Reef Water Quality Protection Plan 2013

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

Fitzroy NRM region

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Executive Summary

Contaminants contained in terrestrial runoff are one of the main issues affecting the health and resilience of the Great Barrier Reef (GBR). In response to a decline in water quality entering the GBR lagoon, the Reef Water Quality Protection Plan (Reef Plan) was developed as a joint Queensland and Australian government initiative. The plan outlines a set of water quality and management practice targets, with the long-term goal to ensure that by 2020 the quality of water entering the reef from broad scale land use has no detrimental impact on the health and resilience of the GBR. 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.

To help achieve the targets, improvements in land management are being driven by a combination of the Australian Government's reef investments, along with Queensland Government and industry led initiatives in partnership with regional Natural Resource Management (NRM) groups.

Catchment modelling was one of the multiple lines of evidence used to report on the progress being made towards the water quality targets. Other components of the program include: paddock scale modelling and monitoring of the effectiveness of land management practices, monitoring of the prevalence of improved practices over time, catchment loads monitoring, catchment indicators and finally, marine monitoring. This report is a summary of the Fitzroy NRM region modelled load reductions for sediment, nutrients and herbicides resulting from the adoption of improved management practices. The report outlines the progress made towards 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 Fitzroy region is one of six NRM regions adjacent to the GBR. It is approximately 37% (156,286 km^2) of the total GBR catchment area (423,122 km^2), and is characterised by grazing (78% of the total area) and intensive agriculture land uses (6% of the total area). The region is comprised of six drainage basins: Styx, Shoalwater, Water Park Creek, Fitzroy, Calliope, and Boyne. The Fitzroy is ranked as a medium-high risk to the health of the GBR for fine sediment, and a priority for PSII herbicide and DIN management from intensive agriculture (cotton and grains cropping) in the recent literature.

The eWater Ltd Source Catchments modelling framework was used to calculate sediment, nutrient and herbicide loads entering the GBR lagoon. Major additions and improvements to the base modelling framework were made to enable the interaction of soils, climate and land management to be modelled. Enhancements include incorporation of SedNet modelling functionality to enable reporting of gully and streambank erosion and floodplain deposition, incorporation of the most appropriate paddock scale model outputs for major agricultural industries of interest and the incorporation of annual cover layers for hillslope erosion prediction in grazing lands.

The water quality targets are set against the anthropogenic baseline load (2008–2009 land use and management). Improved management practices from 2008–2013 were modelled for four Report Cards covering management changes in grazing and cropping. These were compared to the anthropogenic baseline load, and from this a reduction in constituent loads was estimated. An ABCD framework (A = aspirational, D = unacceptable) was used for each industry to estimate the proportion of land holders in each region in each category for the baseline and then following implementation of the improved land management practices. In order to remove the effect of climate variability a static climate period was used (1986–2009) for all scenarios. The average annual loads and the relative change in loads due to industry and government investments were then used to report on the percentage load reductions for the four Report Cards. It is important to note that this report summarises the modelled, not measured, average annual loads and load reductions of key constituents and management changes reflected in the model were based on practice adoption data supplied by regional Natural Resource Management (NRM) groups and industry.

Fit for purpose models generated the daily pollutant loads for each individual land use. The paddock scale models HowLeaky and APSIM were used to calculate loads for a range of typical land management practices for cropping and sugarcane areas respectively. For grazing and nature conservation areas, the Revised Universal Soil Loss Equation (RUSLE) was used to calculate daily soil loss estimates, with the grazing systems model GRASP used to determine the relative changes in ground cover (C-factor) resulting from improved grazing management practices. An Event Mean Concentration (EMC) approach was used to calculate loads for the remaining minor land use areas.

Source Catchments was coupled to an independent Parameter EStimation Tool (PEST) to perform hydrology calibrations. A multi-part objective function that minimised differences between (1) modelled and observed daily discharges (2) modelled and observed monthly discharges and (3) exceedance curves of modelled and observed discharges were used. Once calibrated, three criteria were used to assess model performance: daily and monthly Nash-Sutcliffe Coefficient of Efficiency (NSE) and difference in total gauging station stream flow volumes. The NSE is a measure of how well modelled data simulates observed data, where 0.8–1 for monthly flows is considered a good fit. The modelled flows showed good agreement with observed flows with 57 of the 86 gauges (67%) having monthly NSE values >0.8, and three-quarters of gauges had total runoff volumes within 20% of observed flows. The average annual modelled flow (1986–2009) from the Fitzroy region is 6 million ML, which accounts for 9% of the total GBR average annual flow.

Modelled outputs for the total baseline scenario indicate that approximately 1,948 kt/yr of total suspended sediment (TSS) load is exported to the GBR from the Fitzroy NRM region. The estimated regional TSS load is a 3.6 times increase from predevelopment loads. A total nitrogen (TN) load of 4,244 t/yr is estimated to be exported to the GBR from the Fitzroy region, with the Fitzroy basin contributing 87% of the total load. A total phosphorus (TP) load of 1,093 t/yr is estimated to be exported to the GBR from the Fitzroy region, with the Fitzroy Basin contributing 90% of the total load. TN and TP loads are estimated to have increased by 1.3 and 2.3 times respectively over predevelopment loads. The PSII load was approximately 588 kg/yr for the Fitzroy region, with 90% of the load coming from the Fitzroy Basin. Table 1 provides a summary of the total baseline and anthropogenic baseline Fitzroy NRM region load, and the percentage reduction due to Report Card 2013 management improvements.

Three main approaches were used to validate the GBR Source Catchments modelling. Comparison to previous best estimates, a long-term comparison (1986–2009) against available measured data and thirdly a short-term comparison (2006–2009) against the Queensland Government catchment loads monitoring program estimates (GBRCLMP).

In general, the modelled average annual loads of constituents are lower than previous modelled estimates for the Fitzroy region. The differences in estimates are due to improvements made to constituent generation models improving load estimates in this study. Modelled loads and loads estimated from measured data specifically for model validation are much closer in agreement, with most of the simulated loads generally slightly lower.

Comparing loads for the 23 year period at a monthly time-step, (Moriasi et al. 2007) recommended that if the per cent error performance rating (PBIAS) was within 55% for TSS load and 70% for nutrients, the result could be considered satisfactory. PBIAS for TSS, TN and TP were 3%, 18% and 44% respectively. Using Moriasi et al. (2007) criteria, the modelling results rate “very good” for TSS and TN and “satisfactory” for TP when monthly loads are compared to Joo et al. (2014).

Table 1 Summary of Fitzroy region total baseline and anthropogenic loads and load reduction due to improved management practice adoption (2008–2013)

	TSS (kt/yr)	**TN (t/yr)**	**DIN (t/yr)**	**DON (t/yr)**	**PN (t/yr)**	**TP (t/yr)**	**DIP (t/yr)**	**DOP (t/yr)**	**PP (t/yr)**	**PSII (kg/yr)**
Total baseline load	1,948	4,244	1,272	1,790	1,181	1,093	278	56	759	579
Anthropogenic baseline load	1,407	1,013	49	72	893	612	21	6	585	579
Load reduction (2008–2013) (%)	4.2	2.9	NA	NA	3.3	6	10	8.2	5.6	5.1

NA – DIN and DON were not modelled for management changes

Grazing (open and closed) contributed the largest load component of all constituents. Generally, cropping and nature conservation land uses contributed the next highest loads of all constituents. There has been a 4.2% reduction in TSS load, a 2.9% decline in TN and a 6% decline in TP load as a result of investments in improved management practices from 2008–2013. PSII loads have also been reduced by 5.1%.

The modified version of the Source Catchments model has proven to be a useful tool for estimating load reductions due to improved management practice adoption. The underlying hydrological model simulates streamflow volumes that show good agreement with gauging station data, particularly at long-term average annual and yearly time-steps. At shorter time scales (weeks to days) the model tends to underestimate peak discharge and overestimate low flow. Future work will explore the potential to re-calibrate the model with greater emphasis on simulating high flows. However, the current hydrological model performs very well for sites with good historical flow records. These results suggest that reasonable confidence can be given to modelled flow results for streams and catchments in the Fitzroy region where no flow data exists.

Recommendations for enhanced model performance include improving gully and streambank erosion input data layers, moving from annual to seasonal ground cover data inputs to improve inter-annual variability in hillslope erosion rates and re-calibration of the hydrological model to better simulate high flows.

The current modelling framework is flexible, innovative and is fit for purpose. It is a substantial improvement on previous GBR load modelling applications, with a consistent methodology adopted across all NRM regions. The model is appropriate for assessing load reductions due to on-ground land management change.

Key messages, outcomes and products from the development and application of the GBR Source Catchments model include:

- Natural Resource Management groups, governments and other agencies now have a new modelling tool to assess various climate and management change scenarios on a consistent platform for the entire GBR catchment.
- Methods have been developed to implement and calibrate a hydrological model that produces reliable flow simulations for gauged sites and increased confidence in modelled flows for ungauged sites
- Daily time-step capabilities and high resolution catchment areas allow for modelled flow volumes and loads of constituents to be reported at catchment scale for periods ranging from events over a few days, to wet seasons and years.

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Acronyms

Acronym	Description
ANNEX	Annual Network Nutrient Export – SedNet module speciates dissolved nutrients into organic and inorganic forms
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 to base or slow flow generated from a functional unit to calculate total constituent load.
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 to quick flow generated from a functional unit to calculate total constituent load.
EOS	End-of-system
ERS	Environment Resource Sciences
FRCE	Flow Range Concentration Estimator – a modified Beale ratio method used to calculate average annual 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
NRM	Natural Resource Management
NRW	Natural Resources and Water (incorporated in 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
PSII herbicides	Photosystem II herbicides – ametryn, atrazine, diuron, hexazinone and tebuthiuron.

Report Cards 2010–2013	Annual reporting approach communicating outputs of Reef Plan/Paddock to Reef (P2R) Program
Reef Rescue	An ongoing and key component of Caring for our Country. 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 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
STM	Short term modelling project
TSS	Total suspended sediment

Units

Units	Description
g/ml	grams per millilitre
kg/ha	kilograms per hectare
kg/ha/yr	kilograms per hectare per year
kt/yr	Kilotonnes per year
L/ha	litres per hectare
mg/L	milligrams per litre
mm	millimetres
mm/hr	millimetres per hour
m^3	cubic metres
ML	megalitres
GL	gigalitres
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, G.L., Ellis, R., Waters, D.K., 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).

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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 regionally developed paddock models to generate the daily pollutant loads for each individual land use, with proven ability to represent land management change for specific GBR agricultural industries.
- 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.
- Incorporation of hillslope, gully and streambank erosion processes, with the ability to also use EMC/DWC approaches.
- Inclusion of small, coastal catchments not previously modelled.
- Integration of monitoring and modelling, and using the modelling outputs to inform the monitoring program.
- Use of a consistent platform and methodology across the six GBR NRM regions that allows for the 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 are static over the model run period and were based on the latest available QLUMP data.
- Predevelopment land use scenario includes all storages, weirs and water extractions represented in the current model, with no change to the current 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 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 are applied at the spatial scale of the data 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) are averaged across catchment areas. Depending on the availability of useful investment data, there may be instances where a load reduction is reported for a particular region or subcatchment that in reality has had no investment in land management improvement. Future programs aim to capture and report spatially explicit management change data.
- Water quality improvements from the baseline for the horticulture, dairy, banana 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. Banana areas are defined in the WT model, but management changes are not provided. Dissolved inorganic nitrogen (DIN) reductions are not being modelled in the grains system, as there is no DIN model available currently in HowLeaky.

- For land uses that require spatially variable data inputs for pollutant generation models (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 landuse 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. Benefits were assumed to happen in the same year.
- Modelling for Report Cards 2010–2013 represent management systems (e.g. A soil, A nutrient and A herbicides practices) rather than individual practices. The potential to overstate the water quality benefits of an A herbicide or nutrient practice through also assigning benefits from adoption of A practice soil management needs to be recognised.
- Gully density mapping is largely based on the coarse NLWRA mapping, with opportunities to improve this particular input layer with more detailed mapping.
- Within the current state of knowledge, groundwater is not explicitly modelled and is represented as a calibrated baseflow and 'dry weather concentrations' (DWC) of constituents. However, 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. Results from this modelling project are therefore indicative of the likely (theoretical) effects of investment in changed land management practices for a given scenario rather than a measured (empirical) reduction in load.

1 Introduction

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

Over the past 150 years Great Barrier Reef (GBR) catchments have been extensively modified 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 (Reef Plan 2009), and again in 2013 (Reef Plan 2013) as a joint Queensland and Australian government initiative (Department of the Premiers and Cabinet 2009, Department of the Premiers 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. A key aspect of the initiative is the Paddock to Reef Integrated Monitoring, Modelling and Reporting (P2R) Program (Carroll et al. 2012). This program was established to measure and report on progress towards the targets outlined in Reef Plan 2009, and combines monitoring and modelling at paddock through to catchment and reef scales.

Detecting changes in water quality with monitoring alone to assess progress towards targets 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. The resultant pollutant load exported from a catchment can be highly variable from year to year. Therefore, the P2R Program used modelling validated against monitoring to report on progress towards Reef Plan 2009 targets.

Modelling is a way to extrapolate monitoring data through time and space and provides an opportunity to explore the climate and management interactions and their associated impacts on water quality. The monitoring data is the most important point of truth for model validation and parameterisation. Combining the two programs ensures continual improvement in the models while at the same time identifying data gaps and priorities for future monitoring.

Report Cards, measuring progress towards Reef Plan's goals and targets, are produced annually as part of the P2R Program. The first Report Card (2009) provided estimates of predevelopment, total baseline and total anthropogenic loads. The first report card was based on the best available data at the time and included a combination of monitoring and modelling (Kroon et al. 2010). It was always intended that these estimates would be improved once the Source Catchments framework was developed. Source catchments was used for subsequent model runs to report on progress towards the water quality targets outlined in Reef Plan 2009. Each year's model run represents the cumulative management changes occurring due to improved management practice adoption for the period 2008–2013. All report cards are available at www.reefplan.qld.gov.au.

The changes in water quality predicted by the modelling will be assessed against the Reef Plan targets. The Reef Plan water quality targets for Reef Plan 2009 (Report Cards 2010–2013) are:

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

The water quality targets were set for the whole GBR and there are six contributing NRM regions: Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary. This document outlines the Fitzroy NRM catchment modelling methodology and results used to report on the constituent loads entering the GBR for the total baseline, predevelopment, anthropogenic baseline (total baseline minus predevelopment load) and post adoption of improved practices from the six regional basins: Styx, Shoalwater, Waterpark Creek, Fitzroy, Calliope and Boyne that make up the Fitzroy NRM region.

1.2 Previous approaches to estimate catchment loads

Over the past 30 years, there have been a series of empirical and catchment modelling approaches to estimate constituent loads from GBR catchments. These estimates can differ 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 a 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, Brodie & Furnas (2005) 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 has also been extensively used to provide estimates of average annual sediment and nutrient loads from GBR catchments (Brodie et al. 2003, Cogle, Carroll & Sherman 2006, McKergow et al. 2005a, McKergow et al. 2005b). Most recently, Kroon et al. (2012) used collated modelling and monitoring information (Brodie et al. 2009), along with recent monitoring data and used the linear regression estimator (LRE) tool to estimate natural and total catchments loads for Report Card 1 (RC1). In the Fitzroy region, the Kroon et al. (2012) estimated total suspended sediment (TSS) load was 4,109 kt/yr, total phosphorus (TP) load was 4,142 t/yr, and total nitrogen (TN) load was 15,126 t/yr; representing a respective 3.3-, 21- and 9-fold increase in constituent loads from predevelopment conditions (Kroon et al. 2012). The estimated current PSII load was 2,269 kg/yr, with no increase factor since predevelopment conditions, as pesticides are not a naturally occurring compound (Kroon et al. 2012).

In considering the modelling approach required for the Paddock to Reef Program, there was no ‘off the shelf’ modelling framework that met all the modelling requirements set out in this project. SedNet alone could not provide the finer resolution time-stepping required, and the Source Catchments modelling framework, whilst used extensively across Australia, cannot inherently represent many variations of a spatially varying practice like cropping, to the level of detail required to allow subtle changes in management systems to have a recognisable effect on model outputs. To address these issues, & answer the questions being posed by policy makers, customised plug-ins for the Source Catchments modelling framework were developed. These plug-ins allowed us to integrate the best available data sources and landscape process understanding into the catchment model. Purpose built routines were developed that enabled representations of processes, such as the effects of temporally and spatially variable ground cover on soil erosion, the aggregation of deterministic crop model outputs to be directly imported into the catchment model and the incorporation of SedNet gully and streambank erosion algorithms (Ellis & Searle 2013).

1.3 Fitzroy modelling approach

A consistent modelling approach was used across all regions to enable direct comparisons of export loads. A standardised 23 year static climate period (1986–2009) was used for all scenarios. 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, as well as floodplain deposition (Wilkinson et al. 2010). Specific and fit for purpose models were used to generate the daily pollutant loads for current and improved practices for each individual land use. This included paddock scale models HowLeaky (cropping) (Rattray et al. 2004) and APSIM (sugarcane) (Biggs & Thorburn 2012), the Revised Universal Soil Loss Equation (RUSLE) (grazing and nature conservation) (Renard et al. 1997) with an Event Mean Concentration/Dry Weather Concentration (EMC/DWC) approach used to generate loads for the remaining land use areas.

The latest remotely sensed bare ground index (BGI) layers were used to derive annual ground cover (Scarth et al. 2006). Ground cover, riparian extent mapping (Goulevitch et al. 2002), and Australian Soil Resource Information System (ASRIS) soils information (Brough, Claridge & Grundy 2006) were all incorporated into the Fitzroy model. Model validation was done using water quality information from the Fitzroy region. The small coastal catchments were also included into the Fitzroy catchment model to ensure the total area contributing loads to the GBR were captured in the model. For a broad overview of the GBR modelling approach refer to Waters and Carroll (2012).

This report outlines the:

- Source Catchments hydrology and water quality model methodology
- Estimated predevelopment, total baseline and anthropogenic baseline loads for 1986–2009 climate period
- Progress towards meeting Reef Plan 2009 water quality targets following adoption of improved management practices.

2 Regional Background

This section provides brief context on the Fitzroy region. A detailed outline of NRM in the region can be found at the Fitzroy Basin Association (FBA) home page (www.fba.org.au). The Fitzroy region (~156,000 km^2) is approximately 37% of the total Great Barrier Reef (GBR) area (423, 134 km^2). The region is drained by six Australian Water Resources Council Basins (AWRC) Figure 1. The Fitzroy basin dominates in terms of area (93%), while the smaller coastal basins the Styx, Shoalwater, Waterpark, Calliope and Boyne make up the remainder (Table 2).

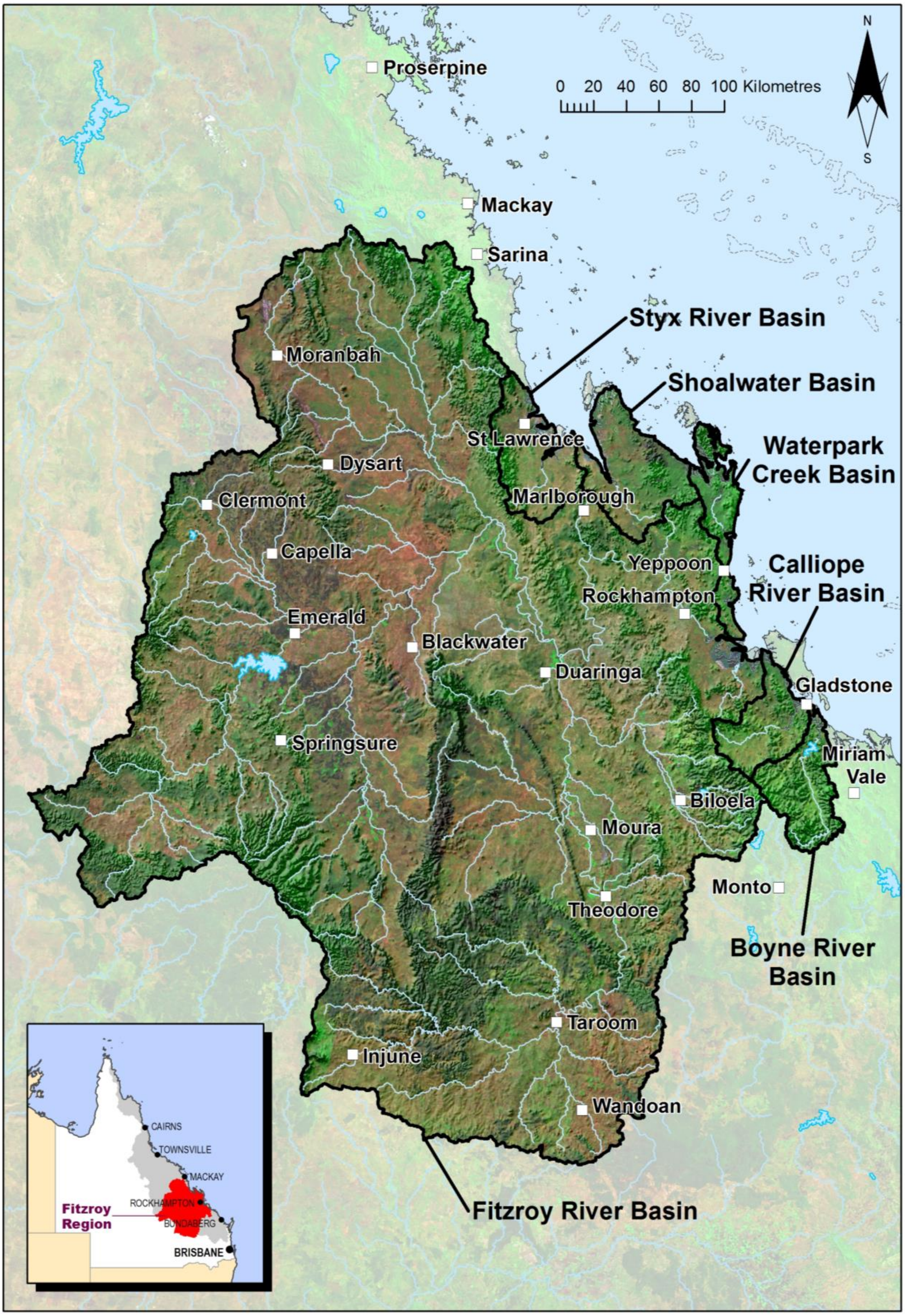

Figure 1 Fitzroy NRM region and six reporting basins

Table 2 Fitzroy basins and modelled area

Basin name	Area (km^2)	% of total area
Styx	3,013	2
Shoalwater	3,601	2
Water Park	1,836	1
Fitzroy	142,552	93
Calliope	2,241	1
Boyne	2,496	2
Total	152,727	100

2.1 Climate

The Fitzroy region experiences a typical sub-tropical climate with humid, wet summers and mild, dry winters. Average yearly rainfall in the catchment ranges from 1,700 mm in north-eastern parts to less than 600 mm in south-western areas (Figure 2); however totals can be highly variable due to climatic drivers such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). Long-term rainfall and stream flow reconstructions (1600–2000) correlate well with ENSO records, indicating a long-term climatic cycle of extended dry and wet conditions (Lough 2007, Lough 2010). Broad hydrological characteristics for the region are described in this report. Here mean annual flow is calculated as ~5,800 GL (1986–2009), of this the Fitzroy produces the majority of the discharge ~80%, with the coastal basins discharging the remaining 20%. Flows are summer / wet season dominant and are highly variable within and between years. The mean maximum temperature in Rockhampton is 32.1°C in December, and the mean minimum temperature occurs in July at 23.1°C.

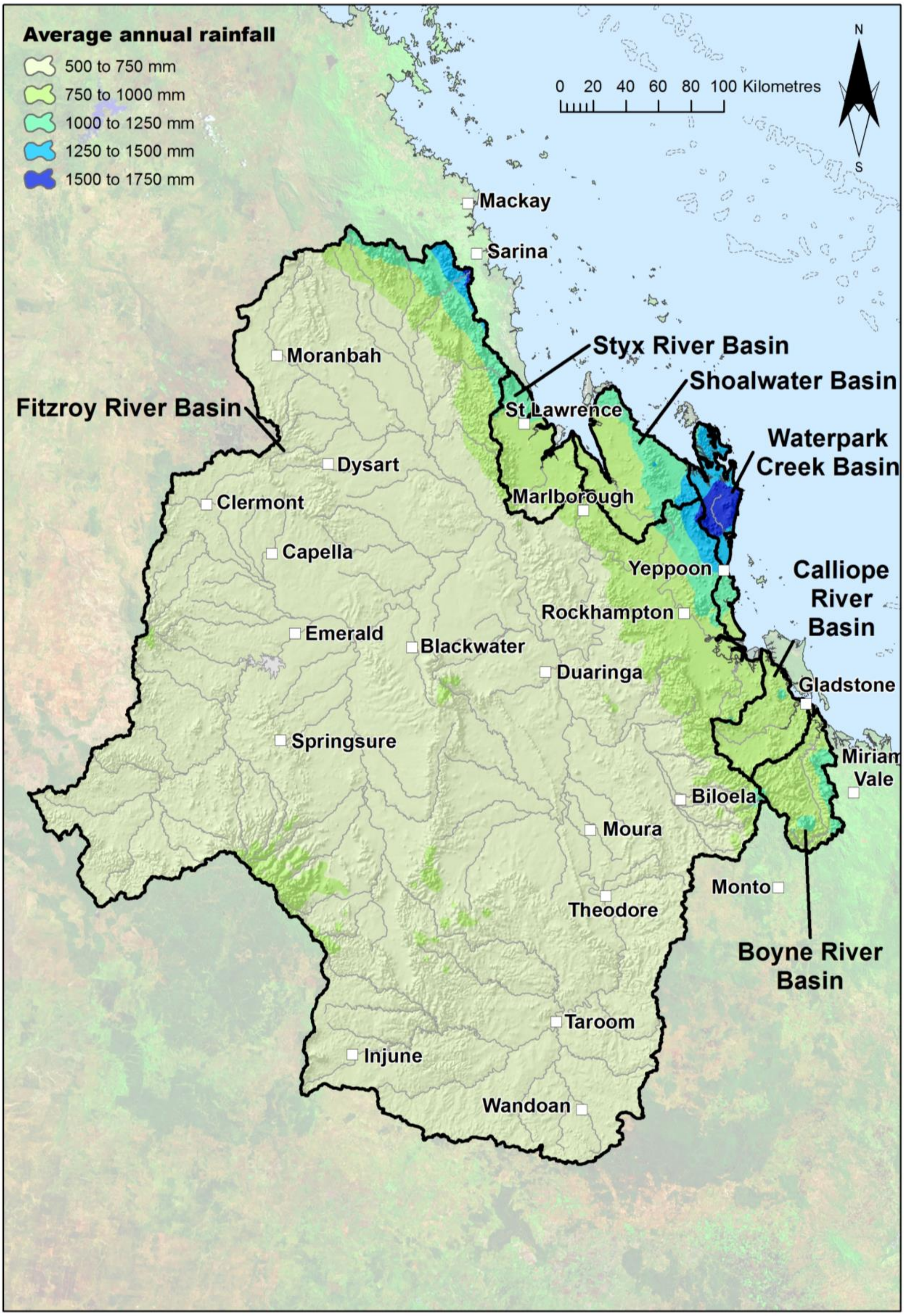

Figure 2 Spatial distribution of Fitzroy NRM region average annual rainfall

2.2 Soils

Shields and Forster (1992) describe the soils of the Fitzroy NRM region as very diverse due to wide variations in lithology, climate and geomorphic processes. No one soils group is dominant and there have been over 100 soils types described with a complex distribution pattern. Cracking clays are predominantly used for cropping throughout the basin, with high erosion on sloping ground where surface cover is low (Carroll et al. 1997). Surface and gully erosion can occur on texture contrast (or duplex) soils where hard setting surfaces increase runoff. Where runoff concentrates and there is a high Exchangeable Sodium Percentage in the clay subsoil, gully erosion is accentuated.

