Reef Water Quality Protection Plan 2013

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

Burnett Mary 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 Burnett Mary (BM) NRM region modelled load reductions resulting from improved management practices for sediment, nutrients and herbicides. 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 Burnett Mary region is one of six NRM regions adjacent to the GBR. It is approximately 12% (52,818 km^2) of the total GBR catchment area (423,122 km^2), and is characterised by grazing and forestry occupying 83% of the total area, with intensive agriculture covering about 5% of the total area. The region is comprised of eight drainage basins: Burnett, Mary, Baffle, Kolan, Elliot, Gregory, Isis, and Burrum. The average annual modelled flow (1986–2009) from the BM region is 2.4 million ML, which accounts for 3.8% of the total GBR catchments average annual flow.

The Source Catchments modelling framework (eWater Ltd) was used to calculate sediment, nutrient, and herbicide loads entering the GBR lagoon. A number of 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 were set against the anthropogenic baseline load (2008/2009 land use and management). Improved management practices implemented between 2008–2013 were modelled for four Report Cards (2010–2013) covering management changes in sugarcane and grazing. These were compared to the anthropogenic baseline load and from this a reduction in constituent loads were estimated. An ABCD framework (A = aspirational, D = unacceptable) was used for each industry to estimate the proportion of landholders in each region in each category for the baseline and then following implementation of the improved land management practices. In order to reduce the effect of climate variability, a static climate period that provided a good representation of wet, dry and average periods (1986–2009) were used 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 reporting periods. 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 were used to generate the daily pollutant loads for each individual land use. The paddock scale models HowLeaky and APSIM were used to generate loads for a range of typical land management practices for cropping and cane areas respectively. For grazing areas, the Revised Universal Soil Loss Equation (RUSLE) was used to generate daily soil loss estimates with the grazing systems model GRASP used to determine the relative changes in ground cover (C-factor) resulting from an improved grazing management practice. An Event Mean Concentration (EMC) approach was used to generate loads for forestry, conservation and the remaining minor land use areas.

Source Catchments was coupled to an independent Parameter ESTimation Tool (PEST) to perform the hydrology calibration. A multi-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 was applied. Once calibrated, three criteria were used to manually assess model performance: daily and monthly Nash-Sutcliffe Coefficient of Efficiency (NSE) and difference in total gauging station streamflow volumes. The Nash-Sutcliffe is a measure of how well modelled observed data agree, where 0.81 for monthly flows is considered a good fit. The modelled flows showed reasonable agreement with observed flows with 22 of the 32 gauges having monthly Nash-Sutcliffe values >0.8 and 26 gauges had total runoff volumes within 20% of observed flows.

State and Australian government investment in improved management practices has resulted in noticeable reductions in pollutant loads for Report Card 2010–2013. There has been a total of 3% decline in total suspended sediment (TSS), 15% decline in TN and 9.8% decline in TP from the BM region. The major reductions in TSS were as a result of improved management practice adoption in grazing and the 15% decline in TN was predominantly for dissolved inorganic nitrogen (DIN) due to adoption of the “six easy steps” nutrient management program in the cane industry.

Modelled outputs for the total baseline scenario (2008/2009) indicate that approximately 462 kt/yr of TSS is exported to the GBR from the BM NRM region. This load accounts for 5% of the entire GBR load, with the Mary basin contributing 76% of the BM load (Table 1). The estimated regional TSS load is a five-fold increase from predevelopment loads. Of the 462 kt/yr total TSS exported from the total baseline scenario, streambank erosion contributed 56% while hillslope erosion and gully erosion contributed 36% and 8%, respectively. In terms of the contribution of land uses to TSS export, grazing contributed 28% of total TSS export. Urban and sugarcane contributed 5% and 4%, respectively, with the other land uses contributing 7%. Streambank erosion accounted for the remaining 56% of TSS export.

Of the 2,202 t/yr of total nitrogen (TN) exported from the region, particulate nitrogen (PN) accounts for 776 t/yr (35%). Total baseline TN load is estimated to be about five times the predevelopment load. Grazing and sugarcane contributed 32% and 26% of the TN export, respectively.

For total phosphorus (TP), particulate phosphorus (PP) accounts for 278 t/yr (71%). TP has increased 2.6 times from the predevelopment load. Of the 392 t/yr total TP export, hillslope and streambank erosion contributed 28% and 17% respectively. Grazing contributed 36% of the TP exported. The Mary basin is the greatest contributor for all constituents except PSII herbicides most of which is exported from the Burrum basin. Table 1 provides a summary of the total baseline BM loads, the contribution of BM loads to the total GBR load and the percentage reduction due to improved management practice adoption. The total baseline model estimated 1,552 kg/yr of pesticide export from the BM region predominantly from sugarcane.

