Creek	4,085	491,201	63	105	1.7	104	42	2.8
	Kolan River	2,901	74,321	8	22	2.7	19	14	22.1
	Burnett River	33,207	193,141	19	38	2.0	33	20	27.1
	Burrum River	3,362	258,813	27	64	2.4	56	37	21.3
	Mary River	9,466	1,400,239	210	546	2.6	534	336	3.4
	Regional total	**53,021**	**2,417,715**	**327**	**775**	**2.4**	**747**	**449**	**6.4**
	GBR TOTAL	**423,122**	**64,161,165**	**5,452**	**11,847**	**2.2**	**11,169**	**6,395**	**10.6**

Table 29 Dissolved inorganic nitrogen loads – Report Card 2013

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Dissolved inorganic nitrogen					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Cape York	Jacky Jacky Creek	2,963	2,830,817	73	73	1.0	73	0	0.0
	Olive Pascoe River	4,180	3,575,881	102	102	1.0	102	0	0.0
	Lockhart River	2,883	2,213,964	59	59	1.0	59	0	0.0
	Stewart River	2,743	1,325,365	35	36	1.0	36	2	0.0
	Normanby River	24,399	4,692,715	138	139	1.0	139	1	0.0
	Jeannie River	3,638	1,309,193	34	34	1.0	34	0	0.0
	Endeavour River	2,182	1,588,862	46	48	1.1	48	3	0.0
	Regional total	**42,988**	**17,536,797**	**487**	**492**	**1.0**	**492**	**5**	**0.0**
Wet Tropics	Daintree River	2,107	2,639,319	323	387	1.2	379	64	11.8
	Mossman River	473	507,886	55	107	1.9	101	52	12.4
	Barron River	2,188	793,802	47	90	1.9	89	43	2.0
	Mulgrave-Russell River	1,983	3,684,046	438	695	1.6	652	258	16.9
	Johnstone River	2,325	4,559,029	506	1,360	2.7	1,304	854	6.5
	Tully River	1,683	3,488,088	344	702	2.0	686	358	4.3
	Murray River	1,107	1,290,985	166	288	1.7	273	122	12.1
	Herbert River	9,844	4,273,490	535	807	1.5	695	272	41.2
	Regional total	**21,710**	**21,236,645**	**2,414**	**4,437**	**1.8**	**4,180**	**2,023**	**12.7**
Burdekin	Black River	1,057	620,226	37	86	2.3	84	48	3.8
	Ross River	1,707	573,747	31	224	7.2	224	193	0.0
	Haughton River	4,051	1,045,169	61	762	12.5	578	701	26.3
	Burdekin River	130,120	8,913,702	576	1436	2.5	1367	860	8.0
	Don River	3,736	846,600	49	139	2.8	134	90	6.2
	Regional total	**140,671**	**11,999,444**	**755**	**2,647**	**3.5**	**2,387**	**1,893**	**13.8**

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Dissolved inorganic nitrogen					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Mackay Whitsunday	Proserpine River	2,494	1,346,466	65	220	3.4	165	155	35.5
	O'Connell River	2,387	1,566,516	75	303	4.0	258	228	20.1
	Pioneer River	1,572	866,019	45	222	4.9	199	177	12.7
	Plane Creek	2,539	1,324,152	88	384	4.4	303	296	27.3
	Regional total	**8,992**	**5,103,153**	**273**	**1,129**	**4.1**	**925**	**856**	**23.8**
Fitzroy	Styx River	3,013	271,616	38	38	1.0	38	0	0.0
	Shoalwater Creek	3,601	387,422	45	45	1.0	45	0	0.0
	Water Park Creek	1,836	391,686	54	54	1.0	54	0	0.0
	Fitzroy River	142,552	4,659,346	1,057	1,106	1.0	1,106	48	0.0
	Calliope River	2,241	117,034	23	23	1.0	23	0	0.0
	Boyne River	2,496	40,307	6	6	1.0	6	0	0.0
	Regional total	**155,740**	**5,867,411**	**1,223**	**1,272**	**1.0**	**1,272**	**49**	**0.0**
Burnett Mary	Baffle Creek	4,085	491,201	12	31	2.6	27	19	23.1
	Kolan River	2,901	74,321	2	21	9.4	10	19	58.1
	Burnett River	33,207	193,141	31	123	4.0	84	93	42.1
	Burrum River	3,362	258,813	17	119	7.1	88	102	30.9
	Mary River	9,466	1,400,239	60	260	4.4	211	200	24.3
	Regional total	**53,021**	**2,417,715**	**121**	**554**	**4.6**	**420**	**433**	**31.1**
	GBR TOTAL	**423,122**	**64,161,165**	**5,274**	**10,532**	**2.0**	**9,676**	**5,258**	**16.3**