2.3 Land use

Grazing is the most common land use in the Fitzroy NRM region, with majority of the region dedicated to cattle production. Large areas of dryland cropping occur in the western part of the basin; while irrigated cropping occurs around the townships of Emerald, Theodore and Biloela. There is also extensive coal mining occurring in the Bowen basin, especially around the townships of Moranbah, Dysart, Blackwater and Moura. The land use categories in the Fitzroy region are presented in Figure 3 and Table 3. A comprehensive outline of land use and its condition can be found in the Department of the Premier and Cabinet (2011) report. The 2011 report outlines the 2009 level of industry practice (e.g. A, B, C or D) for grazing (including ground cover values) and horticulture. In addition riparian and wetland condition are also assessed.

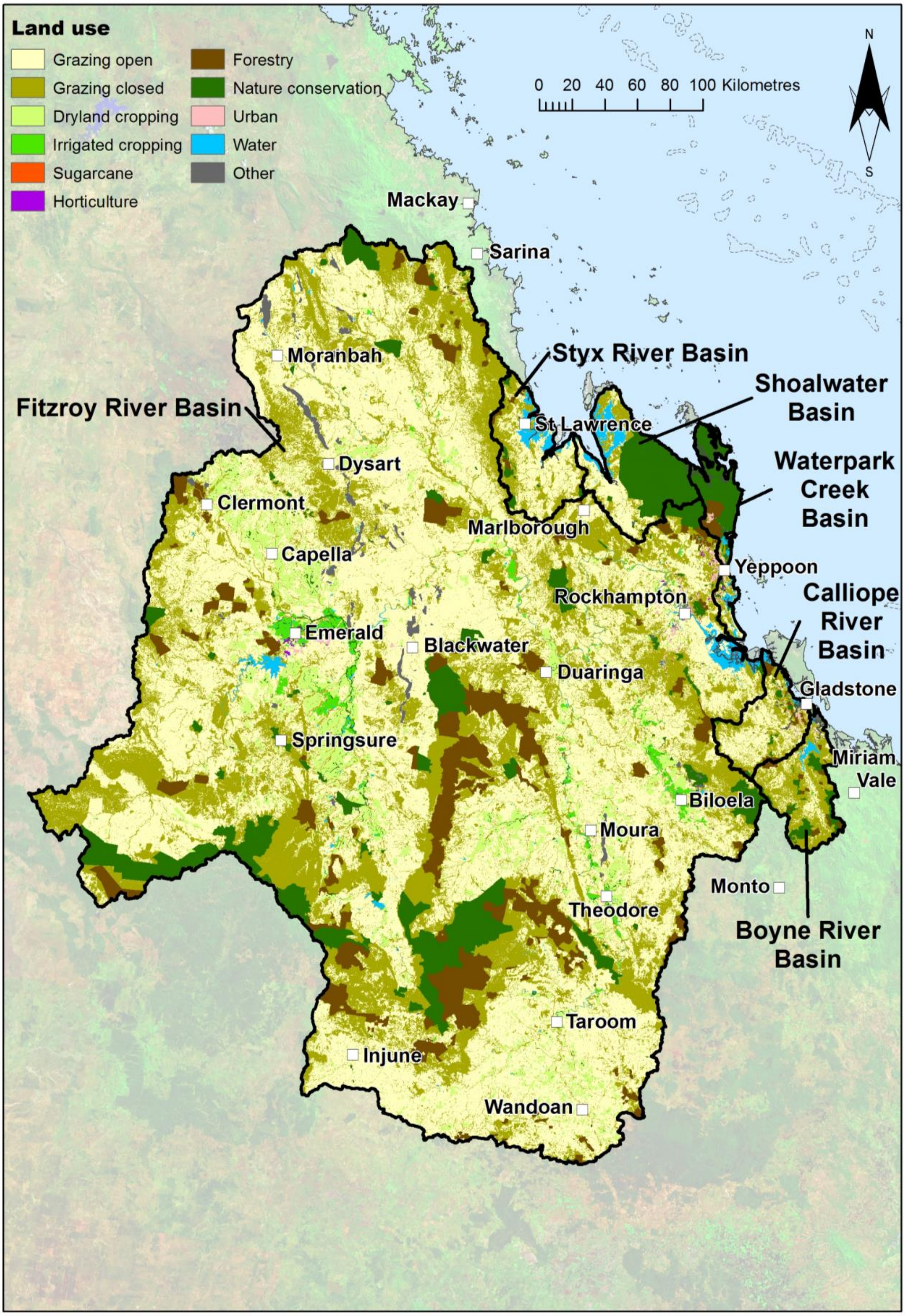

Figure 3 Fitzroy NRM region land use classification

Table 3 Fitzroy NRM region land use area

Land Use	Area (km^2)	Area (%)
Nature Conservation	11,832	8
Other	1,242	1
Grazing (open)	77,021	49
Grazing (closed)	44,491	29
Horticulture	10	<1
Urban	465	<1
Dryland Cropping	7,934	5
Sugarcane	3	<1
Forestry	9,701	6
Irrigated Cropping	1,213	1
Water	2,113	1
TOTAL	**156,025**	**100**

2.4 Water quality issues

The relative risk of reef pollutants to the GBR from agricultural land uses has recently been assessed by Waterhouse et al. (2012). This paper classifies the Fitzroy region as a medium–high risk, for suspended sediment and pesticides. Suspended sediments are dominated by grazing inputs while pesticides are sourced from dryland and irrigated cropping and grazing lands (tebuthiuron). In the wet season, the Fitzroy can produce flood plumes that extend far into the GBR lagoon and Devlin et al. (2012) has rated the inshore area as having high exposure to sediment. In the Waterhouse et al. (2012) relative risk assessment, particulate N and P were not considered as they would likely have a similar management response to sediment. Waterhouse et al. (2012) identified DON and DOP as low risk and were classified as low importance as reef pollutants, while FRP was not assed due to a scarcity of data but it was acknowledged as being potentially important.

Dryland (7,933 km^2) and irrigated (1,213 km^2) cropping are the major agricultural intensive land uses in the region, with high concentrations and loads of nitrogen and fine sediment, compared to other regions, reported from dryland cropping (Murphy et al. in press; Packett et al. 2009). The major sources of pesticide loads from the Fitzroy region are cropping lands. PSII herbicides used in cropping lands and found in receiving waters are atrazine, ametryn, hexazinone and diuron (Packett et al. 2009). The herbicide tebuthiuron has also been detected in runoff originating from grazing lands in the Fitzroy (Packett et al. 2009).

An emerging water quality issue is the number of newer herbicides that are being used in agricultural industries that are either not yet monitored as the analysis methodology has not yet been established or they are appearing in the monitoring data and need to be considered for modelling. The ecotoxicology of these products is usually poorly understood.

Water Quality Improvement Plans (WQIPs) are a part of the 2013 Reef Plan and are designed to identify the main issues impacting waterways and the marine environment from land-based activities and to identify and prioritise management actions that will halt or reverse the trend of declining water quality within an NRM region. The Fitzroy NRM region WQIP is currently being updated by the Fitzroy Basin Association. The modelling will be an important tool to assist with prioritisation of future investment under the WQIP.

3 Methods

The Fitzroy region model was built within the Source Catchments modelling framework. Source Catchments is a water quantity and quality modelling framework that has been developed by eWater Ltd. This framework allows users to simulate how catchment and climate variables (such as rainfall, land use, management practice and vegetation) affect runoff and contaminants, by integrating a range of component models, data and knowledge. Source Catchments supersedes the E2 and WaterCAST modelling frameworks (eWater Ltd 2012). Model input data is provided in Appendix E. A summary of data input sets is also available in Waters & Carroll (2012).

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 hydrologic response units or land use, (eWater Ltd 2013). In the case of the GBR Source Catchments framework FUs were defined as land use categories.

In the GBR Source Catchments Framework there are two modelling components assigned to each FU to represent the processes of:

- Runoff generation
- Constituent generation

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

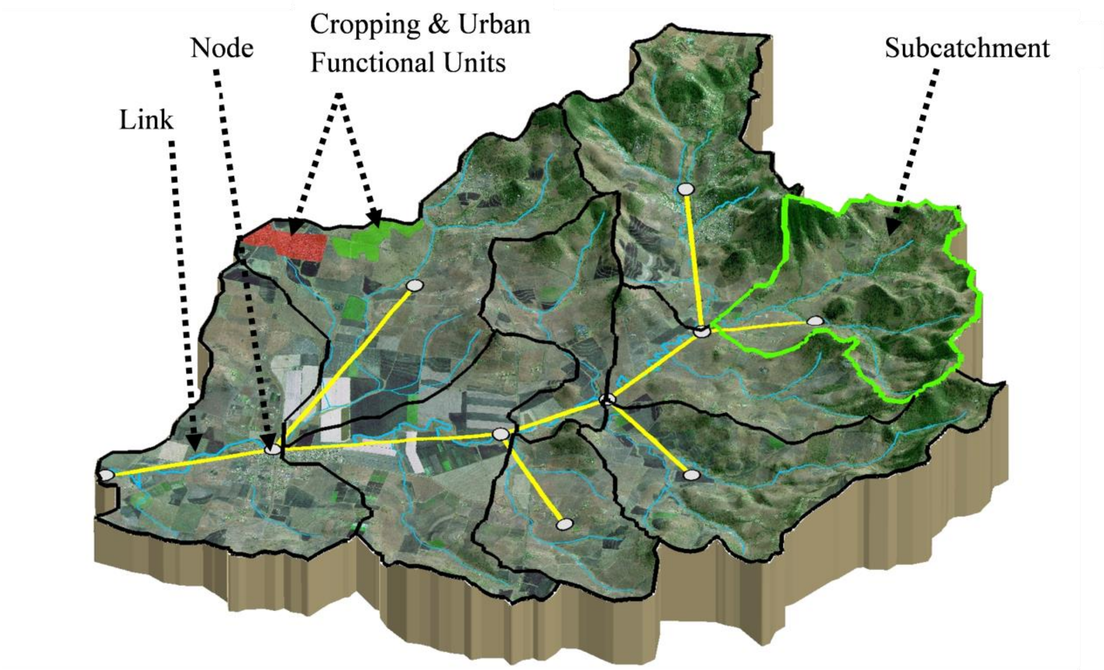

Figure 4 Example of a functional unit (FU) and node-link network generated in Source Catchments. These components represent the subcatchment and stream network

3.1.1 Land use Functional Units

In the Fitzroy region, the most recent land use mapping from the Queensland Land Use Mapping Project (QLUMP) (DSITIA 2012) was used to define the FUs, which were mapped using 2009 imagery. The original detailed QLUMP categories were reclassified into 10 alternative land uses/FUs (Table 3, Figure 3). Grazing land use was spilt into open and closed (timbered) to enable differences in runoff and constituent generation to be reflected in the model. To differentiate between open and closed grazing, closed areas were those areas with a Foliage Protective Cover (FPC) >= 20% (National Committee on Soil and Terrain 2009). Differentiation was made between these two grazing systems to enable representation of different hydrological response units (HRUs) during calibration. Any given land use within a subcatchment is aggregated and represented as a single area in the model hence is not represented spatially within a subcatchment.

3.1.2 Subcatchment generation

The Fitzroy Source Catchments framework encompasses the NRM region with six drainage basins. These basins are delineated into smaller subcatchments using a Digital Elevation Model (DEM). A 100 metre, hydrologically enforced DEM and 50 km^2 drainage threshold was used to identify the major stream network and contributing subcatchments. In this process, some flat coastal areas were not captured. In order to rectify this, the flat coastal areas not captured by Source Catchments were manually added to the DEM derived subcatchment layer in a GIS environment, based on drainage data and local knowledge. The final subcatchment map was then re-imported into Source Catchments. A total of 1,798 subcatchments (including 33 manually defined low-relief coastal catchments) were generated with an average subcatchment area of 87 km^2 (Figure 5). The addition of these flat coastal areas, some of which were not included in previous models, will improve the overall load estimates to the end of system. Subcatchments are routed based on a node-link network. An arbitrary node was created in the ocean as an ‘outlet’ node to enable the aggregation of loads for the entire region for reporting purposes. The selection of the most appropriate stream threshold value for subcatchment, node and link network generation is based on several factors, namely: the resolution of the DEM, the distribution and length of the stream network required to represent bank erosion (Wilkinson, Henderson & Chen 2004) and available computing resources.

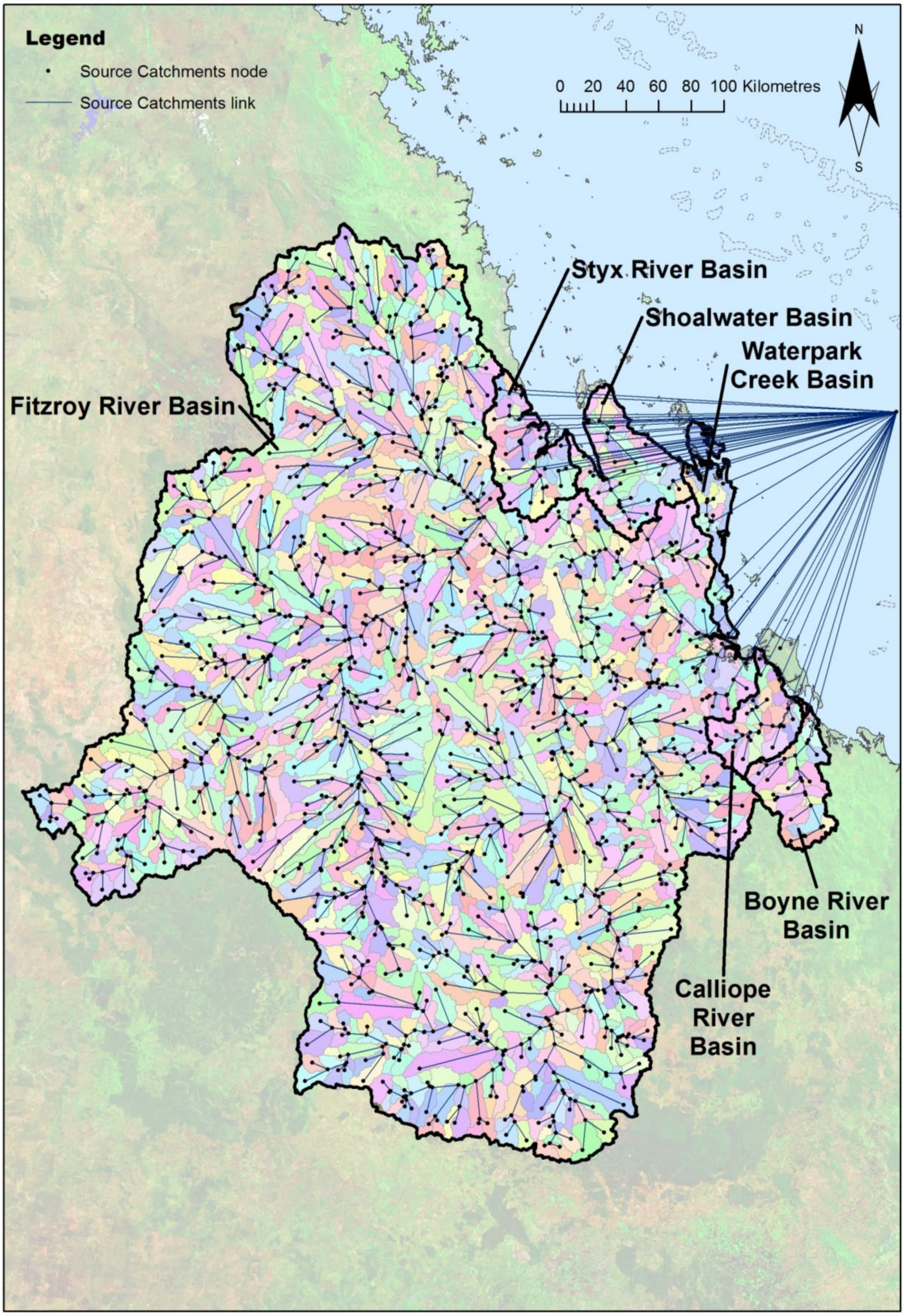

Figure 5 Fitzroy subcatchment, node and link network

3.1.3 Runoff generation

Six rainfall-runoff models are available within Source Catchments. A comparison of the six models (Vaze et al. 2011) concluded that there is little difference between these six models for broad scale application. SIMHYD is a catchment scale conceptual rainfall-runoff model that estimates daily stream flow from daily rainfall and areal potential evapotranspiration (PET) data (eWater Ltd 2013). The SIMHYD rainfall-runoff model was chosen due to its extensive application and proven performance to satisfactorily estimate stream flow across Australia (Chiew, Peel & Western 2002) and in particular for a large catchment in the GBR (Ellis, Doherty & Searle 2009). An investigation of the performance of a number of other models available in Source Catchments was undertaken (Zhang, Waters & Ellis 2013) following the release of Report Card 2010 and Report Card 2011. As a result of this work, the Sacramento model will be applied in future model calibration due to its improvement in runoff predictions.

Each FU possesses a unique instance of the SIMHYD rainfall-runoff and constituent generation models (Chiew, Peel & Western 2002). Typically, 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, and subcatchment outlets. Links connect nodes, and represent streams. A range of models can be applied to links to route or process water and constituents throughout the network (eWater Ltd 2013).

3.1.4 Constituent generation

In the GBR Source Catchments framework, there is the ability to link to external models and/or add your own component models as specific ‘plug-ins’ to customise for particular modelling objectives. This capability has been extensively used to incorporate the most appropriate constituent generation models across the GBR (Figure 6). SedNet modelling functionality has been incorporated to generate gully and streambank erosion and floodplain deposition within the daily time-step model. This relies upon the daily disaggregation of annual estimates of generation, or even long-term average annual estimates of generation in some cases. Whilst the methods used to perform daily disaggregation of the long-term estimates are mathematically sensible, it is recognised that simple disaggregation of the long-term estimates means that analysis of model outputs at a subannual resolution will yield results that are difficult to reconcile with observed events or data.

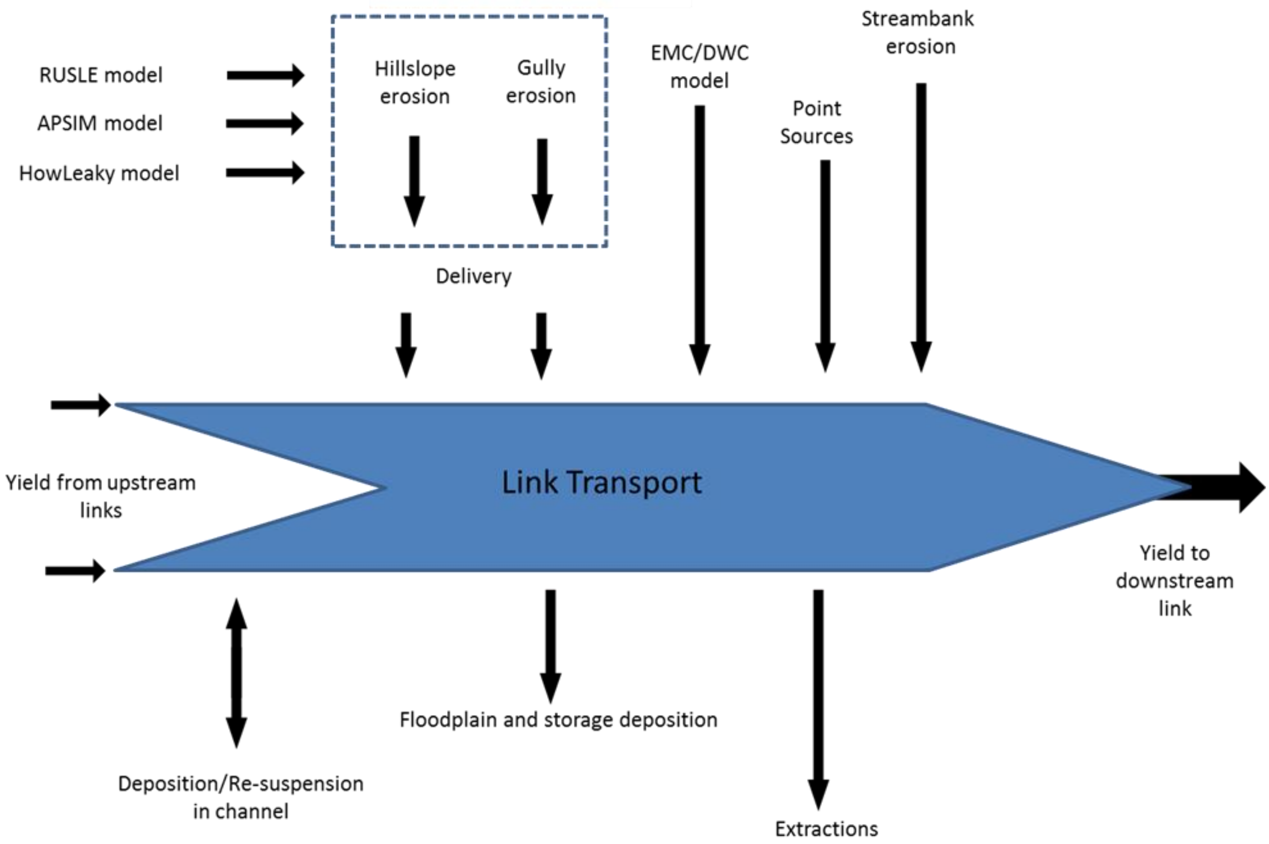

Figure 6 Conceptual diagram of GBR Source Catchments framework

The APSIM (Agricultural Production Systems Simulator) model was chosen for modelling sugarcane (Keating et al. 2003), particularly for dissolved inorganic nitrogen (DIN) in runoff. The HowLeaky model, with some enhancements, was used to model herbicides and phosphorus in sugarcane and all constituents for cropping areas cropping areas (Rattray et al. 2004, Robinson et al. 2010). The Source Catchments framework was selected to meet the increasing demand to improve and re-interpret the models at subannual (seasonal, monthly, recognised event) scales. Future work will look to examine the underlying concepts and available daily input data with the aim that these models become more robust at subannual time-steps.

3.1.5 Climate simulation period

A 23 year climate period for simulation was chosen (1/7/1986–30/6/2009). The modelling was constrained to this period for three reasons 1) it coincided with the availability from 1986 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 input files generated for each subcatchment were used to calculate daily runoff. Rainfall and PET inputs were derived from the Department of Natural Resource 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 subcatchment, over the modelling period (1986–2009).

3.2 Hydrology

Hydrology calibration is a major aspect of constituent load modelling, given that constituent generation is driven by rainfall and runoff. Thus it was imperative that the hydrology calibration process was rigorous, and achieved the best possible results. The calibration process was developed building on previous calibration work in the GBR (Ellis, Doherty & Searle 2009). The SIMHYD rainfall-runoff model was selected as the preferred model. The rationale for selecting SIMHYD is outlined in section 3.1.3. Runoff and 'slow flow' (subsurface seepage and low energy overland flow) aggregated at a subcatchment outlet, are transferred to the stream network then routed through the link system via the Laurenson flow routing model (Laurenson & Mein 1997). Storage dynamics (dams/weirs) were simulated, as well as irrigation extractions, channel losses and inflows such as sewage treatment plant discharges, through specific node models.

3.2.1 PEST calibration

Hydrology calibration was undertaken using PEST, a model-independent parameter estimation tool (Doherty 2009). Parameter optimisation incorporated both the SIMHYD rainfall-runoff parameters and two Laurenson flow routing parameters within a subcatchment. The estimation of rainfall-runoff and flow routing parameters was undertaken simultaneously.

A three-part objective function was employed, using log transformed daily flows, monthly flow volumes and flow exceedence to achieve an optimum calibration. The monthly flow volume component ensures that modelled volumes match measured volumes over long periods, the exceedance values ensure the flow volumes are proportioned well into baseflows and event flows, while the log transformed daily flows replicates the hydrograph shape (Stewart 2011). The three objective functions have been used successfully in other modelling applications (Stewart 2011). The absolute value of components will vary widely for all observation groups depending on the magnitude of the values contained within each component and the number of values in each time series. However, this does not mean those small value components are not as important as large value components (Stewart 2011). To overcome this inadvertent weighting, each component of the objective function has been weighted equally.

Regularisation was added prior to running PEST. This ensures numerical stability resulting from parameter non-uniqueness, by introducing extra information such as preferred parameter values. Parameter non-uniqueness occurs when there is insufficient observation data to estimate unique values for all model parameters, and is an issue in large models such as those in the GBR (Stewart 2011).

Once calibration was completed, model performance was assessed for the 86 Fitzroy gauges used in the calibration process. Performance was assessed for the calibration period 1/1/1970–31/3/2010. Most gauges had the complete flow record for the entire year calibration period.

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 ∞ values. If NSE = 0, then the model prediction is no better than using average annual runoff volume as a predictor of runoff. 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 simulated and observed values (Chiew & McMahon 1993). Detail on the actual PEST setup, operation and linkage with Source Catchments can be found in Appendix B.

3.2.2 Stream gauge selection for calibration

Flow data were extracted from DNRM's Hydstra Surface Water Database to provide the 'observed' flow values for calibration. A subset of 86 gauging stations were identified as suitable for PEST calibration, this was based on the following criteria that gauging stations were:

- Located on the modelled stream network
- Had a minimum of 10 years of flow record (post 1970) with suitable corresponding quality codes in the DNRM database, and

Gauges that had been moved and had <10% contributing area difference to its predecessor were merged into one continuous dataset.

3.2.3 Rainfall-runoff model parameterisation approach

The SIMHYD rainfall-runoff model contains nine parameters. Seven of these were made 'adjustable' for each SIMHYD instance exposed to PEST for calibration. The Pervious Fraction parameter was fixed to 1 (assuming no impervious areas of significance), therefore making the Impervious Threshold parameter redundant, and also fixed. Default SIMHYD and Laurenson flow routing parameters were used as the starting values.

3.2.4 Model regionalisation

To further simplify the number of adjustable parameters assessed by PEST during calibration, FUs deemed to have similar hydrologic response characteristics were grouped into three broad hydrologic response units (HRUs): forest, grazing and cropping (see Appendix C, Table 24). These broad groupings were selected from previous research in central Queensland which suggested these land uses have measurably different hydrologic characteristics between virgin scrub and land that has been cleared for grazing and cropping (Yee Yet & Silburn, 2003; Thornton et al. 2007). Flow routing models were also grouped according to the same regions. FUs, links and nodes continued to operate as discrete units within the Source Catchments structure. Regionalisation was only implemented via the template and instruction files that PEST assessed. This method of parsimony implies uniformity within, but not between, calibration regions.

Each gauging station included in the calibration represented its own region and modelled subcatchments were therefore divided into 86 regions (Figure 7). Regions were based on the contributing area to a gauge. Nested gauge (gauged upstream or downstream by other gauges) regions 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). Given the size of the Fitzroy project, at over 1GB, and the number of parameters, the Fitzroy was further split into four calibration quadrants, made up of:

- South West – 20 regions – 460 parameters
- South East – 21 regions – 483 parameters
- North West – 12 regions – 276 parameters
- North East – 33 regions – 690 parameters

To calibrate the Fitzroy hydrology, parallel PEST was run across an eight machine, 32 core dedicated network completing over 55,000 models runs. This represents over 570 days of central processing unit (CPU) time (Stewart 2011).