Table 1 Summary of Burnett Mary total baseline load contribution to the GBR and load reduction due to improved management practice adoption (2008–2013)

	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)	PSIIs (kg/yr)
Total baseline load	462	392	278	78	35	2,202	775	554	873	1,528
BM baseline load contribution to GBR (%)	5.4	6.2	6.1	6.8	5.8	6.0	6.5	5.3	6.1	9.1
BM load reduction (2008–2013)	2.9	9.8	12.2	4.2	2.4	14.9	6.4	31.1	9.0	27.5

By land use, grazing was the biggest source of TSS contributing 132 kt/yr or about 29% of total export load, followed by urban and sugarcane contributing 5% and 4% of the total load. Grazing (32%) and Sugarcane (26%) contributed the largest total baseline TN load, with sugarcane the greatest contributor of DIN (65% of total baseline load). For TP, grazing (36%) followed by urban (12%) and sugarcane (10%) were the highest contributors, PP was similar with grazing (37%), sugarcane (12%) and urban 11% of the total load. Sugarcane generated the biggest proportion of PSII herbicides (98% of total load), with the remaining 2% coming from grazing and cropping.

In contrast, forestry, horticulture and dryland cropping contributed the largest per unit area of TSS to export (0.12 t/ha/yr, 0.06 t/ha/yr and 0.06 t/ha/yr) respectively, while sugarcane (6 kg/ha/yr) and urban (2.2 kg/ha/yr) were the largest per unit area contributors of TN export. Horticulture (0.66 kg/ha/yr) and sugarcane (0.46 kg/ha/yr) contributed the highest TP per unit area export. Sugarcane was the single most important per unit area contributor (17.4 g/ha/yr) of PSII herbicides exported to the GBR lagoon.

For Report Cards 2010–2013, there has been a total reduction in TSS loads of 3%, DIN 31% and PSII herbicides 28% following mostly Reef Rescue investment in sugarcane in the Six Easy Steps nutrient management program.

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 stream flow 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. This resulted in an under prediction in modelled flows (total volume difference). 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 in the Burnett Mary region where no flow data exists.

Comparison of modelled loads with load estimates from monitoring data indicated that the loads calculated for Burnett Mary are a significant improvement on previous estimates of loads for the region. The results will provide a baseline from which to assess the impact of improved management practices in subsequent years as a result of State and Australian Government investment. Moreover, knowledge of constituent budget and the contribution of the different processes (sources) enable us to prioritise on-ground management actions that would result in optimal impact on water quality improvement and progress towards water quality targets. Spatial patterns of contribution to pollutant export can also give us guidance on the selection of water quality monitoring sites for the collection of data that can be used for both model calibration and validation.

In general, the modelled average annual loads of constituents are lower than most previous modelled estimates for the Burnett Mary region. This is due to the different approaches used to derive the loads, improvements made to constituent generation and transport modelling methodologies and utilising the most recent data sets. Long-term loads generated using a modified Beale ratio were calculated for the Burnett basin end-of-system (EOS) (Joo et al. 20114) and the average annual loads generated by Source Catchments are within recommended ranges of model performance criteria values (Moriasi et al. 2007). Modelled loads and loads estimated from the GBR Catchment Loads Monitoring Program (GBRCLMP) are also generally in close agreement. Modelled TSS, TN and TP loads were, respectively, within 55%, 68% and 70% of measured loads.

It is important to note these are modelled load reductions, not actual load reductions and are based on the adoption of changes in management. Results from this modelling project are therefore a useful indicator of the likely (theoretical) effects of investment in changed land management practices rather than a measured (empirical) reduction in loads.

Major recommendations for enhanced model performance include:

- Re-calibration of the hydrological model to better simulate maximum discharge
- Incorporation of constituents found in sub-surface drainage for cropping such as sugarcane

- Revised gully and streambank erosion input data and
- Moving from the use of annual to seasonal ground cover data inputs.

The current modelling framework is flexible, innovative and 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 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 an underlying hydrological model that produces reliable flow simulations for gauged sites and increased confidence in modelled flows for un-gauged sites.
- Daily time-step capabilities and high resolution Source Catchments 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
BM	Burnett Mary
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
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
Six Easy Steps nutrient management program	Integrated sugarcane nutrient management tool that enables the adoption of best practice nutrient management onfarm. The Six Easy Steps program forms part of the nutrient management initiative involving BSES limited, CSR Ltd and the Queensland Department of Environment and Resource Management (DERM). It is supported by CANEGROWERS and receives funding from Sugar Research and Development corporation (SRDC), Queensland Primary Industries and Fisheries (PI&F) and the Australian Department of the Environment, Water, Heritage and the Arts.
STM	Short-term modelling project

Units

Units	Description
g/ml	grams per millilitre
kg/ha	kilograms per hectare
kg/ha/yr	kilograms per hectare 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).

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Advancements and Assumptions in Source Catchments modelling

The key modelling advancements to note are:

- The 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 spatially and temporally variable cover over the 23 year modelling period, rather than a single static cover factor for a particular land use.
- The representation of identifiable hillslope, gully and streambank erosion processes, with the ability to also use EMC/DWC approaches.
- The inclusion of small, coastal catchments not previously modelled.
- Integration of monitoring and modelling, and using the modelling outputs to inform the monitoring program.
- The 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 2009 QLUMP data.
- The predevelopment land use scenario includes all dams, 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 pesticides and fertilisers 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 reductions are not being modelled in the grains system, as there is no dissolved inorganic nitrogen 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 land use within each subcatchment. These characteristics are then used to provide a single representation of aggregated pollutant generation per land use in each subcatchment.
- The 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” pesticides practices) rather than individual practices. The potential to overstate the water quality benefits of an “A” pesticide 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 (2001) mapping, with opportunities to improve this particular input layer with more detail mapping.
- Within the current state of knowledge, groundwater is not explicitly modelled and is represented as a calibrated baseflow and ‘dry weather mean concentrations’ 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 (Anon 2003) was initiated and updated in 2009 and again in 2013 through a joint Queensland and Australian government initiative (Department of Premiers and Cabinet 2009, 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. It combines monitoring and modelling at paddock through to catchment and reef scales.