Table 30 Dissolved organic nitrogen loads – Report Card 2013

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Dissolved organic nitrogen					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Cape York	Jacky Jacky Creek	2,963	2,830,817	477	477	1.0	477	0	0.0
	Olive Pascoe River	4,180	3,575,881	683	683	1.0	683	0	0.0
	Lockhart River	2,883	2,213,964	369	369	1.0	369	0	0.0
	Stewart River	2,743	1,325,365	255	276	1.1	276	21	0.0
	Normanby River	24,399	4,692,715	1,182	1,196	1.0	1,196	14	0.0
	Jeannie River	3,638	1,309,193	250	250	1.0	250	0	0.0
	Endeavour River	2,182	1,588,862	369	400	1.1	400	31	0.0
	Regional total	**42,988**	**17,536,797**	**3,585**	**3,652**	**1.0**	**3,652**	**67**	**0.0**
Wet Tropics	Daintree River	2,107	2,639,319	241	685	2.8	685	444	0.0
	Mossman River	473	507,886	41	69	1.7	69	28	0.0
	Barron River	2,188	793,802	70	192	2.8	192	122	0.0
	Mulgrave-Russell River	1,983	3,684,046	327	549	1.7	549	223	0.0
	Johnstone River	2,325	4,559,029	378	700	1.9	700	323	0.0
	Tully River	1,683	3,488,088	256	443	1.7	443	186	0.0
	Murray River	1,107	1,290,985	124	283	2.3	283	160	0.0
	Herbert River	9,844	4,273,490	399	948	2.4	948	549	0.0
	Regional total	**21,710**	**21,236,645**	**1,835**	**3,870**	**2.1**	**3,870**	**2,035**	**0.0**
Burdekin	Black River	1,057	620,226	73	151	2.1	151	78	0.0
	Ross River	1,707	573,747	61	174	2.9	174	113	0.0
	Haughton River	4,051	1,045,169	120	343	2.8	343	222	0.0
	Burdekin River	130,120	8,913,702	1133	2319	2.0	2319	1,186	0.0
	Don River	3,736	846,600	97	199	2.1	199	102	0.0
	Regional total	**140,671**	**11,999,444**	**1,484**	**3,185**	**2.1**	**3,185**	**1,701**	**0.0**

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	Dissolved organic nitrogen					
				Predevelopment (t/yr)	Total baseline (t/yr)	Increase factor	Report Card 2013 (t/yr)	Anthropogenic baseline (t/yr)	Total change (%)
Mackay Whitsunday	Proserpine River	2,494	1,346,466	104	223	2.1	208	119	12.0
	O'Connell River	2,387	1,566,516	119	284	2.4	270	165	8.5
	Pioneer River	1,572	866,019	67	166	2.5	163	99	3.1
	Plane Creek	2,539	1,324,152	109	278	2.6	247	169	18.4
	Regional total	**8,992**	**5,103,153**	**398**	**950**	**2.4**	**888**	**552**	**11.3**
Fitzroy	Styx River	3,013	271,616	56	56	1.0	56	0	0.0
	Shoalwater Creek	3,601	387,422	66	66	1.0	66	0	0.0
	Water Park Creek	1,836	391,686	78	79	1.0	79	0	0.0
	Fitzroy River	142,552	4,659,346	1,477	1,548	1.0	1,548	71	0.0
	Calliope River	2,241	117,034	33	33	1.0	33	0	0.0
	Boyne River	2,496	40,307	9	9	1.0	9	0	0.0
	Regional total	**155,740**	**5,867,411**	**1,719**	**1,790**	**1.0**	**1,790**	**72**	**0.0**
Burnett Mary	Baffle Creek	4,085	491,201	52	101	2.0	101	49	0.9
	Kolan River	2,901	74,321	10	40	4.1	33	31	22.4
	Burnett River	33,207	193,141	32	96	3.0	87	64	14.4
	Burrum River	3,362	258,813	38	124	3.2	110	86	16.4
	Mary River	9,466	1,400,239	198	510	2.6	492	312	5.8
	Regional total	**53,021**	**2,417,715**	**331**	**873**	**2.6**	**824**	**542**	**9.0**
	GBR TOTAL	**423,122**	**64,161,165**	**9,351**	**14,320**	**1.5**	**14,209**	**4,969**	**2.2**