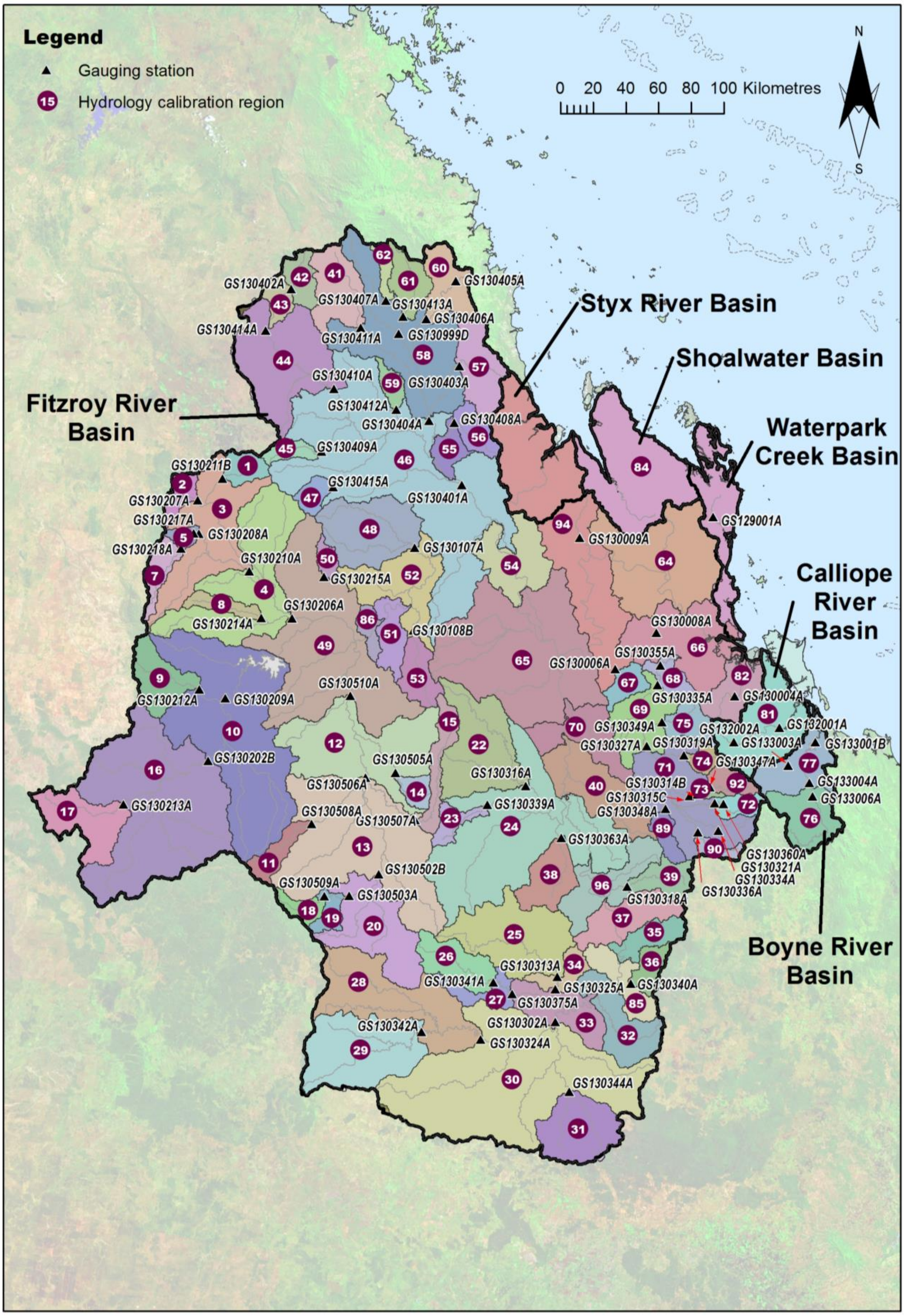

Figure 7 Hydrology calibration regions for Fitzroy

3.3 Constituent modelling

The key water quality constituents modelled, are outlined in Reef Plan and shown in Table 4. Total suspended sediment (TSS) is 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 Great Barrier Reef 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 sub-catchments, and at the Fitzroy basin outlet, >95% of the total suspended sediment (TSS) was very fine sediment (<20 µm).

With regard to herbicides, Reef Plan focuses on the reduction in loads of herbicides considered ‘priority’; atrazine, ametryn, diuron, hexazinone and tebuthiuron. These are photosystem II (PSII) inhibiting herbicides which are applied for residual herbicide control; collectively they are referred to as PSIIs. 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). The catchment models were set up to include tebuthiuron as one of the five PSIIs, however due to the availability of application data it was only modelled in the Fitzroy and Burnett Mary regions. The focus on reducing the use of these PSII herbicides has anecdotally led to increasing use of ‘alternative’ residual herbicides, which fulfil a similar weed control role. In future modelling, it may be necessary to include the alternative residual herbicides due to changing land management practices.

Table 4 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)
PS II herbicides	
atrazine, ametryn, diuron, hexazinone, tebuthiuron	

The most appropriate paddock scale model outputs were used to generate data for Source Catchments. These were APSIM for sugarcane, with the HowLeaky model for herbicides and phosphorus, HowLeaky for cropping, RUSLE for grazing and EMC/DWC models for the remainder. A more detailed summary of the models used for individual constituents for sugarcane, cropping and grazing are shown in Table 5. In addition, SedNet functionality has also been incorporated to model the contribution of gully and streambank erosion and floodplain deposition processes. A detailed description of the models used at the FU and link scale can be found in Shaw & Silburn (2014) and Ellis & Searle (2014).

Table 5 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

Dynamic SedNet is a Source Catchments 'plug-in' developed by DNRM/DSITIA specifically for this project. The plug-in provides a suite of constituent generation and in-stream processing models that simulate the processes represented in the SedNet catchment scale water quality model (that is, gully and streambank erosion, as well as floodplain deposition processes) at a finer temporal resolution than the original average annual SedNet model. The Dynamic SedNet plug-in also provides access to a variety of data analysis, parameterisation and reporting tools. These tools are an important addition as the complexity of a Source Catchments model, (both spatially and temporally) representing SedNet processes across many landscapes, is very difficult to adequately populate and communicate in a traditional water quality modelling sense. The following sections describe the Source Catchments Dynamic SedNet model configuration. The description includes:

- How constituents are generated at the FU and link scale
- Data requirements of each of the component models
- Methodologies used to simulate constituent generation and transport process for each FU within a subcatchment, link (in-stream losses, decay, deposition and remobilisation) and node (extractions and inputs to the stream).

3.3.1 Grazing constituent generation

Rainfall and ground cover are two dominant factors affecting hillslope runoff and erosion in the GBR. Previous studies report that gully erosion is also a significant source of sediment to the GBR (Dougall et al. 2006, Wilkinson et al. 2005, Wilkinson et al. in press). Given grazing occupied over 75% of the GBR, it was important that the models chosen represented the dominant erosion processes occurring in these landscapes, and the spatial variability observed across such a large area. Dynamic SedNet incorporates daily rainfall, and spatially and temporally variable cover to generate erosion.

The component model referred to as the SedNet Sediment (RUSLE & Gully) combines two sub-models; the Hillslope Dynamic RUSLE model and the Dynamic Gully Model, representing hillslope and gully contributions to sediment supply respectively.

3.3.1.1 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 on 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. The model is:

$$A = R * K * S * L * C * P \tag{1}$$

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 value)

L = Slope length (static value)

S = Slope steepness (static value)

C = Cover management factor (one value generated per year for each 25 m x 25 m grid cell)

P = Practice management factor (static value)

In the GBR Source Catchments framework, a daily time-step, spatially variable RUSLE was used to generate hillslope sediment predictions in grazing areas. The spatial data inputs were assessed at a fine resolution, with results accumulated up to a single representation of the particular grazing instance within each subcatchment. The spatial and global parameter values applied for Fitzroy model are shown in Table 26.

Rainfall erosivity factor (R) values were calculated using the generalised rainfall intensity method (Yu 1998). Catchment daily rainfall used in the hydrology modelling provided the daily rainfall input (Queensland Government 2011).

Soil erodibility factor (K) raster was calculated using methods of Loch & Rosewell (1992). Soil data for these calculations was sourced from the Queensland ASRIS database using the best available soils mapping for spatial extrapolation (Brough, Claridge & Grundy 2006).

Slope steepness factor (S) was calculated by methods outlined in Lu et al. (2003). The slope values for these calculations are derived from the 1 second shuttle DEM (Farr et al. 2007). The use of shuttle DEMs has been found to miscalculate slopes on floodplain areas or areas of low relief. The slope map produced from the 1 second shuttle DEM was therefore modified for the defined floodplain areas, with a value more appropriate for floodplains slope of 0.25%. This was value was approximated from the measurement of slope values produced from a range of high resolution DEMs, covering floodplains in the Fitzroy region.

Slope length factor (L) was set to 1 for grazing areas and is only applicable where rill erosion can occur. The assumption was that rill erosion is generally not found in low intensity grazing systems.

The K, S and L factors are temporally constant and combined into one raster. The raster is a product of the best resolution K, S and L factors linear multiplied, then resampled to a grid resolution of 100 m.

Cover management factor (C) can be applied in Source Catchments at three time-steps: monthly, annual and static. Here an annual time-stepping representation of the C-factor was selected due to the availability of the relevant satellite imagery at an annual scale at the time of model development. Using an annual time-step for the C-factor ensures that extended wet and dry periods are reflected in hillslope erosion processes. This is an improvement on previous modelling approaches where a single static C-factor was applied both spatially and temporally for each land use. Seasonal cover will be incorporated to further improve erosion estimates when data is available, as it will better represent inter-annual variability in RUSLE predictions. Ground cover is estimated using Bare Ground Index (BGI) (Scarth et al. 2006) (version CI2). This product is derived from Landsat TM Satellite (25 m) imagery. BGI values were subtracted from 100 to provide a ground cover index (GCI). The GCI was calculated each year using a single NRM region BGI mosaic of images captured between July and October (dry season). The GCI is currently only considered to be accurate in areas where the Foliage Projected Cover (FPC) (Goulevitch et al. 2002) is <20%. To deal with this, the GCI was classified into 'no tree' areas (FPC <20%) and 'tree' areas (FPC >20%). The 2009 FPC coverage was used to represent the 'tree' coverage, for all years. The 2009 was chosen to correspond with the latest land use mapping, also mapped to 2009.

'No tree' (where FPC <20%) C-factors (C_f) were derived as follows (Rosewell 1993):

$$C_f = EXP\left[-0.799 - (0.0474 \times GC) + (0.000449 \times GC^2) - (0.0000052 \times GC^3)\right] \quad (2)$$

Where GC is the percentage cover in contact with the soil.

Where FPC >20%, the C-factor was calculated using methods outlined in (Kinsey-Henderson 2007). This took the form of the following equation:

$$C_f = 1.0286 \times 10^{-8}\left[(100 - FPC)^{3.3907}\right] \quad (3)$$

Practice management factor (P) is the support practice factor, a measure of the effect on erosion of soil conservation measures such as contour cultivation and bank systems (Rosewell 1993). There was insufficient information available to apply P factors in this study, therefore P was set to 1 in all regions.

The daily RUSLE soil loss calculation provides an estimate of the sediment generation rate at the hillslope scale. To estimate the suspended fraction of the total soil loss, the RUSLE load is multiplied by the clay and silt fraction provided in the ASRIS layers (the best data source available to generate this layer at the GBR scale). The clay and silt fraction is based on the International particle size fraction classification (<20 µm) (National Committee on Soil and Terrain, 2009). The use of a particle size distribution raster in the current modelling to determine the fine sediment fraction (and calculate fine sediment load transported to the stream network) is an improvement from previous modelling studies that used SedNet (e.g. Brodie et al., 2003 and Cogle et al., 2006). These SedNet studies used a hillslope delivery ratio (HSDR) to alter the RUSLE-estimated eroded soil mass into a 'suspended sediment' in-stream mass, rather than the product of the fine fraction and HSDR as applied in this study (Equation 4). The clay and silt fraction values in the ASRIS data layer are derived as a function of many laboratory analysed soil samples from a range of soil types, hence the data incorporates the spatial variability of fine fractions across the GBR.

A sediment delivery ratio (SDR) was then applied to this load, and was selected based on past research using a standard 10% delivery ratio (Wilkinson, Anderson and Chen, 2004; Hateley et al 2009). However, in some regions the SDR was increased so that the generated fine sediment load better matched monitored data, or to counter the per cent cover generated by the BGI layers which was thought to be too high. The SDR for this region can be found in Table 26. The equation takes the form: (eq 4):

$$\text{Total suspended sediment load (kg/ha)} = \text{RUSLE sediment load (kg/day)} * (\text{silt} + \text{clay}_{\text{(prop)}}) * \text{SDR} \qquad (4)$$

This estimates the total suspended sediment (TSS) load which reaches the stream ().

Nutrient generation models

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

$$\text{Hillslope particulate nutrient load (kg/ha)} = \text{RUSLE sediment load (kg/day)} * \text{clay}_{\text{(prop)}} * \text{Surface nutrient concentration (kg/kg)} * \text{Enrichment factor} * \text{Nutrient Delivery Ratio (NDR)} \qquad (5)$$

This estimates the total suspended nutrient load which reaches the stream.

For the dissolved nutrient load, an EMC/DWC value (mg/L) is multiplied by the quick and slow flow output (Table 30). These models are described in (Ellis & Searle 2014) and replicate the original SedNet approach to dissolved and particulate nutrient generation modified to a daily basis. Enrichment ratios and load conversion factors are outlined in Table 29. Three rasters are required as inputs to these models, two nutrient rasters (surface nitrogen and phosphorus), as well as a surface clay (%) raster. The surface soil nutrient layers were from the Queensland ASRIS database.

Herbicide generation models

Tebuthiuron, a PSII herbicide, is the main herbicide used in grazing lands for control of regrowth. Tebuthiuron is applied to selected areas of land and is not repeated 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. No data has been provided to model changes in its application beyond the baseline year. Hence, the EMC/DWC values represented the pesticide concentration from grazing lands once in the stream (Appendix E, Table 32).

3.3.1.2 Gully – sediment, nutrient generation models

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

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

$$AASS\ (t/year) = (P_s * \alpha_{xs} * GD_{FU} * A_{FU}) / Age \qquad (6)$$

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 FU (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. Spatial raster inputs and parameter global values are shown in (Table 27). The gully density layer (National Land and Water Resources Audit (NLWRA)) was used the input raster (km/km^2) for gully density in the Fitzroy (NLWRA 2001). Much of the Australian research on gully erosion has occurred in south-eastern Australia, and measurements of gully cross sectional area suggest a value of 10–23 m^2 would be appropriate in SedNet modelling (Hughes & Croke 2011, Prosser & Winchester 1996, Rustomji et al. 2010); 10m^2 was used in the Fitzroy model. The soil bulk density (g/cm^3) and b-horizon clay plus silt (%) rasters were both created from the Queensland ASRIS dataset. The year of disturbance can either be input as a raster or as a uniform value. In the Fitzroy model, a uniform value of 1870 was applied.

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

3.3.2 Cropping constituent generation

In the GBR Source Catchments framework the component model referred to as the Cropping Sediment (Sheet & Gully) model combines the output from two sub-models; the Cropping Soil Erosion model and the Dynamic Gully Model. The time series loads of daily hillslope erosion (t/ha), as calculated by HowLeaky (Rattray et al. 2004) are combined with the daily gully erosion estimate as outlined above.

3.3.2.1 Hillslope sediment, nutrient and herbicide generation

Daily time series loads of fine sediment, nutrients and herbicides were supplied from HowLeaky model runs for the dryland and irrigated cropping FUs (Shaw & Silburn 2014). DIN and DON were modelled using an EMC. Simulations of a range of typical cropping systems in the Fitzroy were run in the HowLeaky model to represent unique combinations of soil groups, climate and land management.

Runoff was modelled in HowLeaky using a modified version of the Curve Number approach (Shaw & Silburn 2014, Littleboy et al. 1989). 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.

Hillslope erosion was predicted in HowLeaky using the modelled runoff, USLE 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. In addition, the Freebairn & Wockner equation has been tested and calibrated for 14 sites in Queensland, predominantly in the GBR, for a detailed summary of 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.

Dissolved phosphorus in runoff was modelled in HowLeaky as a function of saturation of the soil P sorption complex while particulate phosphorus was modelled as a function of sediment concentration in runoff and the soil P status (Robinson et al. 2011). As the HowLeaky model did not differentiate between forms of dissolved P, a ratio was applied to the dissolved P on import to the catchment model. While the fractions of DIP/DOP are known to vary by site and situation, a value was selected from the limited available literature (e.g. Chapman et al. 1997) which showed that DOP could represent up to 20% of dissolved P in leachate/soil water.

Herbicide mass balance and runoff losses were modelled using HowLeaky (Shaw et al. 2011), an enhanced version of (Rattray et al. 2004). Modelling of herbicide applications at the paddock scale was based on theoretical scenarios that represent a ‘typical’ set of applications under an A, B, C or D set of management practices. 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. 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).

3.3.2.2 Gully sediment, nutrient generation –‘Dynamic Gully Model’

Gully modelling for cropping lands used the same methodology as for grazing lands. Refer to section 3.3.1.2 above. Similarly to the grazing areas, the total subcatchment contribution for cropping FU’s combines the hillslope and gully loads. Gully nutrients are derived as a function of the gully particulate sediment load, the subsurface clay % and the soil nutrient concentrations.

3.3.3 Other land uses: Event Mean concentration (EMC), Dry Weather Concentration (DWC)

The remaining land uses: urban, other and horticulture have had Event Mean Concentration/Dry Weather Concentration (EMC/DWC) models applied. In the absence of specific models for these land uses, EMC/DWC models were applied to give an estimate of the daily load, where:

$$\text{Daily Load (kg)} = (\text{EMC x quickflow runoff}) + (\text{DWC x baseflow runoff}) \qquad (7)$$

Quick flow runoff represents the storm runoff component of daily runoff and the remainder being base (or slow) flow. A constituent EMC/DWC (mg/L) model was applied for a particular functional unit; an estimate was made using available monitoring data, or where monitored data was not available, via best estimates from previous studies/estimates (Bartley et al. 2012, Rohde et al. 2008, Waters & Packett 2007). When reliable long-term monitoring data was available, an EMC value for a constituent was calculated directly from the load and flow data for the entire period.

DWCs were calculated from data collected during low flow periods (reflecting baseflow). Where there was insufficient data available a value of 50% of the applied EMC was used for the DWC. Low flow periods were defined as the lowest 20^{th} percentile of daily flows; see Appendix E (Table 32) for values used in this model. It is important to highlight that the EMC/DWC applied in this model represent 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.

To simplify the results, any sediment generation models that use an EMC approach assume that the EMC derived load incorporates both hillslope and gully contributions. To derive an estimate for the total hillslope and gully contribution, the EMC derived load was split by taking the percentage of hillslope and gully sources estimated for the remainder of the region and applying the same proportion to the EMC derived source. The EMC derived source for dissolved nutrients was added to diffuse dissolved source load to simplify the results.

3.3.4 Subcatchment models

3.3.4.1 Point sources

Sewage Treatment Plants (STPs) were deemed a significant point source contribution to nutrient loads exported to the GBR. The larger STPs with an arbitrary criterion of a minimum 10,000 equivalent person's (EP) capacity were included (Table 6). STP details and data were provided by DNRM's (formerly Environment Protection Agency) Point Source Database (PSD). The flows and load data were then used to calculate an average annual flow volume and load.

Table 6 Sewage Treatment plants >10,000 equivalent persons

STP	Discharge point	Catchment	Latitude	Longitude	EP
Yeppoon Sewage Treatment plant	Corduroy Creek	Water Park	-23.158568	150.7056	10,000–50,000
North Rockhampton Sewage Treatment	Fitzroy River	Fitzroy River	-23.3746	150.5274	10,000–50,000
South Rockhampton Sewage Treatment Plant			-23.3954	150.5292	10,000–50,000
West Rockhampton Sewage Treatment Plant			-23.3586	150.4906	10,000–50,000

The Source Catchments model required average annual loads (kg/yr) of DIN, DOP, DIP and DOP. However the majority of the nutrient data in the PSD database was reported as TN, TP and Ammonia (as N-NH3). Twelve STPs from Queensland with recorded concentrations of DIN, DON, DIP, DOP TN and TP were used to calculate the mean percentage of each constituent to the total. Of the 12 STPs, eight were tertiary and four were secondary treatment plants. No differentiation was made between tertiary and secondary treatment plants, as there was a 10% difference in N speciation and 4% difference in P speciation. Moreover, STP sources only account for a small fraction of the total nutrient budget. Out of the 12 STP plants, 550 samples were used to calculate N speciation mean percentages and 469 samples used to calculate P speciation, see Table 7 for percentages. Data pairs were discarded where the speciation concentration added together was greater than the TN or TP concentration. The fixed percentages were applied to TN and TP data to get the speciation. Annual loads (kg/yr) were then calculated by multiplying the average annual flow (2007-2010) by the average 2010 daily concentration of DIN, DON, DIP and DOP. To reflect the recent upgrades to STPs in the region only the 2010 nutrient concentrations were used.

Table 7 TN and TP speciation ratio's

	DIN of Total N	DON of Total N	DIP of Total P	DOP of Total P
% of total	79%	21%	78%	22%
No. samples	550		469	

3.3.5 In–stream models

The in-stream processes represented in the model are streambank erosion, in-stream deposition, decay and remobilisation and floodplain deposition. The models that have been applied are: the SedNet Stream Fine Sediment Model and SedNet Stream Coarse Sediment Model which simulate sediment generation, deposition and remobilisation in-stream and coarse sediment deposition. The SedNet Stream Particulate Nutrient model has been applied to generate, deposit and remobilise particulate nutrients in-stream. Dissolved nutrients and herbicides were not generated at a link scale. Coarse sediment was not reported.

3.3.5.1 Streambank Erosion

The SedNet Stream Fine Sediment Model calculates a mean annual rate of fine sediment streambank erosion in (t/yr) as a function of riparian vegetation extent, streambank erodibility and retreat rate. The mean annual streambank erosion is disaggregated as a function of the daily flow. For a full description of the method refer to Ellis & Searle (2014) and also see Appendix E for parameter values. The SedNet Stream Particulate Nutrient Model calculates particulate N and P contribution from streambanks by taking the mean annual rate of soil erosion (t/yr) from the stream network (t/yr) multiplied by the ASRIS subsurface soil N and P concentrations.

3.3.5.2 In-stream deposition, decay and remobilisation

The implemented in-stream model allows both deposition and remobilisation of fine and coarse sediment. 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 coarse sediment deposits in the main stream with no remobilisation occurring, while for fine sediment it was assumed that there was no long-term fine sediment deposition in-stream. 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 the Fitzroy model. Monitoring data suggests that dissolved nutrient concentrations showed little reduction from source to the catchment outlet therefore no decay model was 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 (Ellis & Searle 2013). Half-lives were taken from the DT_{50} values for water from the Pesticide Properties Database (PPDB) (Agriculture & Environment Research Unit (AERU) 2006–2013). Before these values were selected for use in the modelling, they were checked against predicted half-lives based on the physical and chemical properties of the herbicides being considered and against field monitoring data of events to determine whether the order of magnitude reported in the database was consistent with field observations in the GBR catchment (e.g. (Smith et al. 2011) and Bob Packett, 2012, pers. comm.). Monitoring in the Fitzroy River designed to target the same ‘parcel’ of water in the upper catchments and again at the mouth of the Fitzroy River indicated that the half-life of atrazine and diuron in-stream was in the order of three to six days, while for tebuthiuron the half-life estimates ranged from approximately 15–60 days (Bob Packett, 2012, pers. comm.). Where values were not available in the PPDB for a specific herbicide, a value was assigned from a compound with similar chemical properties or derived from the monitored data. The herbicide half-life parameters are presented in Appendix E, Table 34.

3.3.5.3 Floodplain (deposition)

Floodplain trapping or deposition occurs during overbank flows. When floodwater rises above rivers banks the water that spills out onto the rivers floodplain is defined as overbank flow. 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 (Wilkinson et al. 2010, Ellis 2014, Prosser et al. 2001b). The SedNet Stream Particulate Nutrient model also calculates the particulate nutrients deposited on the floodplain as a proportion of fine sediment deposition. The loss of dissolved nutrients and herbicides on the floodplain was not simulated.

3.3.5.4 Node models

Nodes represent points in a stream network where links are joined (eWater Ltd 2013). Catchment processes can also be represented at nodes. In the GBR Source Catchments model, irrigation extractions, STP inflows, losses from channels and storages were represented at nodes. The following section outlines how this was undertaken. For the description of these models refer to eWater Ltd (2013).

3.3.5.5 Extraction, Inflows and loss node models

To simulate the removal of water from storages and/or rivers, daily extraction estimates for a river reach were incorporated at relevant nodes. The data was obtained from previous Integrated Quantity and Quality Models (IQQM). Time series data for the Fitzroy Source Catchments model was obtained from the Fitzroy IQQM report (DNRM 2005). Demands for water include town water supply, irrigators and unregulated users. An extraction node model was placed at the node immediately downstream of storages to represent demands taken directly from the storage. Multiple types of extractions were aggregated and placed at the appropriate downstream node. In all cases, the daily time series orders were extended to match the model simulation period (1986–2009).

3.3.5.6 Storages

Storages (dams and weirs) with a capacity >10,000 ML (Table 8) were incorporated into the model at links. Only storages of significant capacity were incorporated as it was impractical to include all storages into the model 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. Additional storage information is located in Table 35.

Table 8 Fitzroy storage details (>10,000 ML capacity)

Storage	Catchment	Construction Date	Capacity (ML)
Callide Dam	Dawson	1988	136,370
Fairbairn Dam	Nogoa	1972	1,297,355
Kroombit Dam	Callide	1992	14,600
Awoonga Dam	Boyne	1982	661,853
Neville Hewitt Weir	Dawson	1976	11,300
Bedford Weir	Mackenzie	1968	22,558
Glebe Weir	Dawson	1971	17,400
Gyranda Weir	Dawson	1987	14,700
Eden Bann	Fitzroy	1994	65,692
Fitzroy Barrage	Fitzroy	1971	81,290
Tartrus Weir	Nogoa	1986	12,055
Bundoora Dam	Mackenzie	1980	10,000
Teviot Dam	Isaac	1995	24,000
Burton Gorge Dam	Isaac	1992	19,264
Lake Brown	Nogoa	1972	31,050

Trapping of fine sediment and particulate nutrients in storages is simulated by the SedNet Storage Lewis Model and the SedNet Storage Particulate Nutrient Deposition model, respectively. Here fine sediment and particulate nutrient is captured using a 'trapping' algorithm based on daily storage capacity, length and discharge rate. The implemented trapping algorithm is a daily modification of the Churchill fine sediment trapping equation (Churchill 1948). Lewis et al. (2013) reviewed and tested an annual weighted version of this equation against measured data for the Burdekin Falls dam and storages in the USA, in general, predictive capability improved with use of daily data. Dissolved constituents are decayed in storages using the SedNet Storage Dissolved Constituent Loss model, which applies a first order decay. Storage details are presented in Table 35.