Detecting changes in water quality through 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 land management practices. The resultant pollutant load exported from a catchment can be highly variable from year to year because of the above factors. Therefore, the P2R program combines modelling and monitoring data to report on progress towards Reef Plan 2009 targets.

Modelling provides a means of extrapolating 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 Paddock to Reef program. The first Report Card 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 Burnett Mary (BM) regional catchment modelling methodology and results used to report on the predicted average annual end of catchment pollutant loads entering the GBR for predevelopment, anthropogenic baseline (total baseline load minus predevelopment load) and improved management practice adoption in 2008-2010 (Report Card 2010), 2008–2011 (Report Card 2011), 2008–2012 (Report Card 2012) and 2008–2013 (Report Card 2013) from the five basins: Baffle, Kolan, Burnett, Burrum and Mary which make up the BM region. In addition to this document, an annual reef report card (providing an overview of progress towards the targets) is available.

1.2 Previous approaches to estimating 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 constant sediment to discharge relationship for all Queensland catchments based on data from the Burdekin River. This approach tended to overestimate sediment loads, particularly in northern GBR catchments. Moss et al. (1992) attempted to accommodate the regional difference in concentrations by assuming a lower uniform sediment concentration for the northern (125 mg/L) compared with southern (250 mg/L) Queensland catchments. In another approach, Neil and Yu (1996) developed a relationship between unit sediment yield (t/km^2/mm/yr) and mean annual run-off (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; McKergow et al. 2005a; McKergow Prosser, Hughes & Brodie 2005b; Cogle, Carroll & Sherman 2006). Most recently, Kroon et al. (2010) used loads compiled by Brodie et al. (2009) and collated modelling and monitoring information, along with recent monitoring data and the linear regression estimator (LRE) tool (Kroon et al. 2012) to estimate natural and total catchments loads. For the Burnett Mary, Kroon et al. (2010) used modelling results of Fentie et al. (2006) which are total suspended sediment (TSS) load of 3100 kt/yr, total phosphorus (TP) load of 3100 t/yr, and total nitrogen (TN) load of 13,000 t/yr; representing a respective 11.8, 8.9 and 15.3 fold increase in constituent loads from predevelopment conditions. They also estimated 1000 kg/yr of herbicide export from the BM region.

In considering the modelling approach required for the Paddock to Reef Program, there was no “off the shelf” modelling framework that could meet all of the modelling requirements. SedNet alone could not provide the finer resolution time stepping required, and Source Catchments 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 system to have a recognisable effect on model outputs. To address these issues, and answer the questions being posed by policy makers, customised plug-ins for Source Catchments 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 enabling representations of processes such as the effects of temporally and spatially variable ground cover on soil erosion, aggregation of deterministic crop model outputs directly into the catchment model and the incorporation of SedNet gully and streambank erosion algorithms were developed (Ellis & Searle 2014).

1.3 Burnett Mary modelling approach

A consistent modelling approach was used across all NRM regions to enable direct comparisons of export loads. A standardised 23 year representative climate period (1986–2009) was used for all scenarios. The eWater Ltd Source Catchments modelling framework (eWater Ltd 2012, 2013) was used to generate sediment, nutrient and pesticide loads entering the GBR lagoon, with SedNet (Wilkinson et al. 2004) modelling functionality incorporated (Wilkinson et al. 2010, Wilkinson et al. 2014) to provide estimates of gully, streambank erosion and floodplain deposition. Specific and fit for purpose models were used to generate daily pollutant loads for total baseline and improved practices for each individual land use. This included paddock scale models of HowLeaky for cropping (Rattray et al. 2004) and APSIM for sugarcane (Wang et al. 2004), the Revised Universal Soil Loss Equation (RUSLE) for grazing (Renard et al. 1997), with an Event Mean Concentration (EMC) approach used to generate loads for conservation and the remaining land use areas.

The latest remotely sensed bare ground index layers (Scarth et al. 2006) riparian extent mapping (Goulevitch et al. 2002), ASRIS soils information (Brough et al. 2006) were all incorporated into the BM model. The GBRI5 loads monitoring program data (Turner et al. 2012) along with other available historical water quality data was used for model validation. The small coastal catchments were also included into the BM catchment to ensure the total area contributing loads to the GBR were captured in the model. This report outlines the:

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

2 Regional background

The Burnett Mary NRM Planning Region (Figure 1) includes coastal catchments south of the Fitzroy Catchment to the Noosa River, including the RAMSAR listed Great Sandy Straits and the Fraser Island World Heritage Area. The area modelled in this project covers 52,818 km^2. The two largest catchments are the Burnett River (33,038 km^2) and the Mary River (9,340 km^2) which discharges into Hervey Bay at the southern tip of the Great Barrier Reef Marine Park. There are also eight smaller coastal catchments, the Baffle, Kolan, Elliott, Gregory, Isis, Burrum, Great Sandy and Noosa in the NRM region. The Baffle and Kolan basins cover an area of 4,035 km^2 and 2,955 km^2, respectively, while the Burrum, Isis, Elliot and Gregory catchments together cover the remaining modelled area of 3,450 km^2 (Table 2). The Australian Water Resources Council (AWRC) defines these catchments as Basins 134 to 140. BM is approximately 12.5% of the total GBR modelled area (423,134 km^2).