Table 31 Photosystem-II herbicide loads – Report Card 2013

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	PSIIs					
				Predevelopment (kg/yr)	Total baseline (kg/yr)	Increase factor	Report Card 2013 (kg/yr)	Anthropogenic baseline (kg/yr)	Total change (%)
Cape York	Jacky Jacky Creek	2,963	2,830,817	0	0	0.0	0	0	0.0
	Olive Pascoe River	4,180	3,575,881	0	0	0.0	0	0	0.0
	Lockhart River	2,883	2,213,964	0	0	0.0	0	0	0.0
	Stewart River	2,743	1,325,365	0	0	0.0	0	0	0.0
	Normanby River	24,399	4,692,715	0	3	0.0	3	3	0
	Jeannie River	3,638	1,309,193	0	0	0.0	0	0	0.0
	Endeavour River	2,182	1,588,862	0	0	0.0	0	0	0.0
	Regional total	**42,988**	**17,536,797**	**0**	**3**	**0.0**	**3**	**3**	**0.0**
Wet Tropics	Daintree River	2,107	2,639,319	0	235	0.0	192	235	18.5
	Mossman River	473	507,886	0	150	0.0	119	150	20.9
	Barron River	2,188	793,802	0	269	0.0	239	269	11.1
	Mulgrave-Russell River	1,983	3,684,046	0	1,482	0.0	1,114	1,482	24.8
	Johnstone River	2,325	4,559,029	0	1,861	0.0	1,264	1,861	32.1
	Tully River	1,683	3,488,088	0	1,359	0.0	1,000	1,359	26.4
	Murray River	1,107	1,290,985	0	862	0.0	590	862	31.6
	Herbert River	9,844	4,273,490	0	2,378	0.0	1,850	2,378	22.2
	Regional total	**21,710**	**21,236,645**	**0**	**8,596**	**0.0**	**6,367**	**8,596**	**25.9**
Burdekin	Black River	1,057	620,226	0	14	0.0	11	14	21.4
	Ross River	1,707	573,747	0	6	0.0	6	6	0.0
	Haughton River	4,051	1,045,169	0	1353	0.0	1163	1,353	14.1
	Burdekin River	130,120	8,913,702	0	632	0.0	555	632	12.2
	Don River	3,736	846,600	0	85	0.0	80	85	5.7
	Regional total	**140,671**	**11,999,444**	**0**	**2,091**	**0.0**	**1,815**	**2,091**	**13.2**

NRM region	Basin name	Area (km^2)	Mean annual flow (ML/yr)	PSIIs					
				Predevelopment (kg/yr)	Total baseline (kg/yr)	Increase factor	Report Card 2013 (kg/yr)	Anthropogenic baseline (kg/yr)	Total change (%)
Mackay Whitsunday	Proserpine River	2,494	1,346,466	0	539	0.0	265	539	50.8
	O'Connell River	2,387	1,566,516	0	1027	0.0	636	1,027	38.1
	Pioneer River	1,572	866,019	0	859	0.0	564	859	34.4
	Plane Creek	2,539	1,324,152	0	1519	0.0	807	1,519	46.9
	Regional total	**8,992**	**5,103,153**	**0**	**3,944**	**0.0**	**2,272**	**3,944**	**42.4**
Fitzroy	Styx River	3,013	271,616	0	22	0.0	22	22	2.6
	Shoalwater Creek	3,601	387,422	0	14	0.0	14	14	0.0
	Water Park Creek	1,836	391,686	0	10	0.0	10	10	0.9
	Fitzroy River	142,552	4,659,346	0	521	0.0	492	521	5.5
	Calliope River	2,241	117,034	0	10	0.0	10	10	0.3
	Boyne River	2,496	40,307	0	2	0.0	2	2	0.2
	Regional total	**155,740**	**5,867,411**	**0**	**579**	**0.0**	**549**	**579**	**5.1**
Burnett Mary	Baffle Creek	4,085	491,201	0	23	0.0	19	23	16.0
	Kolan River	2,901	74,321	0	257	0.0	182	257	29.3
	Burnett River	33,207	193,141	0	271	0.0	208	271	23.4
	Burrum River	3,362	258,813	0	531	0.0	376	531	29.3
	Mary River	9,466	1,400,239	0	445	0.0	324	445	27.2
	Regional total	**53,021**	**2,417,715**	**0**	**1,528**	**0.0**	**1,108**	**1,528**	**27.5**
	GBR TOTAL	**423,122**	**64,161,165**	**0**	**16,740**	**0.0**	**12,114**	**16,740**	**27.6**

Appendix E – Contribution by landuse

Table 32 Contribution to total baseline export by landuse for each constituent for whole of GBR

Constituent	Landuse									
	Nature Con.	Cropping	Forestry	Grazing	Horticulture	Sugarcane	Urban#	Other	Stream*	Total
TSS (kt/yr)	917	189	171	3,816	45	452	79	52	2,824	8,545
TP(t/yr)	938	161	193	2,800	94	864	237	44	964	6,295
PP(t/yr)	564	94	116	1,993	47	655	70	30	964	4,533
DIP(t/yr)	193	53	47	524	35	167	126	10		1,156
DOP(t/yr)	181	14	29	283	13	42	40	3		606
TN(t/yr)	8,350	646	2,076	14,430	632	7,154	1,393	330	1,691	36,702
PN(t/yr)	2,579	170	474	4,778	210	1,437	368	142	1,691	11,848
DIN(t/yr)	2,106	203	368	2,951	318	3,857	621	107		10,533
DON(t/yr)	3,664	273	1,234	6,701	104	1,859	404	81		14,321
PSII (kg/yr)	-	744	-	323	12	15,662	-	-	-	16,742

includes sewage treatment plant contributions

*Represents the streambank contribution