3.4 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 European induced constituent loads from predevelopment conditions (Figure 8).

$$\text{Anthropogenic baseline load} = \text{total baseline load} - \text{predevelopment load} \tag{8}$$

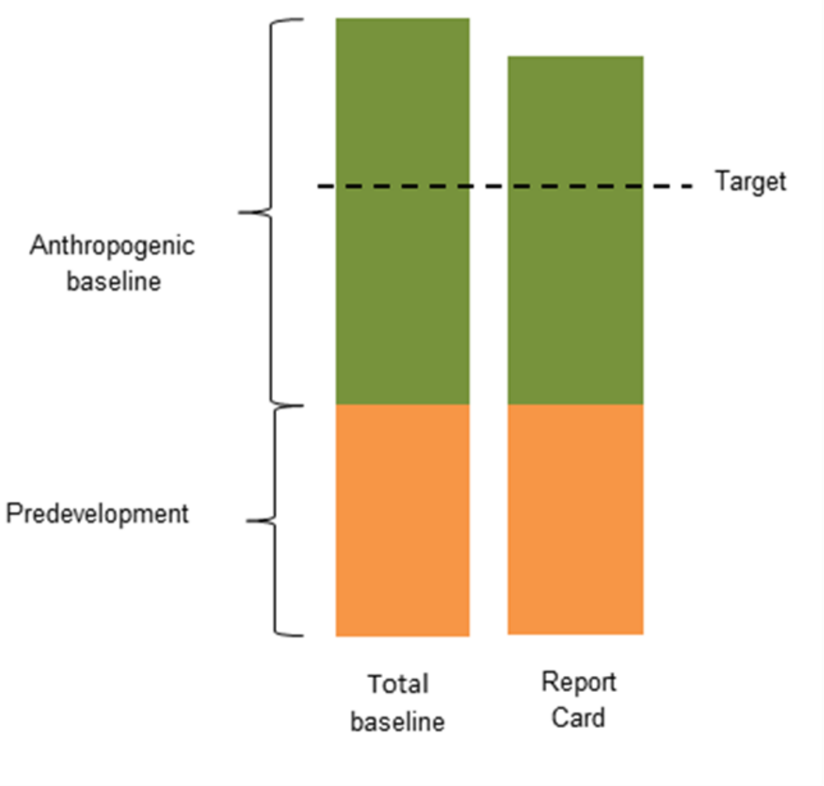

Figure 8 Example of how modelling results will be reported to demonstrate the estimated long-term load reduction resulting from adoption of improved management practices for Report Cards 2010–2013 against the target

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

$$\text{Reduction in load (\%)} = \frac{(\text{Total baseline load} - \text{Report Card 2013 load}) * 100}{\text{Anthropogenic baseline load}} \tag{9}$$

The progress made towards water quality targets due to investments in improved land management are therefore reported as a reduction in the anthropogenic baseline loads. In this section the approach and series of assumptions used to derive total baseline and predevelopment loads and the process to represent management practice change are outlined.

Report cards, measuring progress towards Reef Plan's goals and targets, are produced annually as part of the Paddock to Reef Program. Report Cards 2010-2013 represent management changes based on a yearly period, usually financial year to financial year. The total and anthropogenic baseline load was based on land use and management status at the start of the

2008–2009 financial year. All scenarios were run using the same modelling period 1986–2009 (23 years); see Table 9 for details of the total and anthropogenic baseline and Report Card scenarios. Note that Report Card 2010 includes two years of management change. Report Card 2011 and beyond represent cumulative change each year.

Table 9 Total and anthropogenic baseline and Report Card model run details

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

3.4.1 Modelling baseline management practice and practice change

State and Australian government funds were made available under the Reef Rescue Caring for Our Country investment program 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 include fencing by land type, fencing of riparian areas and the installation of off-stream watering points, all of which aim 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 would result in improvements in offsite water quality. It is important to note that not all reported investments are assumed to have achieved this management system change. This is particularly the case in cropping systems where several specific and inter-related practice changes are often required to complete the transition to a new management system. For a more detailed outline of the methodology used to classify management practice classes refer to the Reef Plan website www.reefplan.qld.gov.au. For a summary of typical management practice changes attracting co-investment, refer to Appendix E, Table 36.

To model management practice change, the baseline management practice was identified and incorporated into the baseline model through the development of an ABCD framework. 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 are classed as:

A – Cutting edge practices, achievable with more precise technology and farming techniques

B – Best management practice, generally recommended by industry

C – Code of practice or common practices

D – Unacceptable practices that normally have both production and environmental inefficiencies.

The proportion of each industry was established in A, B, C or D condition. 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 based on the adoption of improved practices. For more information on the ABCD framework see the Reef Plan website: www.reefplan.qld.gov.au.

The total baseline load was modelled using 2009 land use and 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 including: nature conservation, forestry, open and closed grazing, sugarcane, bananas, cropping, horticulture and dairying (Table 3).

For each of the major industries where investment occurred in the Fitzroy NRM Region (grains and grazing) there were 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 is central to the modelling and reporting on progress towards the reef water quality targets. The variety of sources of information collected in the baseline year (start of 2008/2009 financial year) and adoption of improved management practices from industry and government programs are outlined in Queensland Government Department of the Premier and Cabinet (2013).

Management changes funded through the Reef Rescue Research and Development Program were provided as the numbers of hectares that have moved ‘from’ and ‘to’ each management class level. The threshold and progress towards target definitions are provided in Table 10.

Table 10 Pollutant load definitions of the status/progress towards the Reef Plan 2009 water quality targets

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%

3.4.1.1 Grazing

In grazing lands, for the baseline condition, the ABCD management practice was represented by different ground cover classifications. Cover for the grazing areas were derived from the Ground Cover Index (GCI). The GCI was then translated into a ‘C-factor’. The C-factor is required in the Revised Universal Soil Loss Equation (RUSLE) used for sediment generation in grazing lands.

In grazing the GRASs Production model (GRASP) (McKeon et al. 1990) provided scaling factors for adjusting RUSLE C-factors where management practice changes occur. 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 for grazing given it has been extensively parameterised for 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.

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 from changed management are then linked to Source Catchments to produce relative changes in catchment loads. For grazing, the majority of the baseline management practice for soil was in B class, Table 11 provides % area of the ABCD framework for the baseline, and Report Cards 2010–2013.

Table 11 Summary of the baseline management and management changes for grazing (% area) for the Fitzroy NRM region baseline and Report Cards 2010-2013

Management system	Period	A	B	C	D
		%			
Soil	Baseline	4	49	41	6
	2008-2010	5	49	41	6
	2008-2011	5	49	40	6
	2008-2012	5	50	39	6
	2008-2013	5	51	38	5

Riparian fencing

Improved grazing management (in particular cover management) can have both a direct and indirect effect on gully and streambank erosion rates. Indirect effects of improved grazing management or 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 model by implementing relative reductions in rates of erosion per management class, as described by Thorburn & Wilkinson (2012), (Table 12). The direct effects of riparian fencing are a result of increased cover on the actual stream or gully. Both have a beneficial effect on erosion rates from these areas.

Table 12 Gully and streambank erosion rates relative to C class practice. (Adapted from Table 4, (Thorburn & Wilkinson 2012))

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

To represent this indirect effect on streambank erosion, a spatial analysis was conducted identifying the proportion of each Source Catchments' stream associated with each grazing management class. These proportions were used to produce a weighted streambank erosion rate adjustment factor, with this adjustment factor applied to the bank erosion coefficient for the relevant stream.

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 Report Cards 2010–2013 scenarios. Indirect effects have been applied in Fitzroy for Report Cards 2011–2013 only, and riparian fencing data to represent the direct effects, was only provided to the modelling team for the Fitzroy for Report Cards 2011–2013. For assessing the direct effect of riparian fencing, where investments of riparian fencing were identifiable, the riparian vegetation percentage for the stream was increased linearly with respect to the proportion of the stream now excluded from stock.

3.4.1.2 Grains

The effects of ABCD management practice breakdown for grains in the baseline year (and in years where investment occurred) were represented in a paddock scale model. Daily timeseries files of loads per day per unit area were generated using HowLeaky for each combination of soil, climate, constituent and management system in the Fitzroy catchment. These daily outputs for each constituent were accumulated into a single timeseries for each subcatchment according to spatially relevant weights and imported into Source Catchments. This process allowed the inclusion of spatial (and management) complexity that the Source Catchments framework was unable to represent. For further details on this methodology refer to Shaw & Silburn (2014).

There were no modelled improvements in DIN or DON management in grains for Report Cards 2010–2013, as HowLeaky did not include a dissolved nitrogen model.

Baseline management practice data for grains showed that the majority of the area was under B level practice for soil (61%), nutrient (64%) and pesticide (70%) related practices (Table 13). The change in management class between the baseline and Report Cards 2010–2013 years is presented in Table 13.

Table 13 Summary of the baseline and management changes for grains (% area) for the baseline and Report Cards 2010-2013

Parameter	Period	A	B	C/D
Nutrient	Baseline	15	68	17
	2008-2010	15	70	16
	2008-2011	15	74	11
	2008-2012	15	76	9
	2008-2013	15	76	9
Pesticide	Baseline	10	56	34
	2008-2010	10	59	31
	2008-2011	11	64	25
	2008-2012	11	67	22
	2008-2013	11	71	18
Soil	Baseline	16	55	29
	2008-2010	16	58	26
	2008-2011	17	63	20
	2008-2012	17	66	17
	2008-2013	17	69	14

3.4.2 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, refers to the period since European settlement. The assumptions made to represent predevelopment conditions were:

- Ground cover was increased to 95% in grazing (open and closed) areas
- With the exception of grazing, all land uses had a nature conservation EMC/DWC applied
- An FPC was created to represent 100% riparian cover
- Gully cross-section area was reduced from 10 m^2 to 1 m^2 (90% reduction)

To be consistent with previous catchment modelling undertaken in the GBR, the hydrology, dams and weirs were left unchanged in models in which they are present. Therefore, the load reductions reported were solely due to land management change. As per Table 9, the predevelopment model was run from 1986 to 2009.

3.5 Constituent load validation

Three main approaches were used to validate the GBR Source Catchments modelling. Firstly, a comparison was made with the previous best estimates in Kroon et al. (2012). Secondly, a long-term comparison was made with catchment load estimates derived from all available measured data for the high priority catchments for the 23 year modelling period (Joo et al. 2014) and thirdly, a short-term comparison was made using load estimates from monitoring results that commenced in 2006 in ten high priority catchments (Joo et al. 2012, Turner et al. 2012).

It is important to note that the catchment model outputs are compared or "validated" against measured loads as opposed to the common calibration approach whereby model parameters are adjusted to fit the measured data.

3.5.1 Previous best estimates – Kroon et al. (2012)

Kroon et al. (2012) reported current, pre-European and anthropogenic loads from the 35 reef catchments (in six NRM regions), using published and available loads data. The best estimates for the Fitzroy NRM catchments for the 'current' loads (except PSIIs) were based on past catchment modelling results (McKergow et al. 2005a, Brodie et al. 2009, Dougall et al. 2009, Bartley et al. 2003). The pre-European loads described were from McKergow et al. (2005a) and McKergow et al. (2005b) except for TSS in the Fitzroy where Dougall et al. (2009) and Bartley et al. (2003) was used. Both of these studies also used the SedNet model. The PSII catchment load estimates reported in Kroon et al. (2012) were derived from Brodie, Mitchell & Waterhouse (2009). The difference between the Kroon et al. (2012) current and pre-European load provided an estimate of the 'anthropogenic' load. Anthropogenic loads could not be compared due to differences in modelling periods and methodologies. The Kroon et al. (2012) loads are presented in Appendix A - Previous estimates of pollutant loads. It should be noted that any comparisons made with Kroon et al. (2012) are indicative only, as no information was provided on the dates or time period over which these average annual loads are derived.

3.5.2 Long-term FRCE loads (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 was not sampled for critical parts of the hydrograph. There have been previous attempts to calculate long-term load estimates from this sporadic data. Joo et al (2014) has collated all appropriate data sets to generate estimates of daily, monthly, annual and average annual loads for all EOS gauging stations across the GBR. The standard approaches were examined including averaging, developing a concentration to flow relationship (regression), and/or the Beale Ratio (Joo et al. 2014, Richards 1999, Marsh & Waters 2009). It is acknowledged that these can result in large errors in the load estimates especially when extrapolating far beyond the sampled flow ranges due to lack of representative data (Joo et al. 2014, Marsh & Waters 2009). Joo et al (2014) has applied a Flow Range Concentration Estimator (FRCE) method (a modified Beale ratio method) to provide estimates of annual loads. The mean modelled loads were compared with the likely upper (95th percentile concentration) and likely lower (5th percentile concentration), and mean, FRCE load for all constituents except herbicides across 23 water years (1/7/1986 to 31/6/2009).

In addition to the average annual comparison, Moriasi et al. (2007) developed statistical model evaluation techniques for streamflow, sediment and nutrients. Three quantitative statistics were recommended: NSE, percent bias (PBIAS) and the ratio of the root mean square error to the standard deviation of validation data (RSR). Model evaluation performance ratings were established for each recommended statistic, and are presented in Table 14. Modelled monthly loads were also assessed against these ratings.

Table 14 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

3.5.3 GBR Catchment Loads Monitoring Program (GBRCLMP) (2006–2009)

In 2006, the Queensland Government commenced a GBR Catchment Loads Monitoring Program (GBRCLMP) designed to measure sediment and nutrient loads entering the GBR lagoon (Joo et al. 2012). The water quality monitoring focussed at the end-of-system (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 GBR catchments and three subcatchments (Smith et al. 2012). Five priority PSII herbicides commonly detected from GBR catchments: diuron, atrazine, hexazinone, ametryn and tebuthiuron were tested for. Organochlorine and organophosphate insecticides (e.g. Endosulfan, chlorpyriphos) as well as fungicides are also tested for. In general, the EOS sites capture freshwater flows from 40% to 99% of total basin areas and do not include tidal areas and small coastal catchments (Joo et al. 2012). In the Fitzroy for model validation the catchment modelled loads for one EOS site is compared with the catchment monitoring for the 2006 to 2009 period for fine sediment and nutrients.

4 Results

This section is separated into hydrology and modelled loads. In the hydrology section, the results of the calibration process will be presented, as well as a general summary of the hydrology of the GBR regions. The modelled loads section includes the results of the total baseline, anthropogenic baseline and predevelopment loads. The validation of the Fitzroy Source Catchments modelled data is then presented using load estimates from measured and previous modelled data. Progress towards targets due to investment is reported against the anthropogenic baseline for Report Card 2013. A summary of the total baseline load by land use and land use by basin is also reported, as well as a mass balance summary of the sources and sinks by constituent. For a full list of the Fitzroy region loads for Report Cards 2010–2013 refer Appendix F–I, Table 37 through Table 40.

4.1 Hydrology

4.1.1 Calibration performance

Model performance was assessed for the 86 Fitzroy gauges used in the calibration process. Performance was assessed for the calibration period 1970–2010. The results for the three performance criteria: daily NSE (>0.5), monthly NSE (>0.8) and total modelled volume difference ± 20% of observed volume are listed (selected sites presented in Table 15). Thirty three of the 86 gauges met all three criteria, 27 gauges met two of the criteria, 17 gauges met only one of the criteria and nine gauges satisfied none of the criteria. The 'traffic light' colour scheme shows those gauges that met all three criteria as green, gauges that met two of three criteria as orange, and the gauges that met only one criterion are shaded red. The total volume difference is also represented spatially, with grey areas indicating ungauged catchments.

Monthly NSE values >0.8 suggest a good result for modelling runoff for catchment studies (Chiew & McMahon 1993). Fifty seven gauges or 66% of gauges had monthly NSE values > 0.8. 74% of gauges met the volumetric difference criteria. Most modelled gauge data (64%) under predicted the total runoff volume. Whilst the statistics indicate the overall fit was sufficient for average annual and annual flow predictions, close inspection of the hydrograph shape and timing suggests that the daily simulated runoff is often poorly matched to observed flows.

Table 15 Results of Fitzroy region hydrology calibration for key locations (1970–2010)

Site Name	Gauge	Area km^2	Years of record	Daily NS	Monthly NS	% Vol.
Basin Sites						
Fitzroy River at The Gap	130005A	135,757	39	0.43	0.89	-2%
Waterpark Creek at Byfield	129001A	1,288	39	0.63	0.88	-27%
Calliope River at Castlehope	132001A	212	39	0.75	0.93	-25%
Boyne River at Riverbend	133001B	2,258	19	0.66	0.97	-17%
Sub-basin						
Isaac River	130401A	19,719	39	0.34	0.94	-11%
<3000 km^2						
Nogoa River	130215A	252	33	0.16	0.81	10%
Nogoa River	130214A	401	16	0.44	0.8	-17%
Nogoa River	130207A	409	39	0.46	0.87	-10%
Nogoa River	130211B	438	12	0.54	0.94	11%
Nogoa River	130218A	563	9	0.13	0.71	-9%
Nogoa River	130217A	735	8	-0.35	0.6	-9%
Nogoa River	130208A	758	35	0.58	0.94	0%
Nogoa River	130212A	1,108	16	0.61	0.92	-17%
Nogoa River	130213A	1,498	16	-0.3	0.71	3%
Comet River	130509A	351	24	0.54	0.81	-12%
Comet River	130505A	356	17	-0.38	0.79	-18%
Comet River	130508A	541	16	0.62	0.86	2%
Comet River	130503A	561	22	0.09	0.9	18%
Comet River	130507A	776	21	-0.19	0.4	-8%
Isaac River	130407A	258	39	0.37	0.92	-1%
Isaac River	130409A	344	18	0.49	0.84	-9%
Isaac River	130415A	388	16	0.44	0.71	2%
Isaac River	130402A	551	18	0.18	0.72	-32%
Isaac River	130413A	757	38	0.77	0.97	-2%
Isaac River	130412A	1,023	17	0.22	0.74	-11%
Isaac River	130406A	1,044	39	0.81	0.96	-6%
Isaac River	130414A	1,214	26	0.57	0.79	-23%
Isaac River	130403A	1,291	39	0.71	0.84	-39%
Isaac River	130411A	1,306	17	0.21	0.89	-5%
Mackenzie River	130108B	776	39	0.2	0.85	-32%
Mackenzie River	130107A	2,126	17	0.62	0.96	1%
Dawson River	130336A	233	37	0.19	0.47	-32%
Dawson River	130319A	300	39	0.61	0.73	-30%
Dawson River	130348A	369	34	0.31	0.42	-52%
Dawson River	130321A	373	35	0.11	0.79	-33%
Dawson River	130339A	407	16	0.54	0.85	-9%
Dawson River	130347A	415	16	0.64	0.79	-71%
Dawson River	130340A	459	6	0.69	0.98	-3%

Dawson River	130335A	472	38	0.72	0.87	-21%
Dawson River	130315C	547	32	0.36	0.66	-5%
Dawson River	130349A	593	33	0.76	0.87	-25%
Dawson River	130318A	683	14	0.35	0.54	-30%
Dawson River	130363A	999	10	0.55	0.94	12%
Dawson River	130341A	1,056	20	0.25	0.62	-24%
Dawson River	130375A	1,597	3	0.43	0.99	11%
Dawson River	130344A	1,678	35	0.41	0.76	-4%
Dawson River	130316A	2,473	39	0.32	0.73	-10%
Dawson River	130313A	2,660	39	0.35	0.51	-19%
Dawson River	130342A	2,871	16	0.62	0.96	-7%
Fitzroy River	130004A	389	39	0.41	0.77	22%
Fitzroy River	130006A	436	38	0.33	0.74	-40%
Fitzroy River	130008A	503	22	0.67	0.85	-19%

In Figure 10 the volumetric difference between measured and modelled flows is plotted against the total gauge discharge. There is a clear pattern that the gauges with a smaller total gauge discharge have a greater volumetric flow difference, while those gauges with a large gauge discharge have the smallest error between measured and modelled flows. The total volume difference is also represented spatially (Figure 9). It is also demonstrated in both Figure 10 and Figure 11 that the model is under predicting flows, compared to the measured flows. This is evident in the negative volumetric differences in Figure 10, and the number of points below the 1:1 line in Figure 11. Four flow exceedance curves are provided as examples of modelled vs measured flow in Appendix D, Figure 26 to Figure 29.

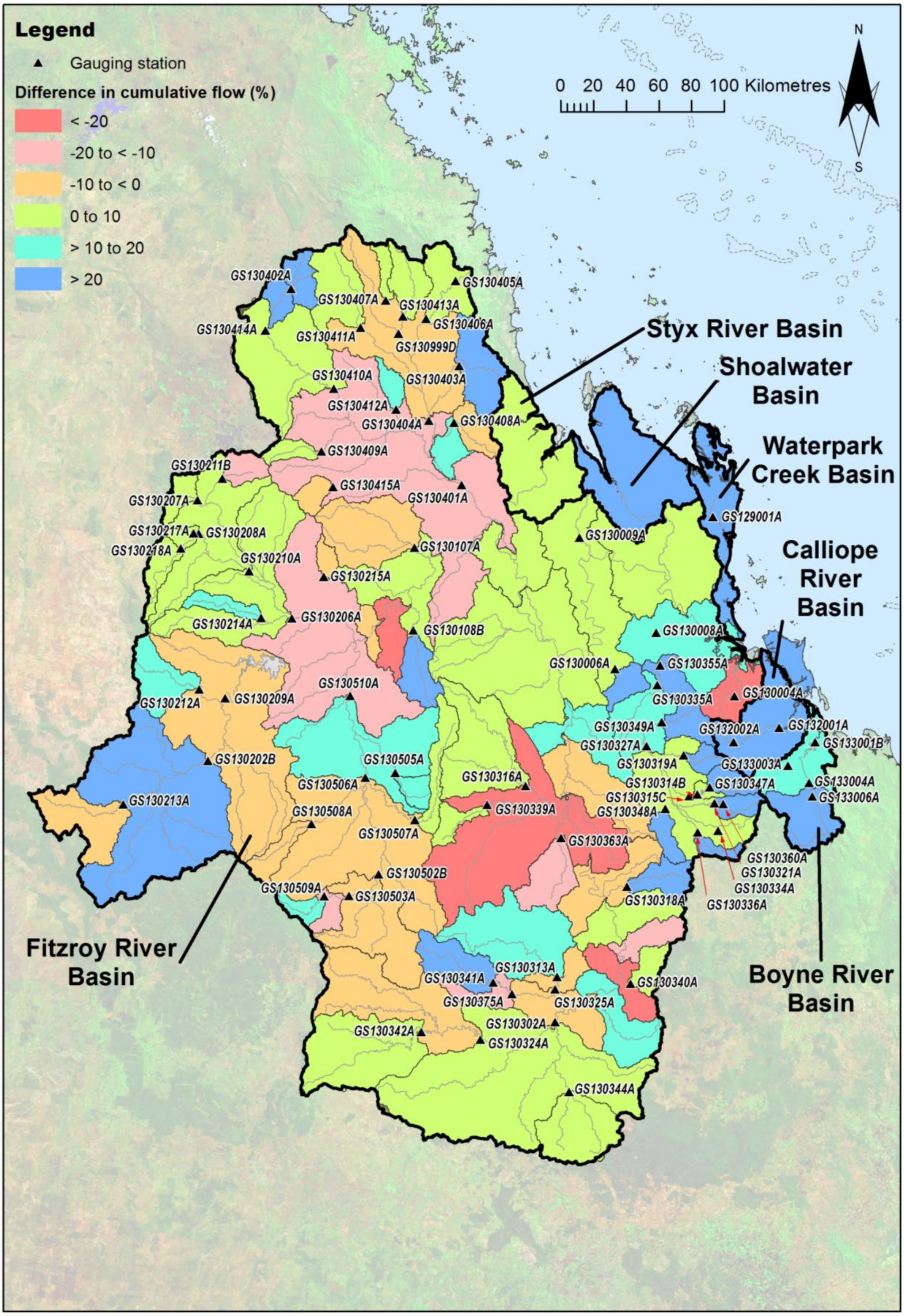

Figure 9 Percentage volume difference for Fitzroy calibration regions

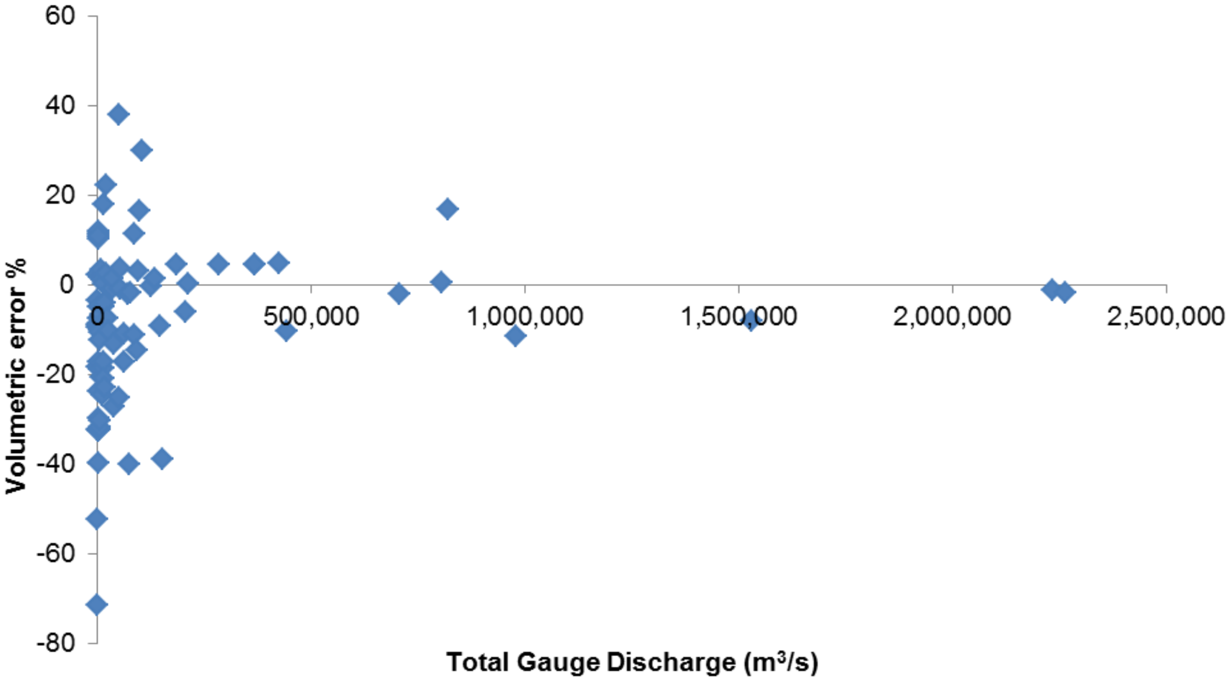

Figure 10 Change in volumetric error between measured and modelled flows against total gauge discharge

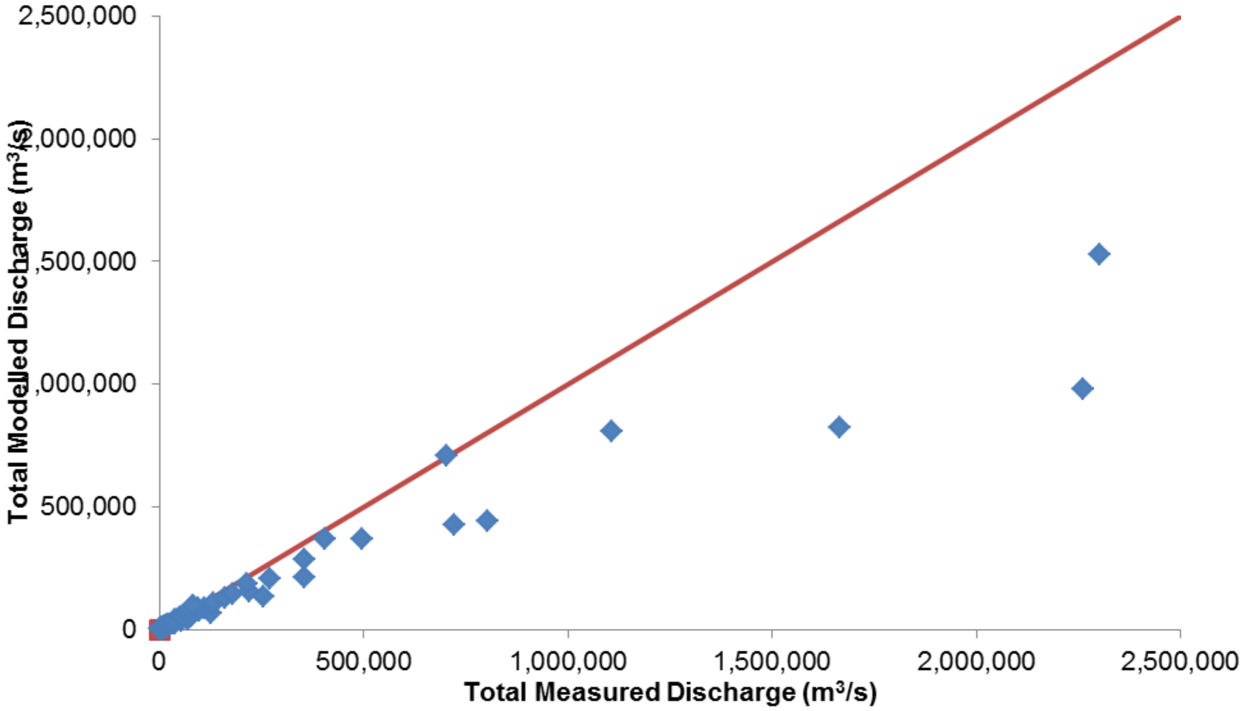

Figure 11 Modelled versus measured flows in the Fitzroy NRM region

4.1.2 Regional discharge comparison

The modelled average annual flow (1986–2009) for the Fitzroy region was 5,870,000 ML/yr, which is 9% of the total modelled GBR average annual flow (Figure 12). The Wet Tropics has the largest average annual flow for the modelled period compared to the five other GBR regions. The next largest flow comes from the Cape York region (18,000,000 ML/yr), which is roughly double the area of the Wet Tropics region.