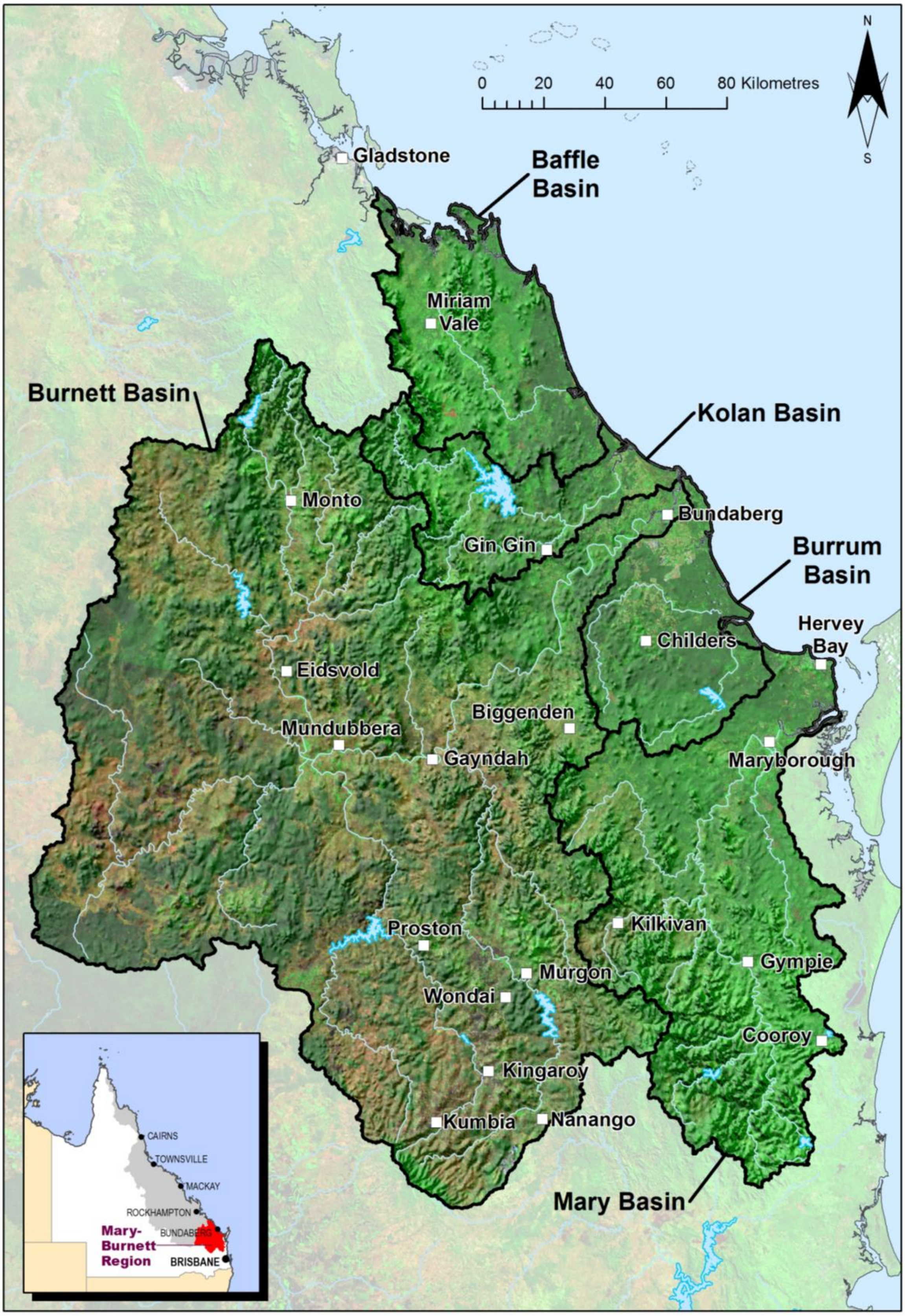

Figure 1 Burnett Mary NRM region

Table 2 Areas of the five basins in the BM in km^2 and as percentage of total regional area

Basin name	Basin number	Area (km^2)	Area (% of total area)
Baffle	134	4,035	8
Kolan	135	2,955	6
Burnett	136	33,038	63
Burrum	137	3,450	7
Mary	138	9,340	18
Total		**52,818**	**100**

2.1 Climate

The region experiences a typically tropical climate with distinct wet and dry seasons. Most of the rain in the region falls between December and March when tropical cyclones cross the Queensland coast from the Coral Sea. Rainfall in the NRM region varies from less than 750 mm/yr in the semi-arid Burnett River Headwaters to 2000 mm/yr in the humid coastal strip and Mary River headwaters (Figure 2). The Lower Burnett and Upper Barambah subcatchments have a similar rainfall pattern to some coastal (Burrum) and the Western Mary subcatchments, but otherwise the Burnett basin is regionally distinctive with rainfall mostly below 800 mm/yr.

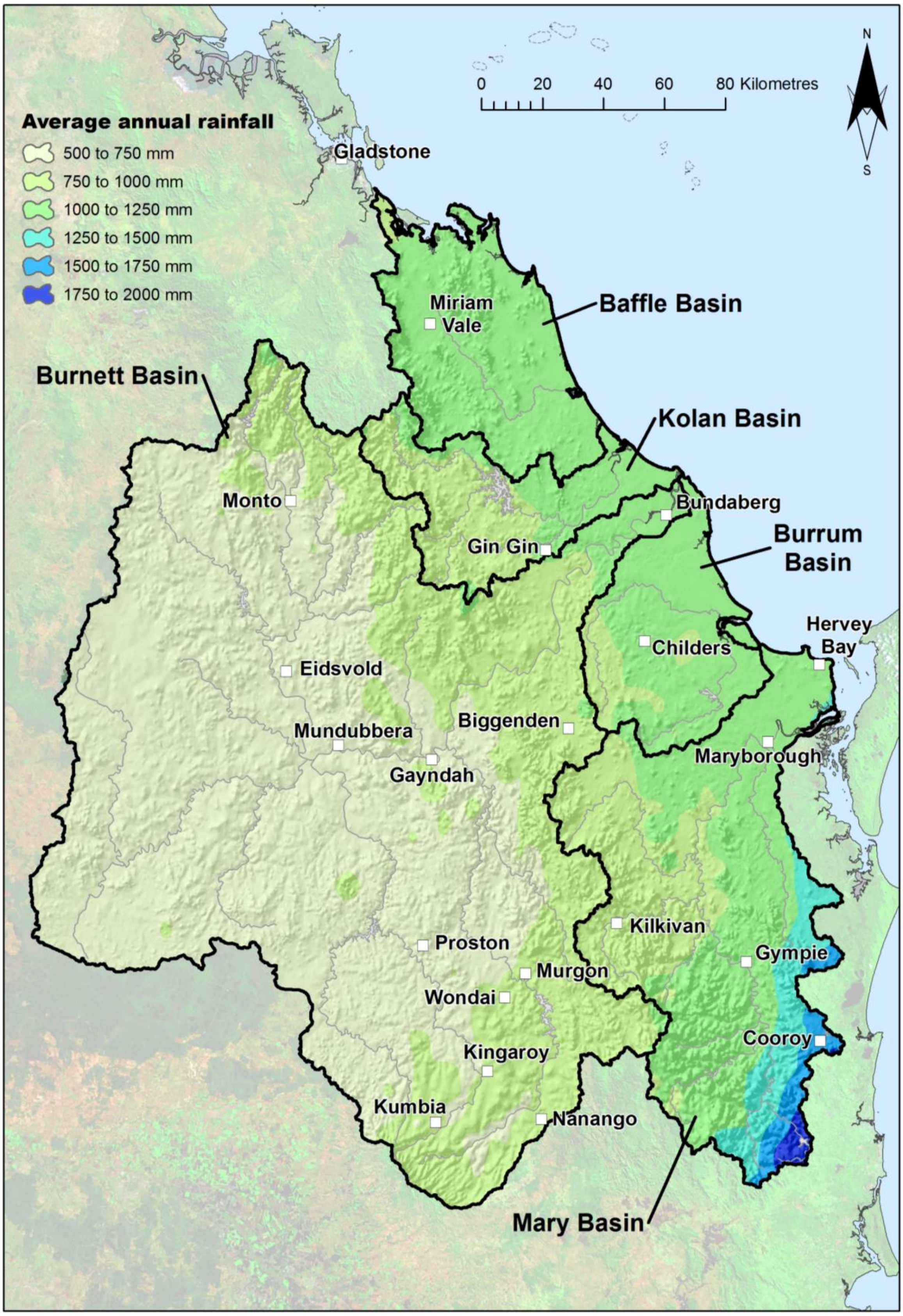

Figure 2 Burnett Mary region average annual rainfall

2.2 Hydrology

The Burnett Mary region experiences a highly seasonal rainfall, and as such, a seasonal pattern in flow. A distinct wet season occurs during December to June, with peak river flows typically occurring during the same period. Low flows are recorded during the dry season (August to November), with flow ceasing altogether at some gauging stations. During the dry season, many of the rivers have disconnected waterholes, although some may be connected by minimal subsurface flow. Figure 3 demonstrates the seasonal nature of flow of rivers in the BM region. Despite the considerable difference in catchment area (Burnett River at Walla—32,070 km^2 vs Mary River at Miva—4755 km^2), the flow between the two sites is similar. Howver, there is considerably higher flow from the Mary River at Miva in April, May, July and August indicating spatio-temporal variability in flow regime in the region.