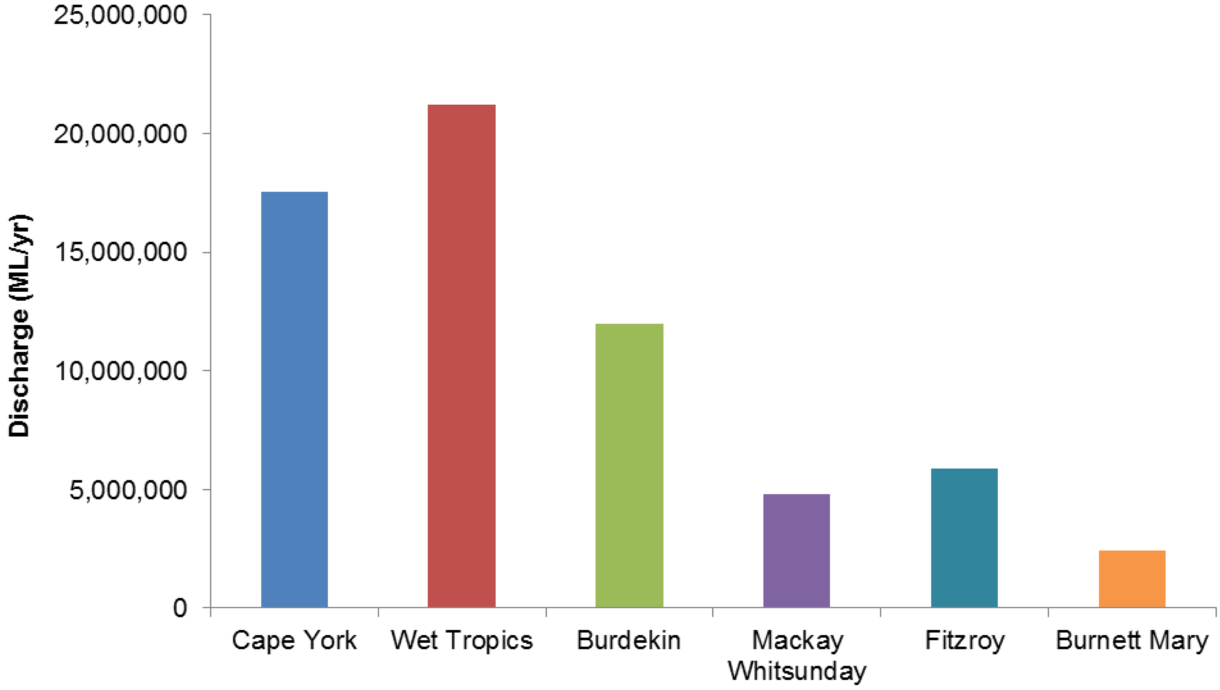

Figure 12 Average annual modelled discharge for GBR regions (1986-2009)

Within the Fitzroy region the Fitzroy catchment had the highest average annual flow (4,659, 000 ML/yr), followed by the Waterpark Creek (392,000 ML/yr) then Shoalwater (387,000 ML/yr) catchment (Figure 13).

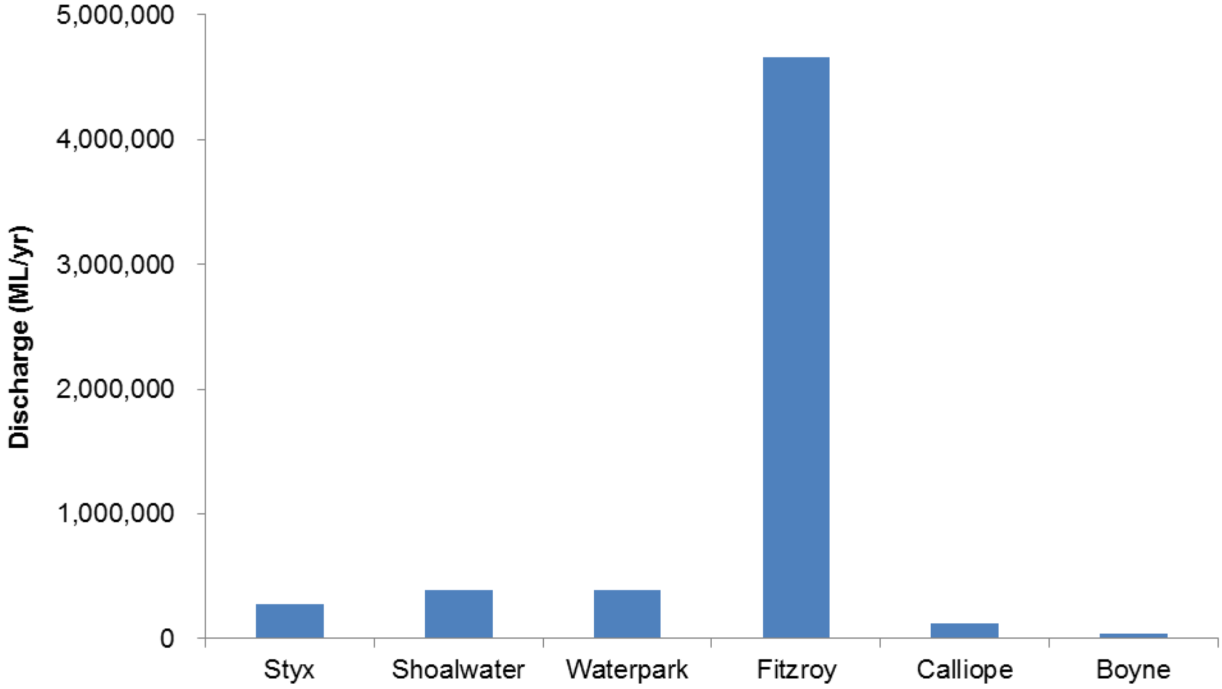

Figure 13 Average annual modelled discharge for the Fitzroy basins (1986–2009)

4.2 Modelled loads

It is estimated that 8,545 kt/yr of fine sediment is exported from the six GBR NRM regions, of this 2,931 kt/yr is predevelopment load, and therefore 5,614 kt/yr is the anthropogenic baseline load across the GBR. In Table 16 the total constituent baseline loads are presented for all regions, while in Table 17 this data is presented as a per cent contribution.

The Burdekin region had the greatest constituent total loads for TSS, PN, TP, DIP, and PP. The Burdekin is a large contributor due to the size of the region, the large flows, and the combination of erosive soil types, gullies, episodic rainfall and steep dissected terrain. Grazing is the predominant land use in the Burdekin. With regard to PSII herbicides, the Wet Tropics has the greatest load (8,596 kg/yr) which is a function of land use, especially the large areas of sugarcane and other irrigated crops within the region, such as bananas, as well as the close proximity of these land uses to the coast. The Wet Tropics supplies 51.4% of the total PSII export from the GBR catchments, and is considerably higher than the second greatest contributor, the Mackay Whitsunday, with 3,944 kg/yr (23.6% of GBR total).

Table 16 Total constituent loads for the six GBR contributing regions

NRM region	Area (km^2)	TSS (kt/yr)	TN (t/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TP (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	PSII (kg/yr)
Cape York	42,988	429	5,173	492	3,652	1,030	531	98	195	238	3
Wet Tropics	21,722	1,219	12,151	4,437	3,870	3,844	1,656	228	130	1,297	8,596
Burdekin	140,671	3,976	10,110	2,647	3,185	4,278	2,184	341	153	1,690	2,091
Mackay Whitsunday	8,992	511	2,819	1,129	950	739	439	132	35	271	3,944
Fitzroy	155,740	1,948	4,244	1,272	1,790	1,181	1,093	278	56	759	588
Burnett Mary	53,021	462	2,202	554	873	775	392	78	35	278	1,528
GBR total	**423,134**	**8,545**	**36,699**	**10,532**	**14,320**	**11,847**	**6,294**	**1,155**	**606**	**4,532**	**16,740**

Of the six GBR regions, the Fitzroy region had the second highest total baseline load for fine sediment, after the Burdekin. In contrast, PSII pesticides were the second lowest, while DIN fell between the Wet Tropics and Cape York NRM regions. In percentage load terms the Fitzroy region contributed 23% of the GBR baseline fine sediment load (1,948 kt/yr). For DIN and PSII pesticides GBR baseline loads, the Fitzroy region contributes 13% (1,272 t/yr) and 4% (588 kg/yr) respectively.

Table 17 Area, flow and regional contribution as a per cent of the GBR total baseline loads for all constituents

NRM region	Area	Flow	TSS	TN	DIN	DON	PN	TP	DIP	DOP	PP	PSII
	% of GBR total											
Cape York	10.2	27.3	5.0	14.1	4.7	25.5	8.7	8.4	8.5	32.3	5.2	0.0
Wet Tropics	5.1	33.1	14.3	33.1	42.1	27.0	32.4	26.3	19.8	21.5	28.6	51.4
Burdekin	33.2	18.7	46.5	27.5	25.1	22.2	36.1	34.7	29.5	25.3	37.3	12.5
Mackay Whitsunday	2.1	8.0	6.0	7.7	10.7	6.6	6.2	7.0	11.4	5.8	6.0	23.6
Fitzroy	36.8	9.1	22.8	11.6	12.1	12.5	10.0	17.4	24.0	9.3	16.7	3.5
Burnett Mary	12.5	3.8	5.4	6.0	5.3	6.1	6.5	6.2	6.8	5.8	6.1	9.1
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Within the Fitzroy region, the Fitzroy River catchment was the greatest contributor for all constituents (Table 18).

Table 18 Contribution of major basins to regional total baseline load for the Fitzroy NRM Region

	TSS (kt/yr)	TN (t/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TP (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	PSII (kg/yr)
Styx	68	154	38	56	60	38	8	1	29	22
Shoalwater	53	137	45	66	25	21	9	2	10	14
Water Park	32	150	54	79	18	19	10	2	6	10
Fitzroy	1,740	3,688	1,106	1,548	1,035	983	245	50	687	521
Calliope	44	90	23	33	34	27	4	1	21	10
Boyne	11	24	6	9	10	6	1	0	4	2
TOTAL	**1,948**	**4,244**	**1,272**	**1,790**	**1,181**	**1,093**	**278**	**56**	**759**	**579**

4.2.1 Anthropogenic baseline and predevelopment loads

The anthropogenic baseline load is calculated by subtracting the predevelopment load from the total baseline load. The TSS anthropogenic baseline load for the Fitzroy NRM region was 1,407 kt or 72% of the total baseline load with the remaining 28% attributed to the predevelopment load. For TSS loads, all catchments except Waterpark Creek were dominated (>50%) by the anthropogenic baseline load compared to the total baseline load (Figure 14). The Fitzroy basin has the greatest increase factor from predevelopment loads (four-times increase), followed closely by the Boyne (3.7x increase) and Calliope (2.8x increase). Water Park Creek had only a 1.2x increase in TSS load.

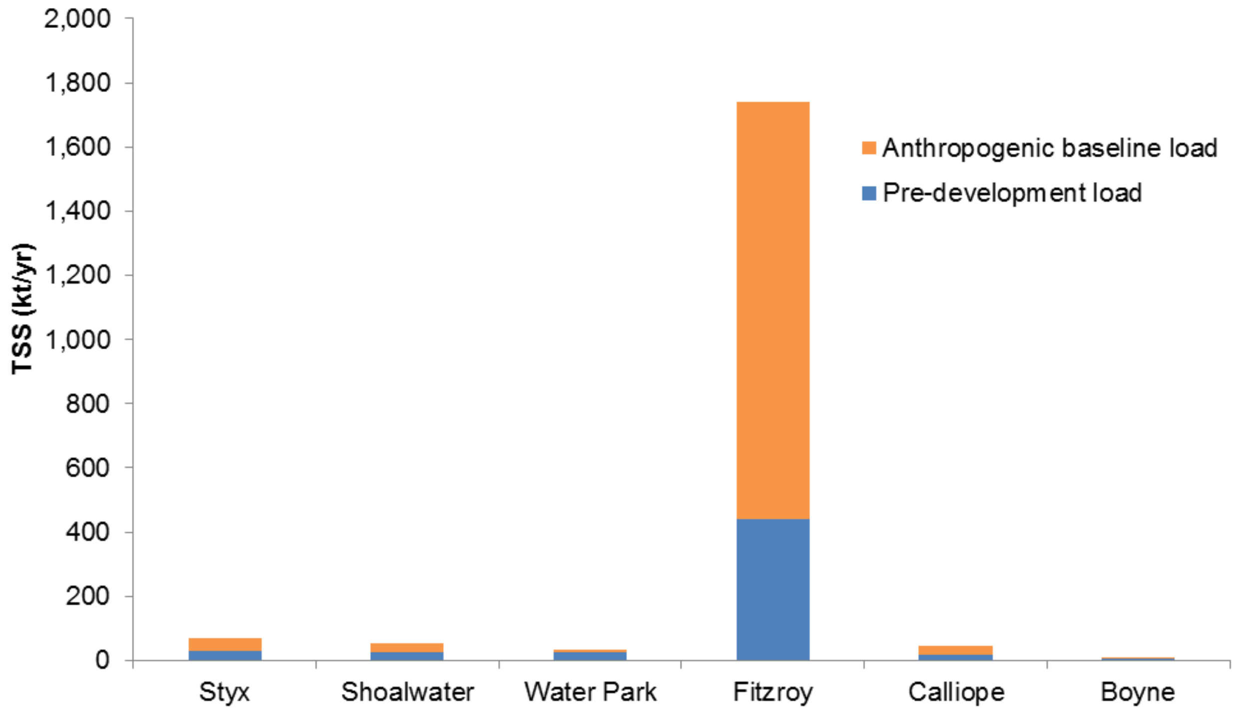

Figure 14 TSS (kt/yr) loads for Fitzroy basins, highlighting the predevelopment and anthropogenic baseline contributions

The total baseline total nitrogen (TN) load exported from the Fitzroy region is estimated at 4,244 t/yr, of which 3,320 t/yr or 76% is predevelopment load. DON is the largest contributor to the TN load (42%) with DIN and PN having similar contributions (30% and 28% respectively). The predevelopment and anthropogenic baseline load for TN for each catchment in the Fitzroy is presented in Figure 15. TN is calculated to have increased 1.3 times from predevelopment conditions for the Fitzroy NRM region. The total baseline total phosphorus (TP) load exported from the Fitzroy region is an estimated 1,093 t/yr, of which 612 t/yr or 56% is estimated to be the baseline load. Unlike N species, PP contributes 69% of the total load, followed by DIP (25%) and a minimal contribution from DOP (5%). The predevelopment and anthropogenic baseline load for TP for each catchment in the Fitzroy is presented in Figure 16. TP is calculated to have increased by 2.3 times from predevelopment conditions for the Fitzroy NRM region.

PSII herbicides total 588 kg/yr in the Fitzroy NRM region, with 90% of these generated in the Fitzroy catchment. Tebuthiuron is modelled for the Fitzroy NRM region as part of the PSII herbicide load. Approximately 310 kg/yr of tebuthiuron is generated, again with 84% generated from the Fitzroy catchment alone.

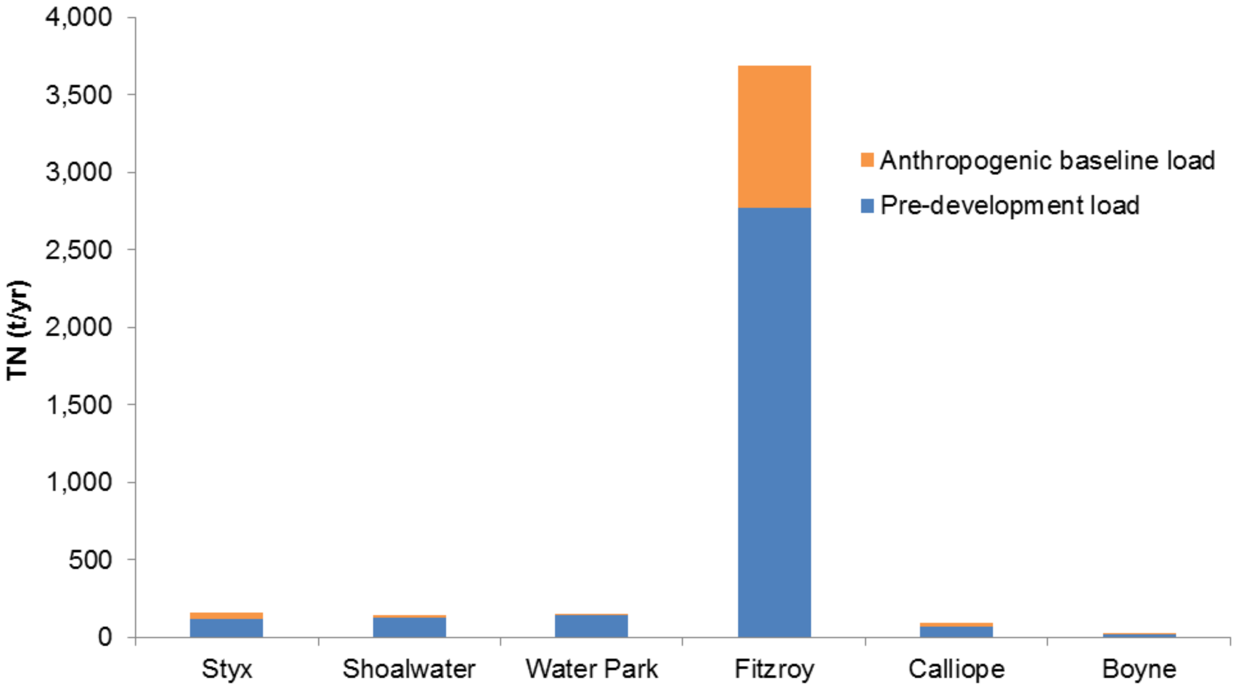

Figure 15 TN export (t/yr) for the Fitzroy basins; highlighting the predevelopment and anthropogenic baseline contributions

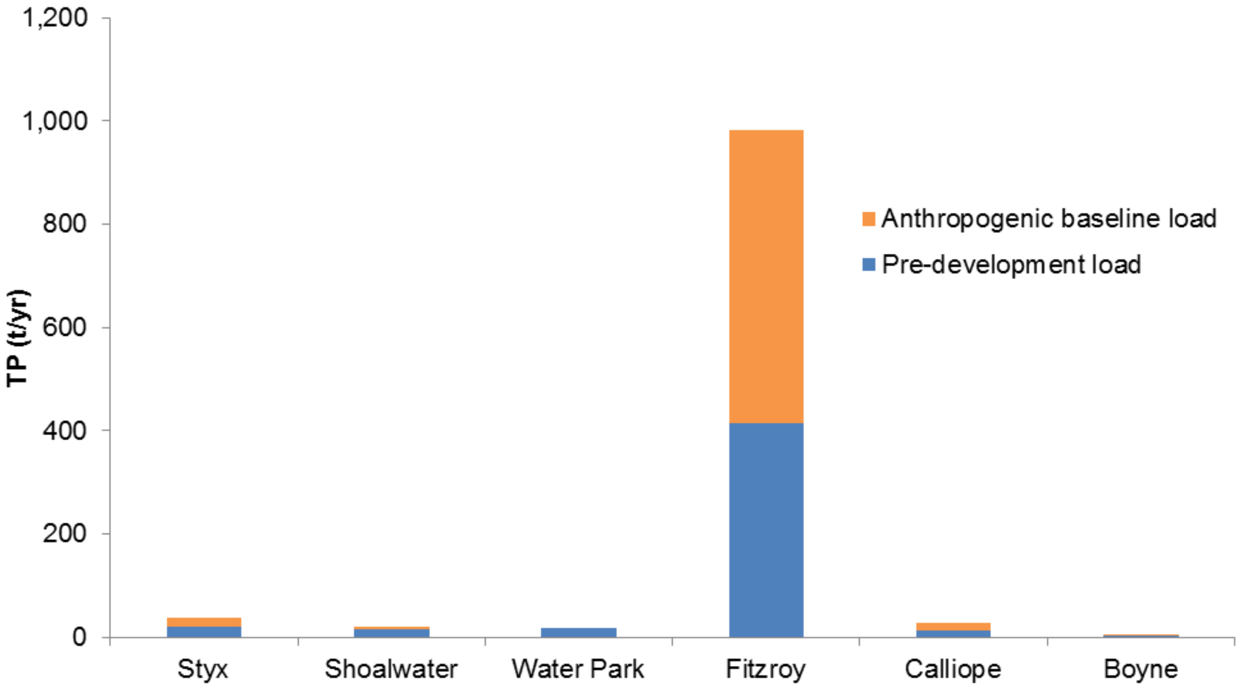

Figure 16 TP export (t/yr) for the Fitzroy basins; highlighting the predevelopment and anthropogenic baseline contributions

4.3 Constituent load validation

There are a range of sources against which the Fitzroy Source Catchments modelling can be compared, or validated. The three key sources are the previous best estimates from Kroon et al. (2012) (LRE and SedNet), the long-term loads report (1986–2009) using the FRCE method (Joo et al. 2014) and the GBRCLMP 2006–2010 monitoring program established by the Queensland State Government (Joo et al. 2012, Turner et al. 2012).

4.3.1 Previous Estimates – Kroon et al. (2012)

Best previous estimates of catchment loads for GBR catchments have been tabulated by Kroon et al. 2012). The fine sediment estimate for the Fitzroy subcatchment was based on SedNet modelling by Dougall et al (2009), while the estimates for the remaining subcatchments were based on McKergow et al (2005a) SedNet modelling. All of the loads calculated for Report Card 2013 are lower than the estimated loads presented in Kroon et al. (2012) for the Fitzroy NRM region (Figure 17). The comparison between these estimated loads for the Fitzroy basin are presented in Figure 18. Major differences for fine sediment occur in the Styx, Calliope and Fitzroy subcatchments where the Kroon et al. (2012) load is more than double the Report Card 2013 load. Similarly for PSII herbicides, the load for the Fitzroy basin is over four times higher in Kroon et al. (2012). This is common across the GBR catchments where PSII herbicide loads have been calculated, and is not a product of the Fitzroy Report Card 2013 model as such, but rather the availability of more comprehensive monitoring data and a greater understanding of PSII herbicide movement and breakdown in a riverine system to calibrate/validate the model.

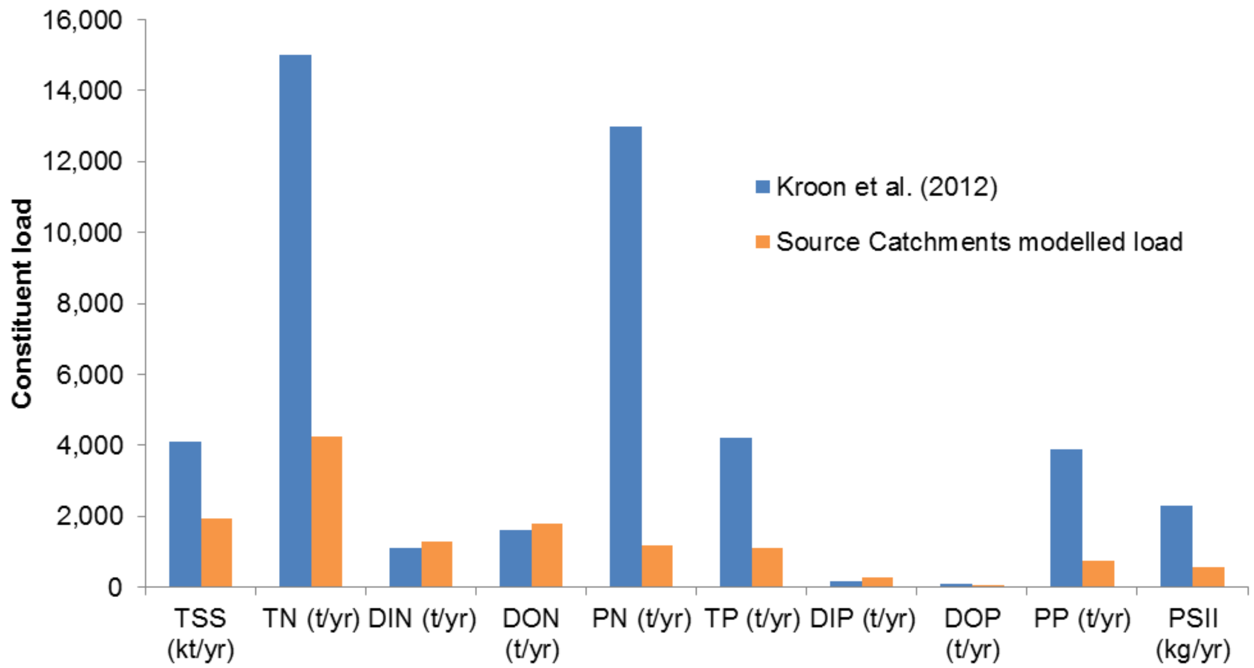

Figure 17 Kroon et al. (2012) and Source Catchments baseline loads for all constituents in the Fitzroy NRM region

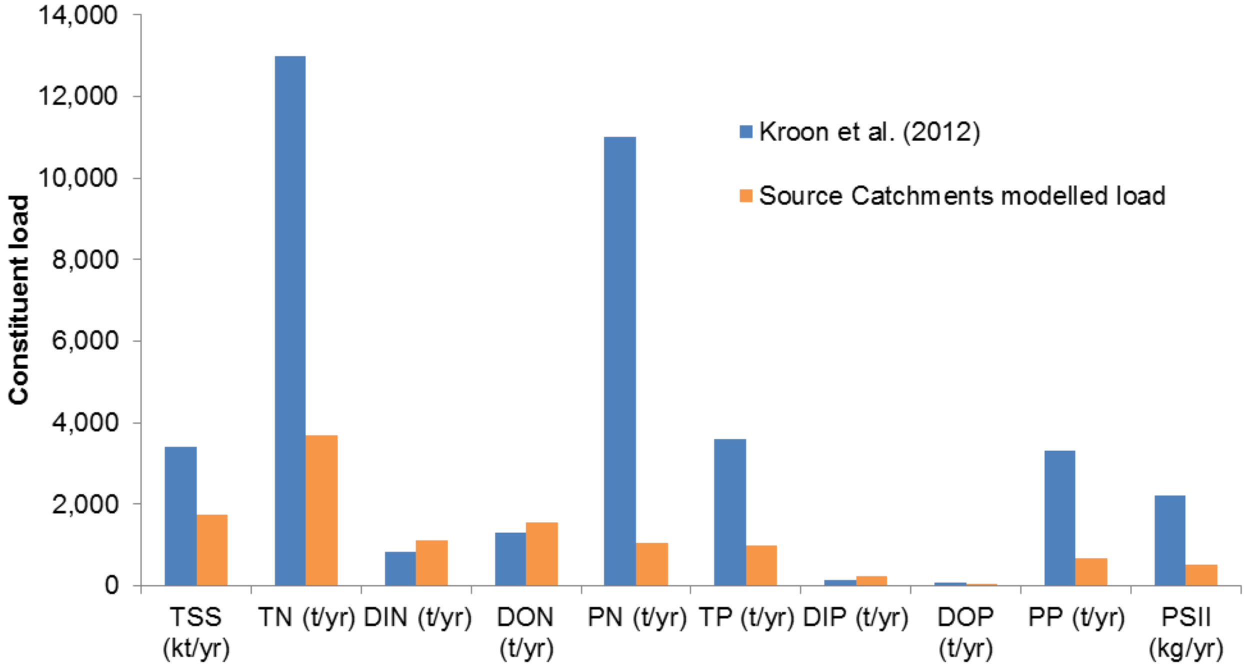

Figure 18 Comparison between Kroon et al. (2012) and Source Catchments baseline loads for the Fitzroy basin

4.3.2 Catchment load estimates (1986–2009)

The Source Catchments and FRCE annual loads for all constituents are presented in Table 19. The fine sediment load, DIN and DON loads match well with the FRCE estimated loads. However, particulate nutrients (both N and P) are significantly lower than the FRCE estimated load, and this causes the TN and TP loads to be at the low end of the likely FRCE estimated load range (Figure 19). In Figure 19 the FRCE likely load range, FRCE estimated load and the Source Catchments load are presented for each constituent.