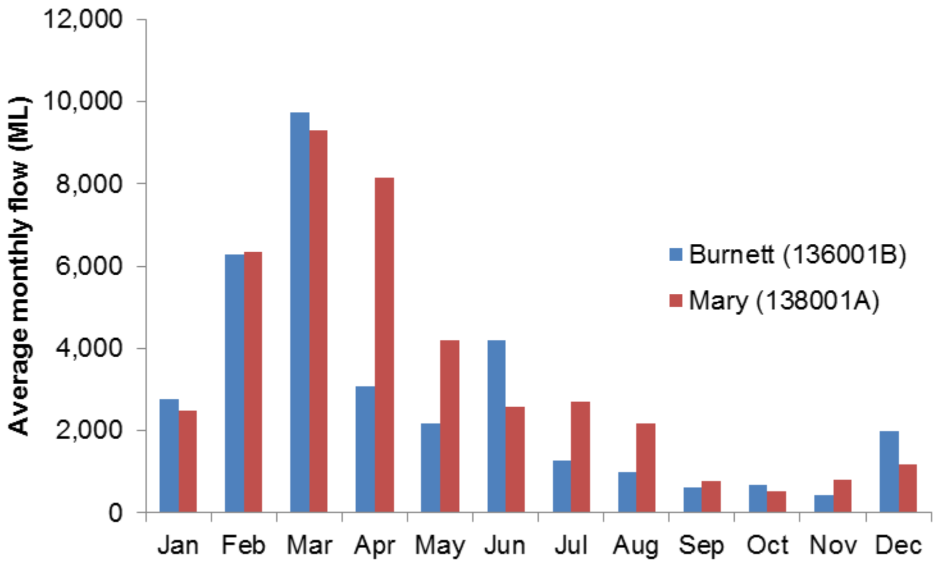

Figure 3 Average monthly flows in the Burnett River at Walla – (136001B) and Mary River at Miva (138001A)

2.3 Geology and soils

Soils in the BM region have been studied by Vandersee and Kent (1983), Smith, Kent & Maher (1993), Donnollan & Searle (1999) and Kent (2002). From these studies, the Burnett Mary can be considered in three parts, the coastal plain and rivers; the mountainous head waters; and the undulating hills in between.

The coastal plain extends about 50 km inland and consists of:

- Acid sulphate soils and remanent beach ridges and dunes formed on a narrow low marine plain adjacent to the coast. Acid drainage has affected water quality in this area
- Sandy to loamy texture contrast soils formed from deeply weathered sedimentary rocks on a relatively flat broad plain west of the marine plain. A low jump-up marks the eastern edge of the plain. Salinity is present in this landscape and the dominant vegetation is wallum
- Deep fertile dark soils formed on narrow floodplains along major rivers
- Deep red soils formed from young volcanic rocks east of Bundaberg.

Rolling hills and plateaus extend west of the coastal plain and make up the majority of the Burnett Mary and consist of:

- Clayey soils formed from basic volcanic rocks on hills
- Sandy soils formed from granite rocks on hills. Some have sodic subsoils and are erodible
- Deep red soils formed from deeply weathered volcanic rocks on plateaus
- Brown or grey sandy or loamy texture contrast soils formed from deeply weathered granitic or sedimentary rocks on plateaus. Some have sodic subsoils and are erodible.

In the west, the catchment boundary is formed by a ring of mountain ranges or high plains and consists of:

- Loamy texture-contrast soils formed on sedimentary, volcanic, acid intrusive and metamorphic rocks on ranges. Most of these soils have sodic subsoils and are erodible
- Dark cracking clays formed on elevated relict alluvial plains at Durong.

2.4 Land use

Land use patterns strongly follow variations in soils and rainfall across the Burnett Mary NRM region. At the regional scale, land uses are structured as a gradient between nature conservation and minimal use (more dominantly in the Mary) to grazing (more dominantly in the Burnett). Irrigated cropping and dry-land cropping are also present in the Burnett, in contrast to fruit and vegetable produce, rural residential, pine forestry, and dairy in the Mary.

The 2009 land use map from the Queensland Land Use Mapping project (QLUMP) (DSITIA 2012b) was the latest land use map available for Burnett Mary at the time of building this model and has been used as the basis for defining the Functional Units (FUs) or land use categories in the model (see Section 3.1.1).The spatial location and breakdown of each FU is presented in Figure 4, Table 3 and Table 4.

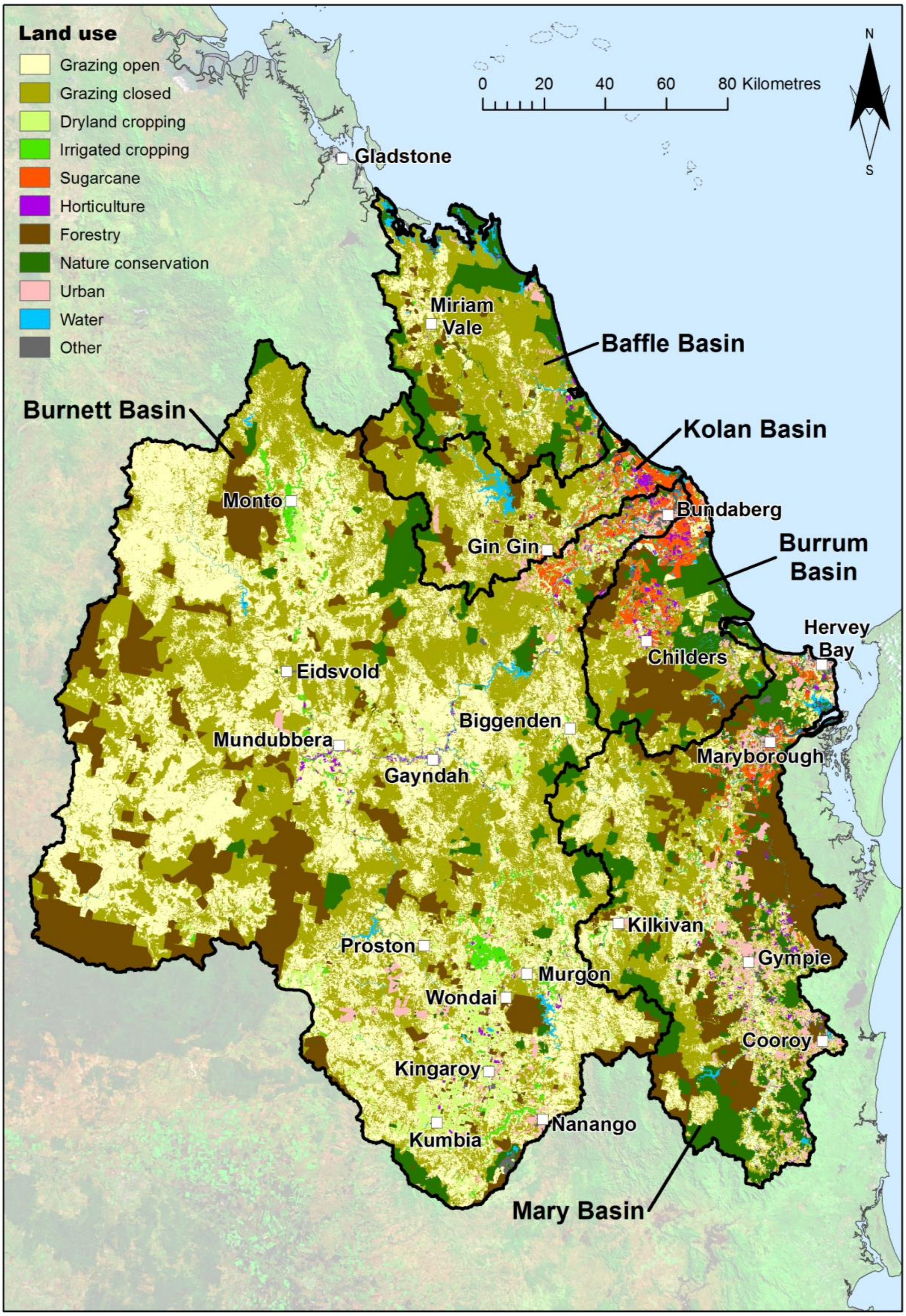

Figure 4 Burnett Mary NRM region land use classification

About 69% of the BM region is classified as grazing land (both open and forested) followed by forestry (14%) and conservation (8%) (Table 3). Whilst sugarcane takes about 1.6% of the BM region, it accounts for 9.2% in the Burrum basin and 5.2% in the Kolan basin (Table 4). Grazing, conservation and forestry are the dominant land uses in all five reporting basins in the BM region. About 9% of the Burrum, 5% of the Kolan and 2% of the Mary is under sugarcane while each of the other basins has less than 2% of its area under sugarcane. Both dryland and irrigated cropping land uses account only 2.5% of the BM region and are mainly in the Burnett basin. Land use area (km^2) in each basin within the BM region is given in Table 30 (Appendix D).

Table 3 Burnett Mary region land use area in km^2 and as a percentage of total area

Land use (2009)	km^2	%
Conservation	4,717	8.9
Dryland cropping	820	1.6
Forestry	7,282	13.8
Grazing forested	19,367	36.7
Grazing open	16,899	32.0
Horticulture	296	0.6
Irrigated cropping	466	0.9
Other	201	0.4
Sugarcane	864	1.6
Urban	1,231	2.3
Water	675	1.3
Total area	**52,818**	**100**

Table 4 The 2009 land use per cent by catchment in the BM region

Land use	Baffle	Burnett	Burrum	Kolan	Mary	Total
Conservation	18.7	4.0	20.9	9.0	17.8	8.9
Dryland cropping	0.0	2.5	0.1	0.1	0.0	1.6
Forestry	7.0	12.2	22.2	9.0	20.6	13.8
Grazing forested	52.7	36.6	27.7	50.7	28.7	36.7
Grazing open	14.6	40.6	9.6	18.1	21.9	32.0
Horticulture	0.4	0.3	1.9	1.1	0.9	0.6
Irrigated cropping	0.1	1.2	0.2	0.2	0.4	0.9
Other	0.2	0.3	1.0	0.1	0.7	0.4
Sugarcane	0.2	0.6	9.2	5.1	2.0	1.6
Urban	1.8	1.1	4.5	3.3	5.8	2.3
Water	4.4	0.6	2.7	3.3	1.2	1.3
Total area	100	100	100	100	100	100