Table 19 FRCE mean and Source Catchment mean modelled constituent loads for the Fitzroy EOS gauging station (1986–2009)

	TSS (kt/yr)	TN (t/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TP (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)
FRCE load estimate	1,749	4,371	954	1,597	1,927	1,714	341	68	1,131
Source Catchments load	1,698	3,596	1,079	1,508	1,010	958	240	49	669
% difference	-3	-22	12	-6	-91	-79	-42	-37	-69

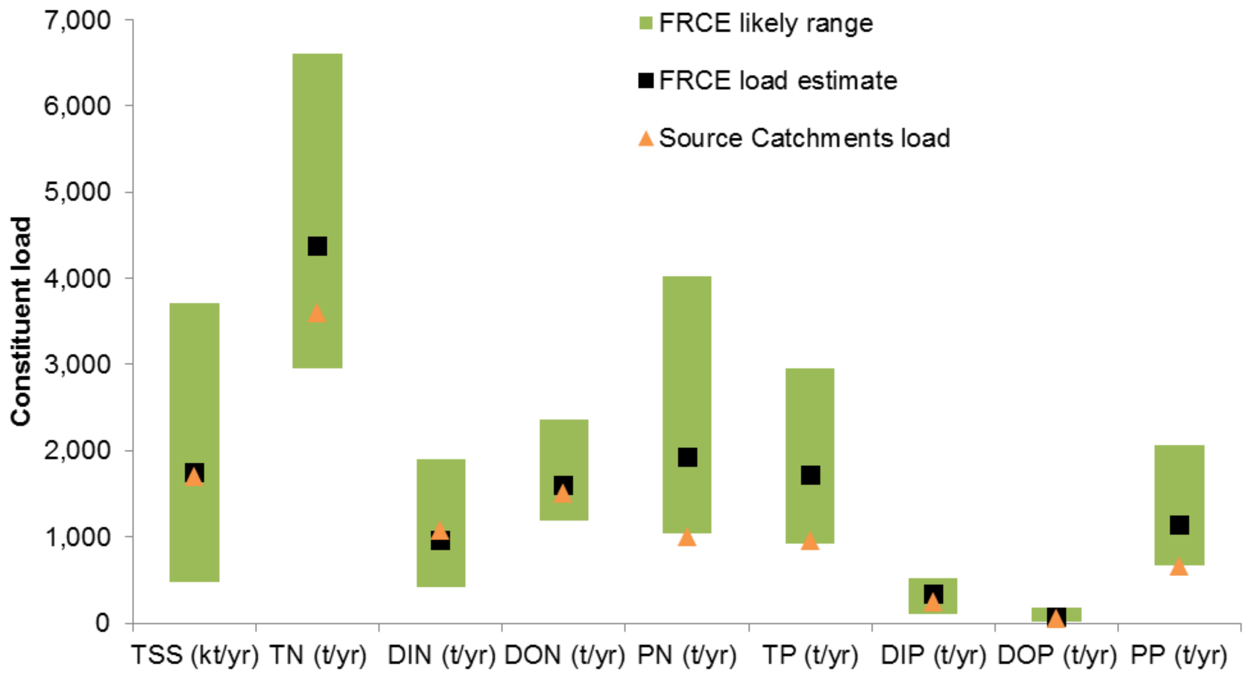

Figure 19 Source Catchments modelled average annual constituent loads, compared to the FRCE average annual constituent load and the FRCE load likely range for 1986–2009 at the Fitzroy EOS gauge

Further inspection of fine sediment annual loads suggests that the model is under-predicting the very large events, and over-predicting the smaller events. This is a result of the model hydrology not matching high flows well, and this will be addressed in the next round of modelling where the hydrology will be recalibrated using the Sacramento model, and greater emphasis placed on matching high flows. However, the long-term estimates for the model period show good agreement with FRCE load estimates.

The modelled loads were also assessed at the monthly time-step using performance statistics based on three evaluation guidelines in Moriasi et al. (2007) (Table 20). TSS and TP were 'unsatisfactory' for NSE and RSR however the PBIAS were 'very good' for TSS and TP and 'satisfactory' for TP. Hence the model adequate for the long term estimates but will require further refinement to improve load estimates at a shorter time step.

Table 20 Performance statistics for TSS, TN and TP load comparisons to FRCE estimates based on three evaluation guidelines in Moriasi et al. (2007) at the monthly time-step

Performance rating	NSE		RSR		PBIAS	
	Value	Result	Value	Result	Value	Result
TSS	0.05	Unsatisfactory	0.97	Unsatisfactory	2.91	Very good
TN	0.61	Satisfactory	0.63	Satisfactory	17.71	Very good
TP	0.25	Unsatisfactory	0.87	Unsatisfactory	44.09	Satisfactory

4.3.3 Catchment Load Monitoring – 2006–2009

The Fitzroy mean GBRI5 loads (averaged over three years, 2006–2009) and the modelled load for the same period at the Fitzroy River at Rockhampton gauging station (1300000) are shown in Figure 20. Modelled flow is over-predicting gauged flow by 20% for the period. However, modelled constituent loads for fine sediment, TN, TP and DIP are all less than the GBRCLMP estimated loads. In contrast, the DIN load is greater than the GBRCLMP estimate.

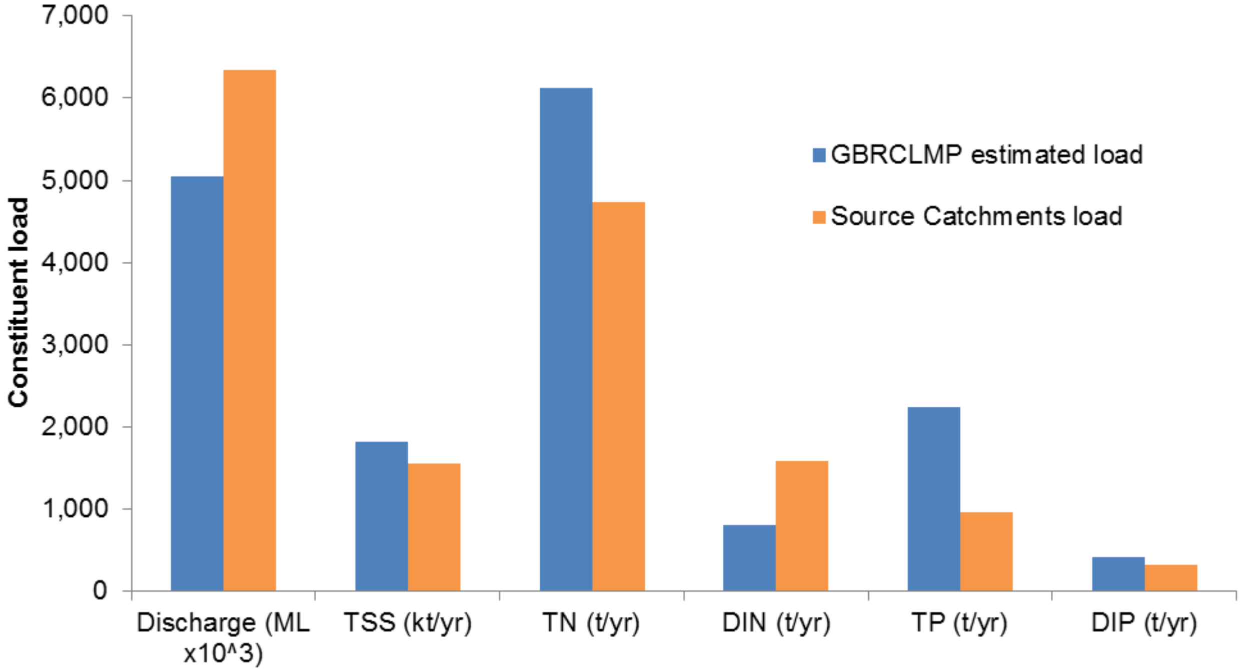

Figure 20 Comparison between Source Catchments modelled loads and GBRCLMP estimated loads for the period 2006–2009 for the Fitzroy River at Rockhampton (gauging station 1300000)

4.4 Contribution by land use

Grazing (open and closed) are the greatest contributors of TSS load to export by land use (Figure 21) comprising approximately 60% of the total TSS exported. Streambank erosion was the second highest at 23% with cropping less than 10% of the total fine sediment exported. Cropping (44%) and Grazing (54%) are the two major sources of PSII herbicides exported. On a per unit area basis however, cropping is the highest followed by grazing and horticulture respectively (Table 21).The complete constituent loads summary for Report Card 2013 are provided in Appendix F.

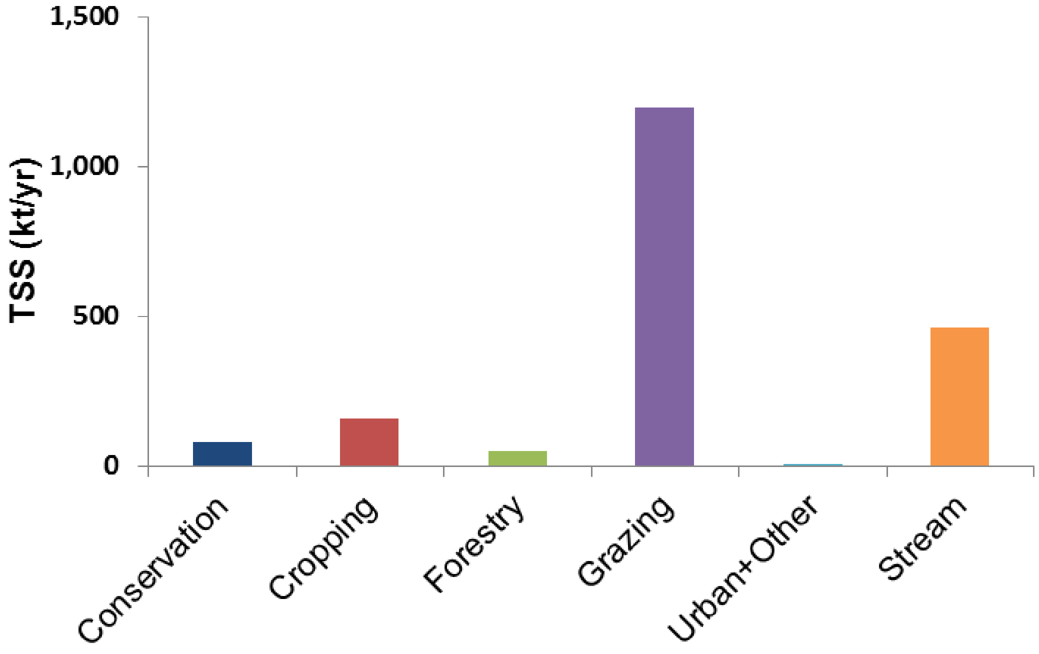

Figure 21 Contribution to total baseline fine sediment export by land use for the Fitzroy NRM region

Table 21 Fine sediment yield to total export per landuse

Land use	t/ha/yr
Conservation	0.07
Cropping	0.17
Forestry	0.05
Grazing	0.10
Horticulture	0.09
Urban	0.05

4.5 Constituent sources and sinks

Of the fine sediment generated for the Fitzroy Region, 43% is exported, with the remaining 53% lost as either floodplain deposition (68%), storage deposition (12%) or in extractions (20%) (Table 22). In all of the GBR models, the in-stream deposition functionality was not enabled as there were some concerns with the algorithm behind it. With an improved understanding of the process, and a better mathematical representation, in-stream deposition will be enabled in future model runs as it has been reported as an important process in many regions. For TN, 72% of the load generated is exported; while for TP 56% of the load generated is exported, with the majority of losses occurring via floodplain deposition and extractions. Of the PSII herbicide load generated, only 31% of the supply is exported, with most of the PSII herbicide load being lost to in-stream decay.

The greatest sources of fine sediment in the Fitzroy are from hillslope and gully sources, the former contributing 35% of the total baseline load, and the latter 45%. Streambank erosion supplies 20% of the total fine sediment load. In Table 22 the sources, sinks and resultant export of each constituent is presented. To estimate the total hillslope and gully contributions for TSS and particulate loads, the EMC derived source was split by taking the percentage of hillslope and gully sources estimated for the remainder of the region and applying the same proportion to the EMC derived source. The EMC derived source for dissolved nutrients was added to diffuse dissolved source load to simplify the results.

Table 22 Fitzroy constituent sources and sinks*

	TSS (kt/yr)	TP (t/yr)	PP (t/yr)	DIP (t/yr)	DOP (t/yr)	TN (t/yr)	PN (t/yr)	DIN (t/yr)	DON (t/yr)	PSII (kg/yr)
SOURCE	**4,202**	**1,968**	**1,596**	**310**	**63**	**5,950**	**2,504**	**1,428**	**2,018**	**1,920**
Hillslope	1,431	576	576	0	0	947	947	0	0	0
Gully	1,933	642	642	0	0	964	964	0	0	0
Streambank	837	378	378	0	0	593	593	0	0	0
Diffuse Dissolved	0	333	0	279	54	3,377	0	1,374	2,004	1,920
Point Source	0	39	0	31	9	69	0	55	15	0
SINK	**2,251**	**857**	**819**	**32**	**6**	**1,657**	**1,276**	**155**	**226**	**1,331**
Reservoir Deposition	255	123	123	0	0	198	198	0	0	0
Flood Plain Deposition	1,522	515	515	0	0	828	828	0	0	0
Extraction	463	207	177	25	5	546	244	123	179	114
Stream Decay	0	0	0	0	0	0	0	0	0	36.1
Residual Link Storage	11	11	4	6	1	85	6	32	47	1,181
EXPORT	**1,952**	**1,112**	**777**	**278**	**56**	**4,293**	**1,228**	**1,273**	**1,792**	**589**

*Note, this table includes the load generated by the Curtis Island subcatchment which has been removed for other Report Card 2013 reporting, and therefore the export loads are marginally higher than the reported loads.

4.6 Progress towards Reef Plan 2009 targets

Overall there has been ‘good’ (fine sediment) to ‘very poor’ (total nitrogen) progress (Table 10) towards meeting the reef water quality targets over the period of Reef Plan 2009 (2008-2013) (Figure 22). This period covers Report Cards 2010–2013, noting that each report card is cumulative. The modelling results suggest there was an 11% reduction in average annual suspended sediment load leaving all GBR catchments from the adoption of improved land management practises with the greatest reduction from grazing areas. In the case of total nitrogen, the average annual load was reduced by 10%, with the greatest reduction from the Burdekin and

Wet Tropics NRM regions. The average annual PSII herbicide load was reduced by 28% (moderate progress), with 70% of the reduction from the Wet Tropics and Mackay-Whitsunday regions. Improved herbicide management practices in the cane industry contributed to the large reduction.

In the Fitzroy NRM region there was a 4.2% reduction in fine sediment load, a 6% reduction in TP (due to a reduction in particulate P) and a 3% reduction in TN. The PSII herbicide load has decreased by 5.1%. The results suggest poor to very poor progress for all constituents where data was provided for Report Cards 2010–2013(Figure 23). Management practice data in the Fitzroy was available for grazing and grains land uses. As there is no functionality in the HowLeaky model to represent DIN, there are no reductions in the DIN load reported across the Report Card periods.

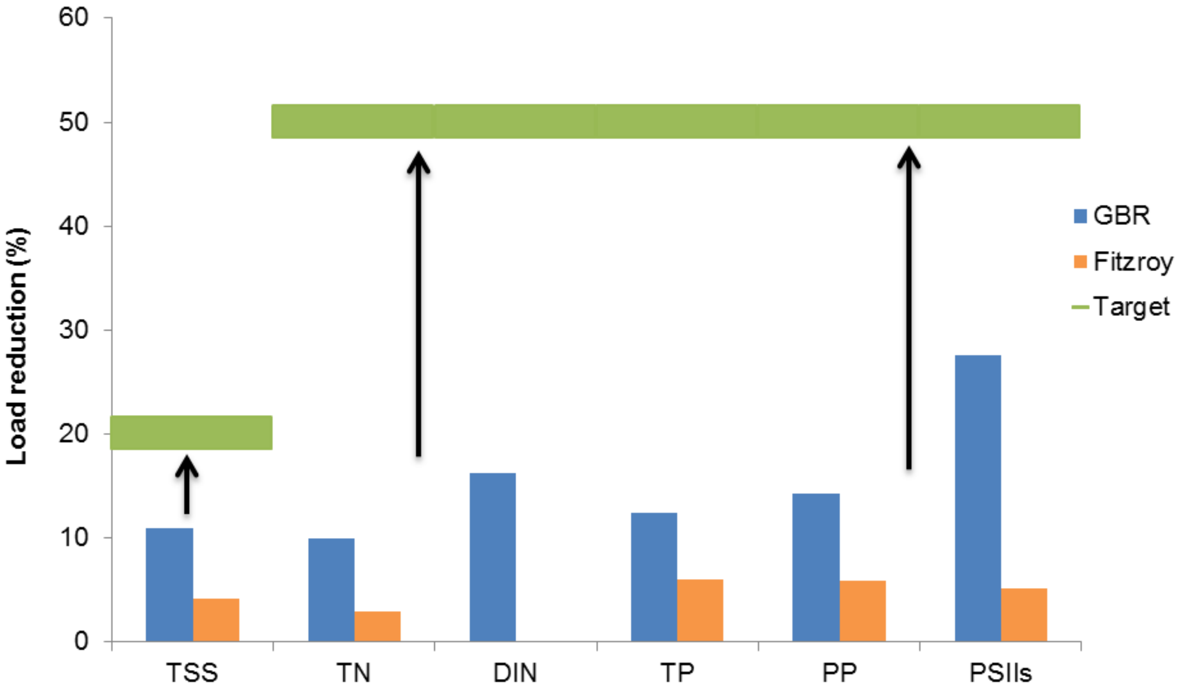

Figure 22 Fitzroy and GBR per cent reduction in key constituent loads from Report Card 2013 management practice changes and load reduction targets

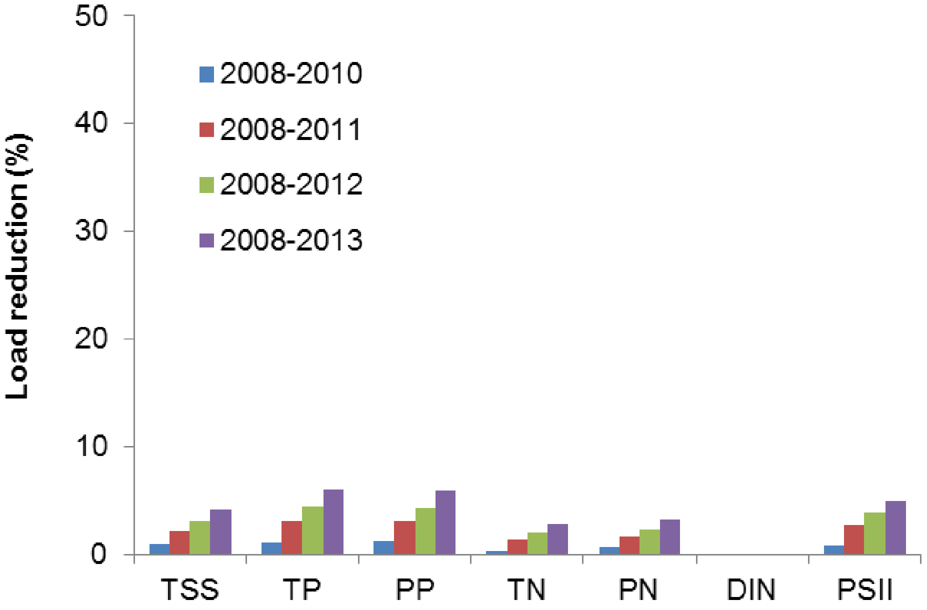

Figure 23 Fitzroy constituent reductions (%) for individual reporting periods

5 Discussion

Catchment modelling has quantified the effects of improved agricultural land management practices adoption on water quality, primarily as a result of government investment. The results are assessed against the Reef Plan water quality targets and the associated focus on end-of-system (EOS) water quality. The use of a consistent modelling platform, Source Catchments, and methodology across all GBR regions, enables the direct comparison of outputs from each region, as well as from each scenario (current total, anthropogenic baseline, predevelopment and management change loads). This study is an updated estimate of the pollutant loads from those in the first Report Card (Kroon et al. 2010) due to use of the most recent point and spatial data sets. It is the first GBR-wide modelling since 2005 that separates the predevelopment or natural component from current total loads (McKergow et al. 2005a, McKergow et al. 2005b). One of the main improvements since the first Report Card (Kroon et al. 2010) was the use of the same modelling platform across the GBR and the inclusion of coastal catchments below the end gauging station to enable the prediction of a total exported load to the GBR. Previous estimates were either not able to model those coastal subcatchments, or used a scaling approach to account for runoff and loads generated from these areas (Wallace et al. 2012; Kroon et al. 2010).

Other improvements included the increase in temporal and spatial resolution of input datasets and the ability to apply a specific model to each functional unit within the Source Catchments modelling framework. A daily time-step model, rather than the traditional long-term average annual model, has allowed the investigation of flows and constituent loads at a range of time-steps. In addition, the availability of event monitoring data collected at a high temporal frequency has enabled model validation down to an event time-step in some instances. The ability to 'plug in' the most appropriate paddock scale model outputs and combine this with models simulating landscape processes such as gully and bank erosion and floodplain deposition into a single framework was invaluable. Other advantages of the current modelling approach include a high level of transparency (that is, repeatability), and high flexibility in analysing the model outputs at a range of scales and time-steps. The high level of validation undertaken in this study was not possible in previous modelling studies due to the availability of data (or lack thereof).

5.1 Hydrology

An improved spatial and temporal representation of hydrology has been a critical enhancement of the catchment modelling undertaken across the GBR. Overall the hydrology calibration for the Fitzroy region was reasonably good for the three performance criteria: daily Nash Sutcliffe Coefficient of Efficiency (NSE) (>0.5), monthly NSE (>0.8) and total modelled volume difference ± 20% of observed volume. Of the 86 gauges used in the Fitzroy 33 met all three criteria, 27 gauges met two of the criteria, 17 gauges met one, and nine satisfied none of the criteria.

Moriasi et al (2007) in a global review of hydrology calibration rated NSE values >0.75 as "very good" performance. In the Fitzroy 66% of stream gauges had monthly NSE values >0.8, with 74% of gauges also meeting the volumetric difference criteria. At the Fitzroy basin scale modelled flow is within 10% of the gauged flow, highlighting the good performance of the hydrology modelling, with the consideration that only long-term average annual load estimates were required for the Reef Plan reporting.

One of the major factors affecting the calibration performance which is common across the GBR is the uncertainty in the SILO rainfall spatial data grids. This uncertainty results from a low density of rainfall gauges in certain areas, particularly in steep terrain where there is large rainfall gradients, and variable lengths of rainfall station records (DSITIA 2013). The low density of rainfall gauging stations across the Fitzroy region is also linked to model performance during wet and dry years. Generally, the model performs well in high flow years and less so during drier years. This is likely related to the inability of the limited rainfall gauge network to capture and delineate isolated storm events during drier years. The spatial attribution of rainfall is one component identified for future model improvements.

In order to align with water planning modelling in Queensland Government it is planned to transition from SIMHYD to the Sacramento rainfall- runoff model, given the model is used in the Integrated Quantity Quality Model (IQQM) for water planning purposes. Recent research has shown that the Sacramento model performs better in some GBR catchments than the SIMHYD model (Zhang, Waters & Ellis 2013). The Sacramento model is also better able to account for losses in the system (e.g. groundwater), which is of particular benefit in the wetter GBR catchments.

5.2 Modelled constituent loads and validation

5.2.1 Constituent load validation

One of GBR Source Catchments model benefits is that modelling can be undertaken to compare loads with quite disparate water quality datasets from different locations and for various time periods (Dougall & Carroll 2013). For the Fitzroy the Source Catchments loads were validated against three other load estimates to determine the performance of the model. Firstly, a short-term catchment monitoring data set for 2006 to 2010 (Joo et al. 2012a) was compared to the equivalent four year modelled loads. Secondly, a regression approach (FRCE) was compared that used a correlation between available measured water quality data to discharge to produce annual and average annual loads for the 23 year model period (Joo et al. 2014). Finally, previous catchment modelled estimates reported by Kroon et al. (2012) which will be considered in section 5.2.2.

In general, the modelled loads matched well with the short-term GBRCLMP (2006–2009) and longer-term FRCE loads. In the short-term comparison the average annual modelled loads tended to be lower than the monitored loads for the three year period, with the difference within the likely range of the monitored loads data.

The 23 year average annual modelled loads for TSS, DIN, DON, DIP and DOP showed close comparison with estimated loads derived by Joo et al (2014), with TN, TP, PN, and PP modelled loads closer to the lower range of estimated loads. It is important to note that the modelled loads are only indicative of actual measured loads. The measured water quality data represents a particular set of land use and land management condition at a particular moment in time. It does not reflect the annual and seasonal variations within the landscape and catchment represented by the catchment modelled loads. Therefore model validation aims to demonstrate that the models are achieving a reasonable approximation of the loads derived from measured water quality data. Consequently, validation 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. Nevertheless, overall there was a promising comparison with the short term monitored GBRCLMP estimates at the annual scale. However, statistics at a monthly scale where generally “unsatisfactory” indicating further work is required if finer scale temporal estimates are required. As on-going catchment monitoring data becomes available, the modelling period will be extended to provide an increasingly more representative average annual comparison.

The Fitzroy Source Catchments model was designed to produce outputs at the long-term average annual scale, even though as previously illustrated the model can be used at shorter time periods. The current calibration objective was to ensure predictions matched the long-term load estimates. Although the short and longer term comparisons provides some confidence that the Fitzroy Source Catchments model is achieving this objective it is critical that water quality monitoring is continued so that more seasonal variability is captured for on-going validation, and for improved estimates of loads to be determined.

5.2.2 Anthropogenic loads

Reef Plan 2009 water quality targets look to reduce the anthropogenic baseline load, which is the loads contribution caused by land modification and management practices since European settlement. Therefore, the anthropogenic load is determined by the difference between the total load and predevelopment load. Although the total constituent load discharged to Great Barrier Reef 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 total Fitzroy regional TSS load export is estimated to be 1,948 kt/yr, and is a 3.5 fold increase on predevelopment loads. The total nitrogen and total phosphorus loads exported estimated to be 4,244 t/yr and 1,093 t/yr, a 1.3 and 2.3 fold respective increase on the predevelopment loads. Although, the Fitzroy Source Catchments and Kroon et al. (2012) have similar increase factors for TSS, Kroon et al (2012) estimated total and predevelopment loads are substantially larger (4,109 and 1,259 kt/yr) than the Source Catchment estimates (1,948 and 542 kt/yr). Likewise, Kroon et al. (2012) increase factors for TP and TN are much larger than Source Catchments estimates.

An explanation for this difference is the current GBR Source Catchment modelling framework includes all major water storages in the regions and a comprehensive representation of removal of constituents due to water extraction. Plus, enhanced spatial and temporally remote sensed ground cover has been used to derive the C-factor for the RUSLE for grazing, the C-factors derived are lower (higher cover) than previously used by other modelling studies, with the result sediment and particulate nutrients generated are lower than previously estimated to be exported from the GBR. In addition, in the GBR Source Catchments framework local and specific point scale models are used to generate sediment, nutrient and pesticide generation from cropping systems. Whereas previous modelling had limited functionality to represent specific management practice constituent generation, with the result higher nutrient estimates reported in Kroon et al*.*, (2010, 2012) are in part due to over-estimation of particulate nutrient loads reported in SedNet-ANNEX modelling for the Fitzroy (Cogle et al., 2006, Sherman and Read 2008). In some cases, Kroon et al. (2012) reported total loads lower than the predevelopment loads, which created a negative anthropogenic load, for example, the DOP anthropogenic load for the Boyne catchment was reported to be -4 t/yr. This highlights the importance of using one single modelling platform when reporting changes to a baseline anthropogenic load.

From a priority investment perspective the Source Catchments model results generally agree with historical monitoring and modelling data for the Fitzroy Basin. Model results indicate that the Dawson and Isaacs subcatchments are major contributors to the total average annual export of fine sediment and particulate nutrients to the GBR lagoon. Fitzroy Basin and subcatchment monitoring data (Packett et al. 2009) suggests that coastal subcatchments with steep slopes and high average annual rainfall such as the Connors River catchment (Isaacs subcatchment) contribute substantial loads on a regular (annual) basis to the coast. There is a lack of monitoring data available to validate modelled exports from the Dawson subcatchment for the modelling period, however, data collected during the 2009–2013 wet seasons should allow for increased confidence in outputs from future model iterations. Both monitoring and modelling results suggest that intensive cropping areas such as the Theresa Creek (Nogoa subcatchment) and Comet River subcatchments can contribute substantial loads of dissolved inorganic nutrients and herbicides to the coast during high rainfall events. Similarly, irrigated and dryland cropping areas in the Dawson and Callide Valley (Dawson) subcatchments could be considered hot spots for average annual contributions of inorganic nutrients and herbicides based on model outputs and limited monitoring data.

5.2.3 Contribution by land use and source

Grazing land, mainly in the Burdekin and Fitzroy, contributes over 75 percent of the TSS loads to the GBR lagoon, followed by sugarcane lands (10 per cent) and land cropped for grains (6 per cent). Other non-agricultural land uses such as conservation, forestry and urban land occupy less than 20% of the GBR catchment area and contribute < 5% of the anthropogenic load of TSS. The dominant nature of the Burdekin and Fitzroy regions on sediment export has been reported previously by (Greiner et al. 2005, McKergow et al. 2005b,Kroon et al. 2012) and the Scientific Consensus statement (The State of Queensland 2013a). Waterhouse et al (2012) in the updated Scientific Consensus Statement have identified these two large grazing catchments as a high to medium risk to the GBR lagoon, and are a clear priority to target sediment reductions.

The main sources of sediment In the Fitzroy are from gullies (45%), hillslope (35%) and streambank erosion (20%), with source areas in each of the main subcatchments. Of the generated fine sediment it is estimated 43% to be exported to the GBR lagoon, and 53% deposited on floodplains, within storages or through extraction of water within the region. Likewise, 72%, 56% and 31% of the generated TN, TP and PSII constituent loads are exported, with most of the PSII loads being lost through stream decay as the flow travels through the large Fitzroy basin.

The Fitzroy and Burdekin basin remain high priority areas for investment in improving grazing management by virtue of their large area, very high total and anthropogenic loads and particularly the large capacity for improvement with substantial areas under C and D grazing management practices. Specific management of gullies is emerging as a need to reduce sediment delivered to the GBR. Effective gully management includes reducing grazing pressure to increase levels of ground cover in vulnerable eroding parts of the landscape, and to reduce runoff volumes from these areas. Plus, targeted remediation works in unstable gullies and other erosion features that can assist with reducing sediment yield (Thorburn, Wilkinson & Silburn 2013).

5.3 Progress towards Reef Plan 2009 targets

Across the GBR TSS loads have been reduced by 11%, TN and TP by 10% and 12.5% respectively. The PSII herbicide load has had the greatest reduction of all constituents at 28%. The modelling shows that good progress has been made towards reaching the 2020 target (Reef Plan 2013) of a 20% reduction in sediment load from the GBR. However, the target of a 50% reduction by 2013 as outlined in Reef Plan 2009 for nutrients and herbicides has not been met. It is clear the 50% nutrient and herbicide reduction targets for Reef Plan 2009 are very challenging, with alternative management strategies required for current and future targets to be achieved. This has been acknowledged in Reef Plan 2013, where timelines for meeting these targets has been revised.

The Fitzroy region had the lowest load reductions across all constituents, with a cumulative reduction of TSS, TP, TN and PSII of 4.2%, 6.0%, 2.9% and 5.1% for the final Reef Plan 2009 Report Card (2013). The small changes in loads are primarily due to relative small changes across management classes in grazing for the reporting periods. For example, there was only a 2% movement out of C class management practice, with just 1% movement in to A class and 1% into B class over the life of Reef Plan 2009. This compares to a 5% movement into A class management practices in grazing in the Burdekin region for the same period.

There was a substantial investment in riparian fencing reported for Report Cards 2012–2013, and this is estimated to account for approximately 25% of the total TSS load reduction for Report Card 2013. In the grains industry, the biggest improvement in soils, nutrients and pesticides management class occurred between Report Cards 2010-2011. Improved pesticide and soil management in grains resulted in a 12% and 11% movement from C class management practices into B class practices between Report Cards 2010-2013. For nutrient management in grains there was a 6% movement from C class management practices into B class practices for the same period.

In the Fitzroy region, there is still approximately 40% and 50% of the area respectively in C and B grazing management practices, likewise almost 70% of grain growers use B class management practice. This highlights the opportunity and scope in the Fitzroy region for further improvements to reduce fine sediment export to the reef lagoon. The supply and use of finer scale spatial management practice data has been identified as an important requirement to both identify priority areas and model more explicitly the constituent load reductions within the region. This is mainly due to the application of non-spatial management practice data for the baseline and Report Cards 2010–2013. Obtaining spatial management data would greatly improve the ability to spatially represent the impact of investments in improved land management on water quality, particularly in the larger GBR NRM regions such as the Fitzroy and Burdekin.

At the start of the Paddock to Reef program it was determined that any major model enhancements would only take place at the commencement of Reef Plan 2013, hence every four years. Only relatively minor enhancements or corrections to the Source Catchments model took place within the Reef Plan 2009 reporting period, with these changes and their relative impacts being outlined in Appendices G to I. This allowed some relative yearly comparison within the Reef Plan 2009 reporting period to be undertaken. However, it is more pertinent to consider the cumulative load reductions at the end of the Reef Plan 2009 reporting period (Report Card 2013) rather than considering the specific individual year reductions.

6 Conclusion

The catchment scale water quality modelling as described in this report is one of multiple lines of evidence used to report on progress towards Reef Plan 2009 targets. Investment in improved land management practices between 2008 and 2013 has resulted in a reduction in sediment load to the GBR from the six NRM regions of 11%. Similarly, total nitrogen and total phosphorus have declined by 9.9% and 12.5% respectively. Pesticide loads have been reduced by 14.6%. The reduction in sediment, nutrient and pesticide loads is positive progress towards meeting the Reef Plan 2013 targets. Specifically in the Fitzroy, fine sediment was reduced by 4.2%, TN reduced by 3% and TP by 6%.

The results from this project are somewhat lower than previous estimates for sediment and nutrient loads from the Fitzroy region. Reasons for the lower estimates include: improved input layers (in particular spatial and temporal cover layers), the ability to apply the most appropriate model to each land use as opposed to a single EMC/DWC or RUSLE approach as applied in previous models. In addition, the availability of recent event monitoring data to validate models against is a major improvement. Over the course of the Paddock to Reef program more empirical data has become available, and it is likely that the modelled outputs from all regions will change as a result of monitoring and modelling feedback.

The Paddock to Reef Program, as a whole, is designed to be an adaptive process, where monitoring and modelling outputs will both inform reef targets and also identify where our current conceptual understanding and knowledge needs to be strengthened (Waters & Carroll 2012). Developing, parameterising and running the catchment model described in this technical report, and accompanying reports, was a considerable challenge. However, what has been developed is a platform for future modelling, and with improvements in technology, data inputs and model concepts, greater confidence in the outputs will be achieved. These changes will provide an enhanced GBR Source Catchments total baseline load and load reductions to that used for Reef Plan 2009. It should be noted, that due to the proposed model enhancements, the outcomes for the Reef Plan 2013 reporting period should not be directly related to the outcomes reported in Reef Plan 2009.

There are numerous achievements of the GBR wide modelling project. Firstly, this project has developed the first temporally and spatially variable water quantity and quality models across the entire GBR including the Fitzroy region. The use of a consistent methodology across whole of GBR enables the direct comparison of loads across regions. The flexible nature of the Source Catchments framework, there is now the ability to differentiate erosion processes (hillslope, gully and streambank), as opposed to traditional daily time step EMC approaches. The benefit of this approach is to enable investigation and targeted investment in the most appropriate areas. Finally, a highly collaborative approach in model development and application has been a very positive outcome of this project. A particular advantage of this is the integration of monitoring and modelling, and using modelling outputs to inform the monitoring program. It follows that the better the modelling performs spatially and temporally the greater the confidence and possible sophistication in targeted management actions

Overall, the catchment scale water quality modelling has been successful, and the aim of reporting progress towards Reef Plan 2009 targets has been achieved. The results show that land managers are on track towards meeting the overall sediment, nutrient and herbicide reduction targets for Reef Plan 2013.

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Appendix A - Previous estimates of pollutant loads

Table 23 Kroon et al. (2012) natural (predevelopment), baseline and total pollutant loads for the Fitzroy NRM region

Basin Name	TSS (kt/yr)			TN (t/yr)			DIN (t/yr)			DON (t/yr)			PN (t/yr)		
	Natural	**Baseline**	**Total**	**Natural**	**Baseline**	**Total**	**Natural**	**Baseline**	**Total**	**Natural**	**Baseline**	**Total**	**Natural**	**Baseline**	**Total**
Styx	25	240	260	52	550	600	23	23	46	24	32	56	5	500	500
Shoalwater	22	73	95	87	170	260	41	10	51	41	15	56	5	160	160
Water Park	10	79	89	86	420	510	41	35	76	41	52	93	4	340	340
Fitzroy	1,100	2,300	3,400	1,300	12,000	13,000	610	210	820	630	670	1,300	70	11,000	11,000
Calliope	20	190	210	46	550	600	20	23	43	21	29	50	5	500	500
Boyne	41	2	43	90	100	190	38	35	73	39	33	6	13	97	110
Regional Total	**1,200**	**2,900**	**4,100**	**1,700**	**14,000**	**15,000**	**770**	**340**	**1,100**	**800**	**770**	**1,600**	**100**	**13,000**	**13,000**

Basin Name	TP (t/yr)			DIP (t/yr)			DOP (t/yr)			PP (t/yr)			PSIIs (kg/yr)		
	Natural	Baseline	Total	Natural	Baseline	Total	Natural	Baseline	Total	Natural	Baseline	Total	Natural	Baseline	Total
Styx	8	260	270	1	2	3	2	1	3	5	260	260	-	23	23
Shoalwater	12	61	73	1	3	4	4	-	4	7	58	65	-	20	20
Water Park	13	58	71	3	-	3	4	1	5	6	57	63	-	13	13
Fitzroy	140	3,500	3,600	7	140	150	62	10	72	75	3,200	3,300	-	2,200	2,200
Calliope	6	150	160	-	1	1	2	-	2	4	150	150	-	18	18
Boyne	14	16	30	1	1	2	4	4	-	9	19	28	-	0	0
Regional Total	**200**	**4,100**	**4,200**	**13**	**150**	**160**	**78**	**8**	**86**	**110**	**3,700**	**3,900**	**-**	**2,300**	**2,300**

TSS = Total suspended sediment, DIN = dissolved inorganic nitrogen, DON = dissolved organic nitrogen, PN = particulate nitrogen, TN= total nitrogen, DIP = dissolved inorganic phosphorus, DOP = dissolved organic phosphorus, PP = particulate phosphorus, TP = total phosphorus, PSII = herbicides.

Appendix B – PEST calibration approach

The process of coupling PEST and Source Catchments is presented in Figure 24. Initially, a model is built in the Source Catchments Graphical User Interface (GUI), which is then run in the E2CommandLine utility. E2CommandLine enables rapid model run times, when compared to running the model within the GUI. TSPROC is a time series processor utility that processes the model output, created by running the model in E2CommandLine, and then prepares an input file for PEST. PEST processes the TSPROC output and creates new parameter sets. The process then returns to running the model in E2CommandLine, with the new parameter set.

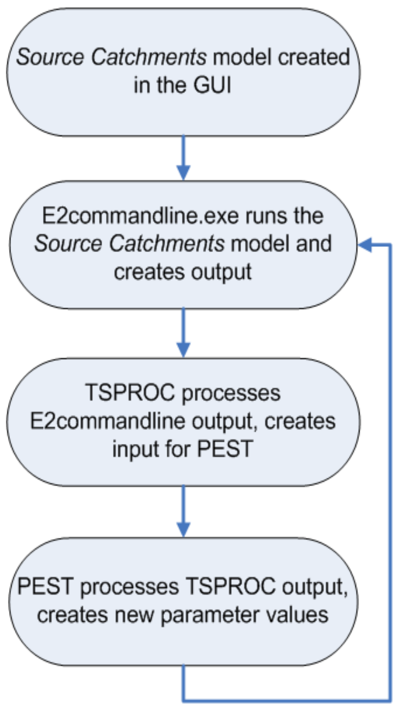

Figure 24 PEST - Source Catchments Interaction (Stewart 2011)

A detailed description of the PEST set up and operation can be found in (Doherty 2009). PEST operates largely via batch and instructional text files. The project team created a number of project specific tools to automate the compilation of these files, where possible. The TSPROC.exe (Time Series Processor) utility was also used to create the files used by PEST (the PEST control file), to manipulate the modelled time series, and present the statistics to PEST for assessment (Stewart 2011). More information on TSPROC can be found in (Doherty 2009). A three-part objective function was employed, using daily discharge, monthly volumes and exceedance times. All three objective functions were weighted equally. Regularisation was added prior to running PEST. This ensures numerical stability, by introducing extra information such as preferred parameter values, resulting from parameter non-uniqueness. Parameter non-uniqueness occurs when there is insufficient observation data to estimate unique values for all model parameters, and is an issue in large models, such as those in the GBR (Stewart 2011).

Given the size of the Fitzroy model, Parallel PEST was used to enable multiple computers (and processors) to undertake model runs at the same time. The programs used, and process of running Parallel PEST is demonstrated in Figure 25.

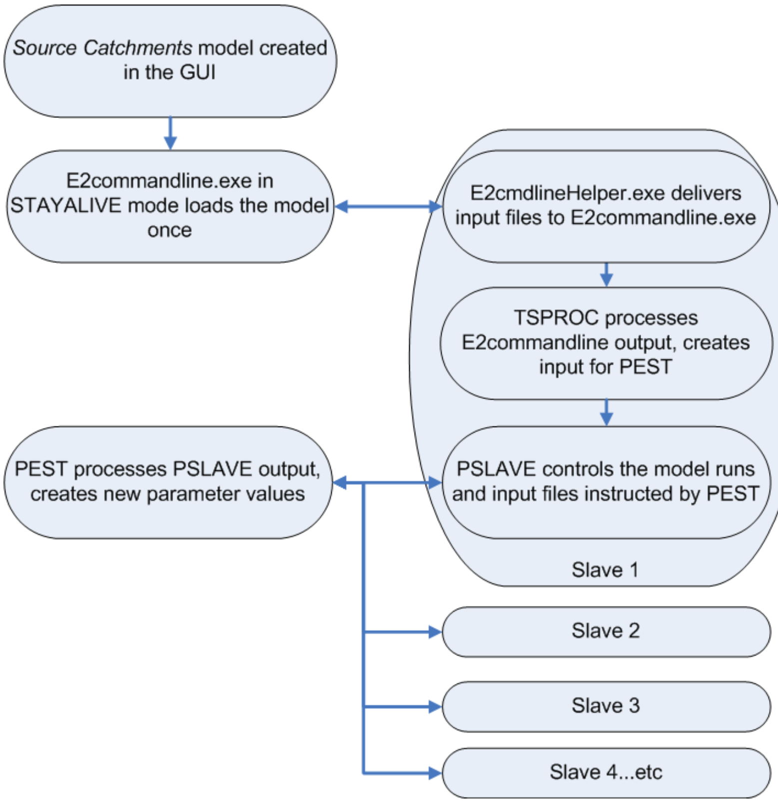

Figure 25 PEST operation (Stewart 2011)

Appendix C - SIMHYD model structure and parameters for calibration

The reclassification of the full set of land uses into three Hydrological Response Units (HRUs) is presented in Table 24. Default SIMHYD and Laurenson parameters were used as the starting values for the calibration process, and these are identified in Table 25.

Table 24 Reclassification of FU's for hydrology calibration

Land use (FU)	HRU
Nature conservation	Forest
Grazing forested	Forest
Grazing open	Grazing
Forestry	Forest
Water	Not considered
Urban	Grazing
Horticulture	Agriculture
Irrigated cropping	Agriculture
Other	Grazing
Dryland cropping	Agriculture

Table 25 PEST Start, Lower and Upper boundary Parameters for SIMHYD and Laurenson models

Model	Parameter	Starting	Lower	Upper
SIMHYD	Rainfall Interception Store Capacity (RISC)	2.25	0.5	5
SIMHYD	Soil Moisture Storage Capacity (SMSC)	240	20	500
SIMHYD	Infiltration Shape (INFS)	5	1.00E-08	10
SIMHYD	Infiltration Coefficient (INFC)	190	20	400
SIMHYD	Interflow Coefficient (INTE)	0.5	1.00E-8	1
SIMHYD	Recharge Coefficient (RECH)	0.5	1.00E-8	1
SIMHYD	Baseflow Coefficient (BASE)	0.1485	3.00E-03	0.3
SIMHYD	Impervious Threshold (fixed at 1)	1		
SIMHYD	Pervious Fraction (fixed at 1)	1		
Laurenson	Routing Constant (k)	2.25	1.0	864000
Laurenson	Exponent (m)	240	0.6	2

The calibrated SIMHYD and Laurenson routing parameters for the 86 calibration regions in the Fitzroy model are available on request.

Appendix D – PEST calibration results

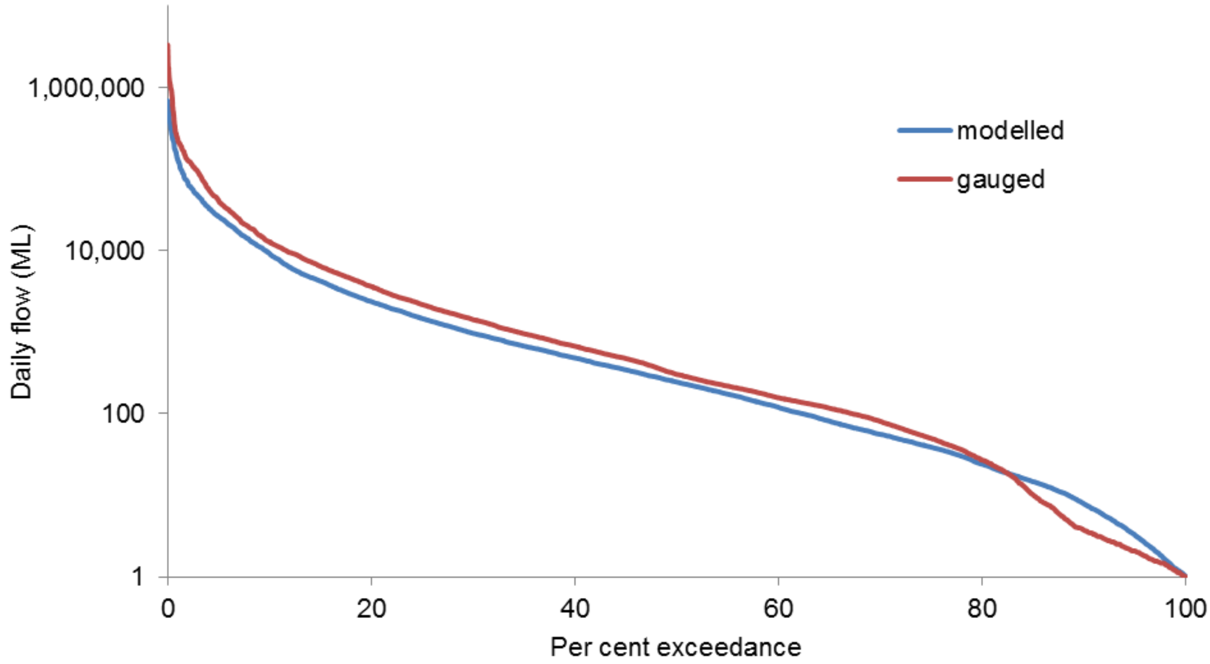

Figure 26 130401a Yatton

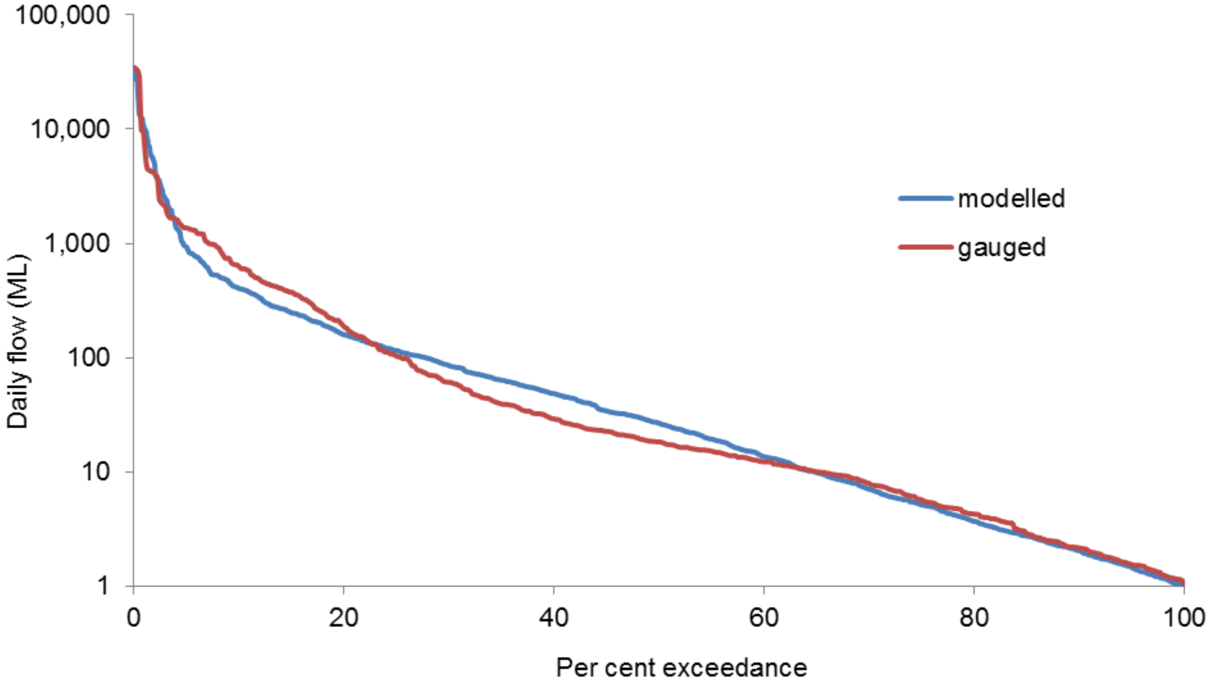

Figure 27 130363a Roundstone

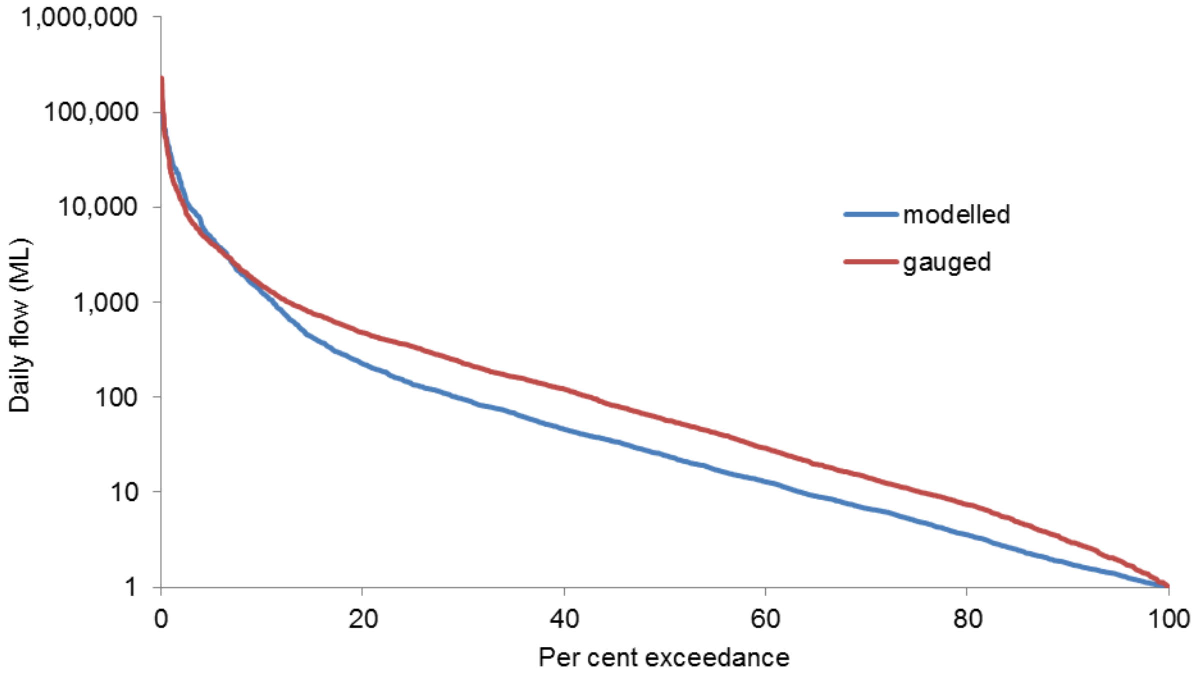

Figure 28 130413a Dennison

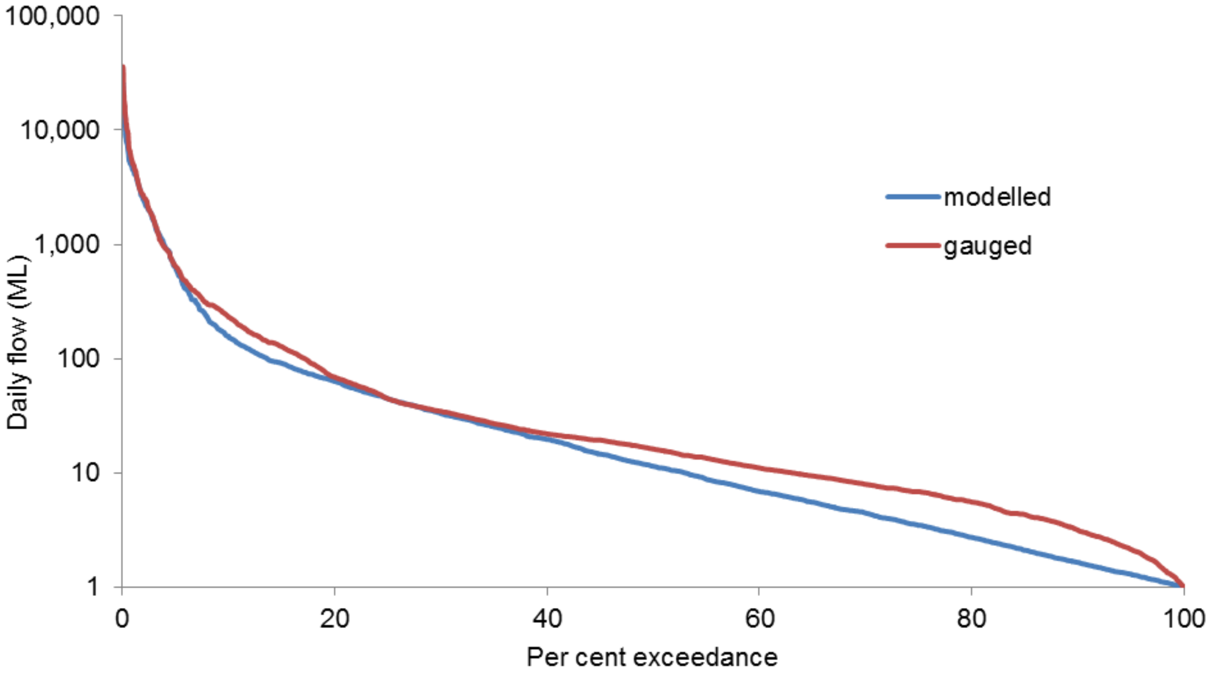

Figure 29 103509a Carnarvon

Appendix E – Dynamic SedNet global parameters and data requirements

Spatial projection

Spatial data was projected in the DNRM Albers Equal-Area projection. It is a conic projection commonly used for calculating area. Albers uses two standard parallels between which distortion is minimised and these are set using the latitudes at 1/5 & 4/5 of the full Y extent of the area of interest. These are the Standard Parallel 1 and Standard Parallel 2 below.

- Central Meridian = 146.0000000
- Standard Parallel 1 = -13.1666666
- Standard Parallel 2 = -25.8333333
- Latitude of Origin = 0.0000000

Grazing constituent generation

Hillslope erosion

Table 26 Hillslope erosion parameters

Characteristic	Value
TSS HSDR value (%)	10
Coarse sediment HSDR value (%)	0
Maximum quick flow concentration (mg/L)	10,000
DWC (mg/L)	100

Gully erosion

Table 27 Gully erosion model parameters

Input parameters	Value
Daily runoff power factor	1.4
Gully model type	DERM
TSS delivery ratio value (%)	100
Coarse sediment delivery ratio value (%)	0
Gully cross sectional area (m^2)	10
Average gully activity factor	1
Management practice factor	Variable
Default gully start year	1870
Gully full maturity year	2010
Density raster year	2010

Nutrients (hillslope, gully and streambank)

The ANNEX (Annual Nutrient Export) model estimates particulate and dissolved nutrient loads. Particulate nutrients are generated via hillslope, gully and streambank erosion, while dissolved nutrients are predominantly generated via point sources (for example, sewerage treatment plants), or from inorganic sources such as fertilised cropping lands (Cogle, Carroll & Sherman 2006).

Six rasters are required as inputs to the Nutrients parameteriser, four nutrient rasters (surface and subsurface nitrogen and phosphorus), as well as surface and subsurface clay (%). All of the nutrient data was derived from the ASRIS database, and 'no data values' were adjusted to the median value for that particular catchment. A 'Land use based concentrations' table is also required (see Table 28), which provides data on EMC/DWC values for each of the functional units.

Table 28 Dissolved nutrient concentrations for ANNEX FUs (Other, Grazing (open and closed), forestry and nature conservation) nutrient generation models

Functional Unit	DIN EMC	DIN DWC	DON EMC	DON DWC	DIP EMC	DIP DWC	DOP EMC	DOP DWC
ANNEX FU	0.13	0.13	0.25	0.25	0.02	0.02	0.01	0.01

Enrichment and delivery ratios are required for nitrogen and phosphorus. The input parameter values used in the Fitzroy are found in Table 29.

Table 29 Nutrient generation parameter values

Parameter	Phosphorus	Nitrogen
Enrichment ratio	2	1.2
Hillslope delivery ratio	10	10
Gully delivery ratio	100	100

Cropping constituent generation

HowLeaky is a point model which was run externally to Source Catchments to model cropping practices. A unique HowLeaky simulation was run for each combination of soil group, slope and climate which was defined through a spatial intersection. A DERM Tools plug-in linked the spatial intersection with databases of parameters to build HowLeaky simulations which could then be batch processed. The intersect shape file also contained information on clay percentage (derived from the ASRIS database) which was used to affect the delivery of fine sediment from the paddock to the stream. Time series files for each of the spatial and management combinations within each subcatchment were accumulated using spatial weighting to generate a single daily load per subcatchment. These time series files were then used as the input for the HowLeaky parameteriser in Source Catchments.

HowLeaky modelling was applied to cropping FUs, which in the Fitzroy include: irrigated cropping and dryland cropping. HowLeaky time series files were prepared by the Paddock Modelling team and were used as an input to the HowLeaky parameteriser in Source Catchments. HowLeaky was applied to four constituents: sediment, dissolved phosphorus, particulate nutrients and herbicides. The HowLeaky input parameters for the Fitzroy region model are shown in Table 30 and Table 31.

Table 30 Cropping nutrient input parameters

Parameter	Constituent	Value
Conversion Factor	DOP	0.2
	DIP	0.8
Delivery ratio (%)	Dissolved nutrients	90
	Dissolved herbicides	90
	Particulates, particulate herbicides	20
Maximum slope (%)	TSS and particulates	10
Use Creams enrichment	P	False
Particulate enrichment	Nitrogen	
Particulate enrichment	Phosphorus	
Gully DR (%)	N and P	100

Table 31 Cropping sediment (sheet and gully) input parameters

Parameter	Value
Clay (%)	36
Hillslope DR (%)	20
Maximum slope (%)	10
FU actually growing sugarcane (%)	N.A
Gully delivery ratio (%)	100
TSS DWC (mg/L)	0

EMC/DWC Values

Table 32 EMC/DWC values (mg/L)

FU	Parameter	TSS	PN	DIN	DON	PN	DOP	DIP
Horticulture	DWC	60	0.36	0.225	0.328	0.03	0.008	0.044
	EMC	120	0.72	0.45	0.656	0.06	0.016	0.087
Other	DWC	40	0.24	0.15	0.219	0.02	0.005	0.029
	EMC	80	0.48	0.3	0.437	0.04	0.011	0.058
Urban	DWC	40	0.24	0.15	0.219	0.02	0.005	0.029
	EMC	80	0.48	0.3	0.437	0.04	0.011	0.058

In-stream models

Streambank erosion

The *'SedNet Stream Fine Sediment Model'* calculates a mean annual rate of fine streambank erosion in (t/yr) and there are several raster data layers and parameter values that populate this model. The same DEM used to generate subcatchments is used to generate the stream network. A value used to determine the 'ephemeral streams upslope area threshold' is also required, and is equal to the value used to create the subcatchment map, which in Fitzroy Region was 50 km^2. Floodplain area and extent was used to calculate a floodplain factor (potential for bank erosion) and for deposition (loss). The floodplain input layer was determined by using the Queensland Herbarium pre-clearing vegetation data and extracting the land zone 3 (alluvium) codes. The Queensland 2007 Foliage Projective Cover (FPC) layer was used to represent the proportion of riparian vegetation. Riparian vegetation was clipped out using the buffered 100 m stream network raster. A value of 12% was used for the FPC threshold for riparian vegetation. A 20% canopy cover is equivalent to 12% riparian veg cover and this threshold discriminates between woody and non-woody veg and we assumed that the non-woody FPC cover (below 12%) is not effective in reducing streambank erosion (Department of Natural Resources and Mines 2003).

Streambank soil erodibility accounts for exposure of rocks resulting in only a percentage of the length of the streambank being erodible material, decaying to zero when floodplain width is zero. The steps below were followed to create a spatially variable streambank soil erodibility layer with its value increasing linearly from 0% to 100% as floodplain width increases from zero to a cut-off value. It is assumed that once floodplain width exceeds the cut-off value, the streambank will be completely erodible (i.e. streambank erodibility = 100%). The cut-off value used was 100 m.

$$\text{Streambank soil erodibility (\%)} = \text{MIN}(100, 100/\text{cut-off}*\text{FPW}) \qquad (10)$$

Where: FPW is floodplain width (m) and cut-off is the cut-off floodplain width (m).

Surface clay and silt values taken from the ASRIS data base were added together to create the clay and silt percentage layer. 'No data' values were changed to the median value, which in Wet Tropics was 65%. Using the raster data layers described above, *'SedNet Stream Fine Sediment Model'* calculates eight raster data sets that are used in the parameterisation process. The calculated rasters are: slope (%), flow direction, contributing area (similar to flow accumulation in a GIS environment), ephemeral streams, stream order, stream confluences, main channel, and stream buffers.

Bank height and width parameters were developed from local gauging station data. Regression relationships were determined between 28 point observations of channel width and upstream catchment area (Figure 30) and channel height and upstream catchment area (Figure 31). In some instances, the cross-section data may have been adjusted, due to the age of these profiles and the dynamic nature of channel morphology, based on local knowledge such as that from the DERM hydrographers. The equation was sourced from (Wilkinson, Henderson & Chen 2004) where:

$$\text{(Coefficient)} * (\text{Area, km}^2) \wedge \text{(Area exponent)} \qquad (11)$$

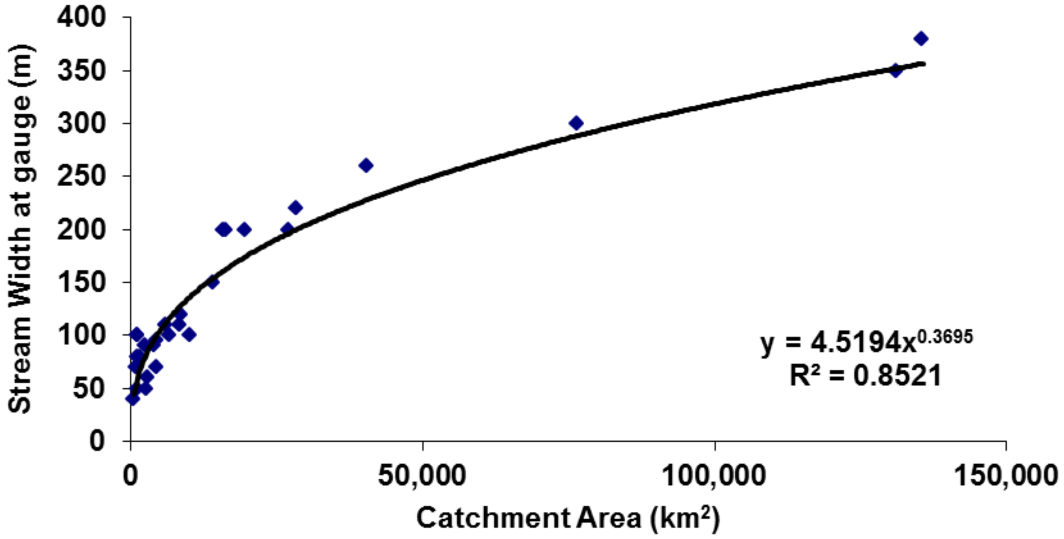

Figure 30 Catchment area vs. stream width used to determine streambank erosion parameters

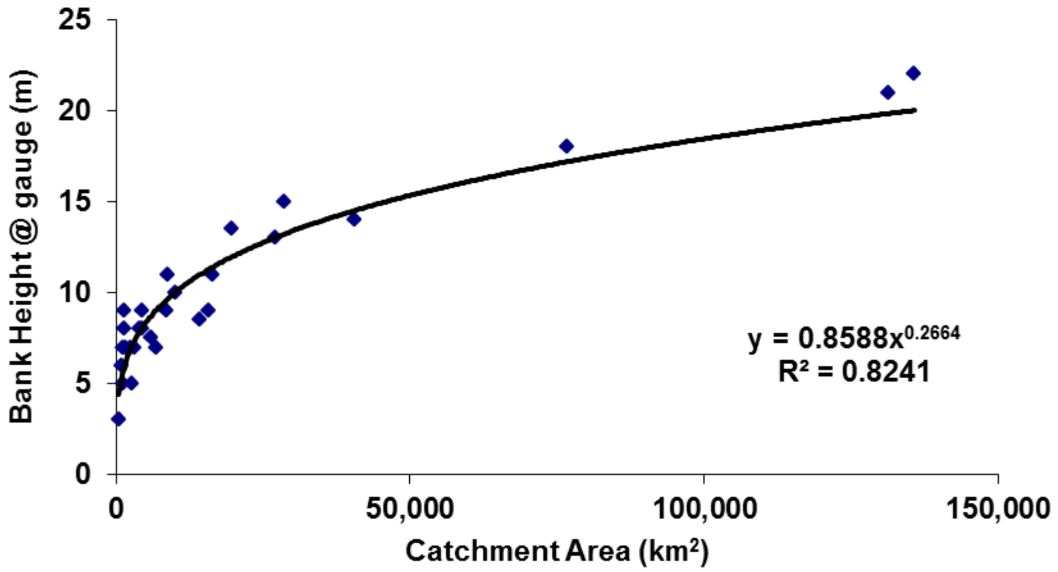

Figure 31 Catchment area vs. bank height used to determine streambank parameters

A series of global input parameters are also required for the *'SedNet Stream Fine Sediment Model'* to run. These were determined on a region by region basis, using the available literature, or default values identified in (Wilkinson, Henderson & Chen 2004). The parameter values for Fitzroy are presented in Table 33.

Table 33 Dynamic SedNet Steam Parameteriser values for Fitzroy

Input Parameters	Value
Bank Height Method: SedNet Variable – Node Based	
Proportion for TSS deposition	0
Catchment Area Exponent	0.266
Catchment Area Coefficient	0.858
Link Width Method: SedNet Variable – Node Based	
Minimum Width (m)	10
Maximum Width (m)	1,000
SedNet Area Exponent	0.369
SedNet Area Coefficient	4.5194
SedNet Slope Exponent	0
Link Slope Method: Main Channel	
Minimum Link Slope	0.00001
Stream Attributes	
Bank Full Recurrence Interval (years)	0
Stream Buffer Width (m)	100
Maximum Vegetation Effectiveness (%)	95
Sediment Dry Bulk Density (t/m^3)	1.5
Sediment Settling Velocity (m/sec)	0.000700
Sediment Settling Velocity for Remobilisation (m/sec)	0.1
Bank Erosion Coefficient	0.00002
Manning’s N Coefficient	0.04
FPC Threshold for Streambank Vegetation (%)	12
Initial Proportion of Fine Bed Store (%)	0
Daily Flow Power Factor	1.4

Herbicide half-lives

Table 34 Herbicide half-lives

Herbicide	Half-life value (seconds)	Days
Atrazine	432,000	5
Diuron	760,320	8.8
Hexazinone	760,320	8.8
Metalochlor	777,600	9
Tebuthiuron	2,592,000	30
2,4-D	2,505,600	29
Paraquat	864,000	10
Glyphosate	216,000	2.5

Storage details

Table 35 Storage details and Lewis trapping parameters for the Fitzroy NRM region storages

Storage details				Lewis trapping parameters						
Storage	Full supply level (m)	Initial storage level (m)	Dead storage (m)	Length of storage (m)	Subtractor parameter	Multiplier parameter	Length/ discharge factor	Length/ discharge power	Capacity = Max geometry*	Use outflow*
Fairbairn	204.2	202	186	15,000	100	800	3.28	-0.2	F	F
Awoonga	40	39	13.5	10,000	100	800	3.28	-0.2	F	F
Kroombit	216.1	209.3	187	500	100	800	3.28	-0.2	F	F

Management practice information

Table 36 Examples of improved management practices targeted through Reef Plan (including Reef Rescue) investments.

Note, this list is not comprehensive (K McCosker, pers. comm.)

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. re-battering 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 10–15 cm below the surface with non-aggressive narrow tillage equipment.
Controlled traffic farming (CTF)	Major farming system change. Changes required to achieve CTF include altering wheelbases on all farm machinery, wider row widths, re-tooling 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 boomsprays	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 F – Report Card 5 modelling results

Table 37 Constituent loads for predevelopment, total baseline, anthropogenic baseline and Report Card 2013 model runs for the Fitzroy NRM region

TSS (kt/yr)	Predevelopment	Total baseline	Increase factor	Anthropogenic baseline load	Report Card 2013	Report Card 2013 change (%)
Styx	28	68	2.4	40	68	0.6
Shoalwater	27	53	2	26	53	1.1
Water Park	27	32	1.2	5	32	0.9
Fitzroy	440	1,740	4	1,300	1,681	4.5
Calliope	16	44	2.8	28	44	0.7
Boyne	3	11	3.7	8	11	1.9
Total region	**542**	**1,948**	**3.6**	**1,407**	**1,889**	**4.2**
TN (t/yr)	**Predevelopment**	**Total baseline**	**Increase factor**	**Anthropogenic baseline**	**Report Card 2013**	**Report Card 2013 change (%)**
Styx	119	154	1.3	35	153	0.5
Shoalwater	121	137	1.1	16	137	0.5
Water Park	140	150	1.1	11	150	0.3
Fitzroy	2,768	3,688	1.3	921	3,659	3.2
Calliope	67	90	1.3	23	90	0.5
Boyne	16	24	1.5	8	24	1.4
Total region	**3,230**	**4,244**	**1.3**	**1,013**	**4,214**	**2.9**
DIN (t/yr)	**Predevelopment**	**Total baseline**	**Increase factor**	**Anthropogenic baseline**	**Report Card 2013**	**Report Card 2013 change (%)**
Styx	38	38	1.0	0	38	0.0
Shoalwater	45	45	1.0	0	45	0.0
Water Park	54	54	1.0	0	54	0.0
Fitzroy	1,057	1,106	1.0	48	1,106	0.0
Calliope	23	23	1.0	0	23	0.0
Boyne	6	6	1.0	0	6	0.0
Total region	**1,223**	**1,272**	**1.0**	**49**	**1,272**	0.0
DON (t/yr)	**Predevelopment**	**Total baseline**	**Increase factor**	**Anthropogenic baseline**	**Report Card 2013**	**Report Card 2013 change (%)**

Styx	56	56	1.0	0	56	0.0
Shoalwater	66	66	1.0	0	66	0.0
Water Park	78	79	1.0	0	79	0.0
Fitzroy	1,477	1,548	1.0	71	1,548	0.0
Calliope	33	33	1.0	0	33	0.0
Boyne	9	9	1.0	0	9	0.0
Total region	**1,719**	**1,790**	**1.0**	**72**	**1,790**	0.0
PN (t/yr)	**Predevelopment**	**Total baseline**	**Increase factor**	**Anthropogenic baseline**	**Report Card 2013**	**Report Card 2013 change (%)**
Styx	25	60	2.4	35	59	0.5
Shoalwater	9	25	2.8	16	25	0.5
Water Park	8	18	2.3	10	17	0.4
Fitzroy	233	1,035	4.4	802	1,006	3.6
Calliope	11	34	3.1	23	34	0.5
Boyne	2	10	5.0	8	10	1.4
Total region	**288**	**1,181**	4.1	**893**	**1,152**	**3.3**
TP (t/yr)	**Predevelopment**	**Total baseline**	**Increase factor**	**Anthropogenic baseline**	**Report Card 2013**	**Report Card 2013 change (%)**
Styx	21	38	1.8	17	38	0.6
Shoalwater	14	21	1.5	7	21	0.5
Water Park	16	19	1.1	2	19	1.2
Fitzroy	414	983	2.4	569	946	6.5
Calliope	13	27	2	13	26	0.5
Boyne	2	6	2.6	4	6	1.0
Total region	**481**	**1,093**	**2.3**	**612**	**1,056**	**6.0**
DIP (t/yr)	**Predevelopment**	**Total baseline**	**Increase factor**	**Anthropogenic baseline**	**Report Card 2013**	**Report Card 2013 change (%)**
Styx	7	8	1.1	0	8	1.2
Shoalwater	9	9	1.0	0	9	0.0
Water Park	10	10	1.0	0	10	0.5
Fitzroy	225	245	1.1	20	243	10.2

Calliope	4	4	1.0	0	4	0.8
Boyne	1	1	1.0	0	1	1.3
Total region	**257**	**278**	**1.1**	**21**	**276**	**10.1**
DOP (t/yr)	**Predevelopment**	**Total baseline**	**Increase factor**	**Anthropogenic baseline**	**Report Card 2013**	**Report Card 2013 change (%)**
Styx	1	1	1.0	0	1	1.1
Shoalwater	2	2	1.0	0	2	0.0
Water Park	2	2	1.0	0	2	0.5
Fitzroy	44	50	1.1	6	50	8.3
Calliope	1	1	1.0	0	1	0.7
Boyne	0	0	0	0	0	1.4
Total region	**50**	**56**	**1.1**	**6**	**56**	**8.2**
PP (t/yr)	**Predevelopment**	**Total baseline**	**Increase factor**	**Anthropogenic baseline**	**Report Card 2013**	**Report Card 2013 change (%)**
Styx	12	29	2.4	17	29	0.6
Shoalwater	3	10	3.3	7	10	0.5
Water Park	4	6	1.5	2	6	1.2
Fitzroy	145	687	4.7	542	653	6.3
Calliope	8	21	2.6	13	21	0.5
Boyne	1	4	4.0	4	4	1.0
Total region	**174**	**759**	**4.4**	**585**	**724**	**5.9**
PSII (kg/yr)	**Predevelopment**	**Total baseline**	**Increase factor**	**Anthropogenic baseline**	**Report Card 2013**	**Report Card 2013 change (%)**
Styx	0	22	0	22	22	2.6
Shoalwater	0	14	0	14	14	0.0
Water Park	0	10	0	10	10	0.9
Fitzroy	0	521	0	521	492	5.5
Calliope	0	10	0	10	10	0.3
Boyne	0	2	0	2	2	0.2
Total region	0	**579**	0	**579**	**549**	**5.1**

Appendix G – Report Card 2010 notes and results

No changes were made to the Fitzroy model pre Report Card 2011. The four model scenario results are presented in Table 38.

Table 38 Report Card 2010 predevelopment, baseline and management change results. Note, these are different to Report Cards 2012–2013 total baseline loads which are the loads that should be cited when referencing this work.

	TSS (kt/yr)	TN (t/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TP (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	PSIIs (kg/yr)
Predevelopment load	547	2,113	769	1,056	289	377	169	34	174	0
Total baseline load	2,034	4,271	1,272	1,790	1,208	1,144	293	60	791	638
Anthropogenic baseline load	1,487	2,157	503	735	919	767	124	26	617	638
Report Card 2010 load	2,018	4,261	1,272	1,790	1,201	1,133	292	60	781	638
Load reduction (%)	1.1	0.4	NA	NA	1.0	1.4	0.3	0.4	1.6	0

Appendix H – Report Card 2011 notes and results

No changes were made to the Fitzroy model between Report Card 2010 and Report Card 2011. The four model scenario results are presented in Table 39.

Table 39 Report Card 2011 predevelopment, baseline and management change results. Note, these are different to Report Cards 2012–2013 total baseline loads which are the loads that should be cited when referencing this work.

	TSS (kt/yr)	TN (t/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TP (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	PSIIs (kg/yr)
Predevelopment load	542	3,230	1,223	1,719	288	481	257	50	174	0
Total baseline load	1,919	4,218	1,272	1,790	1,155	1,081	278	56	747	588
Anthropogenic baseline load	1,377	987	49	72	1,135	600	21	6	573	588
Report Card 2011 load	1,881	4,198	1,272	1,790	867	1,049	277	56	716	563
Load reduction (%)	2.8	2.0	NA	NA	2.3	5.3	5.9	4.8	5.3	4.4

NA – DIN and DON not modelled for management changes, due to no DIN model in HowLeaky.

Appendix I – Report Cards 2012–2013 notes and results

Some changes were made to the Fitzroy model between the production of Report Card 2011 and Report Cards 2012–2013:

- The gully parameteriser (i.e. generating a gully load) was re-run for nature conservation and forestry land uses that had been inadvertently missed during previous model runs. This only added an additional 5% gully supply in the total baseline model.
- Inflow used in as the input to the storage trapping model in Report Cards 2012–2013 instead of outflow which was used in Report Cards 2010–2011.
- Actual storage capacity was used in Report Cards 2012–2013 instead of the maximum storage volume in the storage rating curve in Report Cards 2010–2011. This change is significant where there are many storages and the maximum storage volumes in the rating curves are greater than the actual storage capacities.

The four model scenario results for Report Card 2012 are presented in Table 40.

Table 40 Report Card 2012 predevelopment, baseline and management change results.

	TSS (kt/yr)	TN (t/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TP (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	PSIIs (kg/yr)
Predevelopment load	542	3,230	1,223	1,719	288	481	257	50	174	0
Total baseline load	1,948	4,244	1,272	1,790	1,181	1,093	278	56	759	579
Anthropogenic baseline load	1,407	1,013	49	72	893	612	21	6	585	579
Report Card 2012 load	1,904	4,223	1,272	1,790	1,160	1,066	276	56	734	556
Load reduction (%)	3.2	2.1	NA	NA	2.4	4.4	7.7	0.4	4.3	3.9

NA – DIN and DON not modelled for management changes, due to no DIN model in HowLeaky.