2.5 Water quality issues in the Burnett Mary region

Three Water Quality Improvement plans in the Burnett Mary (Burnett-Baffle Water Quality Improvement Plan, Burrum catchment Improvement Plan and Mary Water Quality Improvement Plan) have identified water quality issues in the region. These include:

- TSS from grazing and streambank erosion,
- Dissolved nutrients from sugarcane, horticulture and urban land uses
- Herbicides from sugarcane, horticulture and cropping land uses.
- Seagrass beds and their dependent fauna are extremely susceptible to inflows of sediment from the mainland. More than 1,000 km^2 of seagrass meadows were lost in Hervey Bay in February 1992 following two large floods in the Mary and Burrum Rivers. As a consequence, the population of dugongs in the area decreased from an estimated 1,466 individuals in 1988 to 92 in late 1992.
- There is believed to be evidence of deterioration in some of the fringing reefs on the Woongarra coast due to discharges of stormwater and/or treated sewage effluent.
- Nutrient rich runoff and drainage to shallow groundwater in cropping areas affects water quality through lateral water movement into the waterways.

3 Methods

The Burnett Mary model was built within the Source Catchments modelling framework. Source Catchments is a water quality and quantity 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, sediment and contaminants, by integrating a range of models, data and knowledge. Source Catchments supersedes the E2 and Water CAST modelling frameworks (eWater Ltd 2013). Model input data is provided in Appendix D. A summary of input data sets is also available in Waters and Carroll (2012).

3.1 GBR Source Catchments framework

A Source Catchments model is built upon a network of subcatchments, links and nodes (Figure 5). A subcatchment is further delineated into 'Functional Units' (FUs) based on common hydrology response or behaviour, (eWater Ltd 2012). 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 and 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.

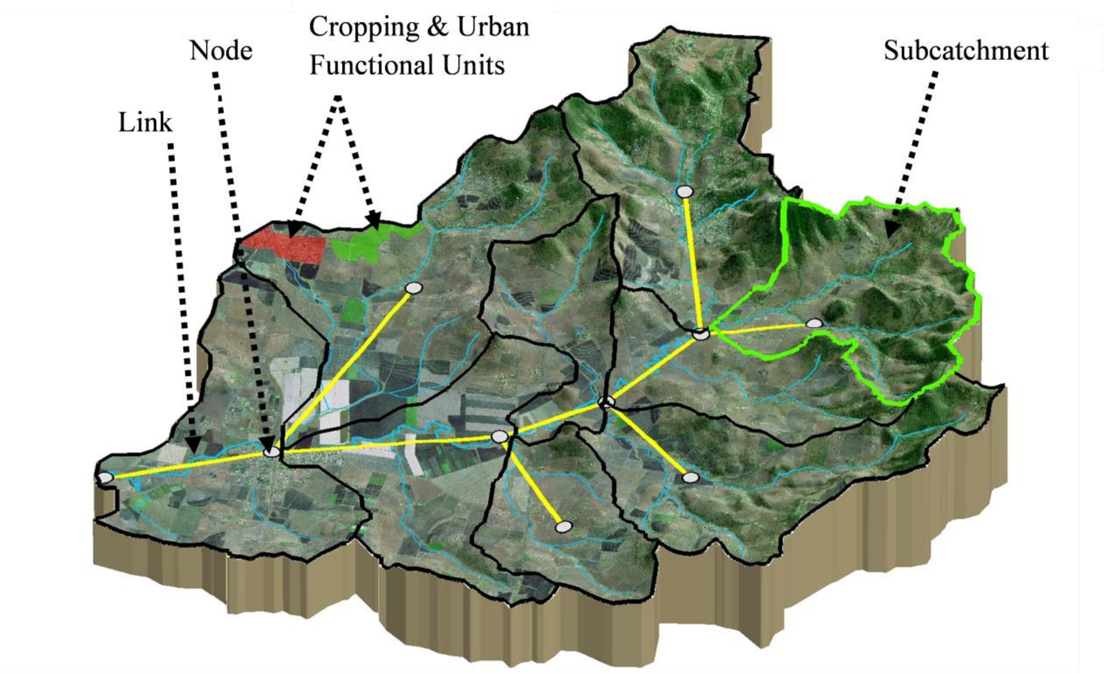

Figure 5 Example of a functional unit and node-link network generated in Source Catchments. These components represent the subcatchment and stream network

3.1.1 Land use functional units

In the Burnett Mary region, the most recent land use mapping from the Queensland Land Use Mapping Project (QLUMP) (DSITIA 2012a–b) was used to define the Functional Units (FUs) which were mapped using 2009 imagery. The original detailed QLUMP categories were reclassified into 11 major land uses (including water). 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 during calibration and to utilise separate C-factor relationships for these grazing systems for which RUSLE was used to model hillslope erosion. 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 Burnett Mary Source Catchments model encompasses the NRM region with five 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 were manually added to the DEM derived subcatchment layer in a GIS environment, based on visual assessment of aerial photography. The final subcatchment map was then re-imported into Source Catchments. A total of 597 subcatchments (including 19 manually defined low-relief coastal catchments) were generated with an average subcatchment area of 88 km^2 (Figure 6). 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. An arbitrary node was created as a 'common 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 and available computing resources (Wilkinson, Henderson & Chen 2004).

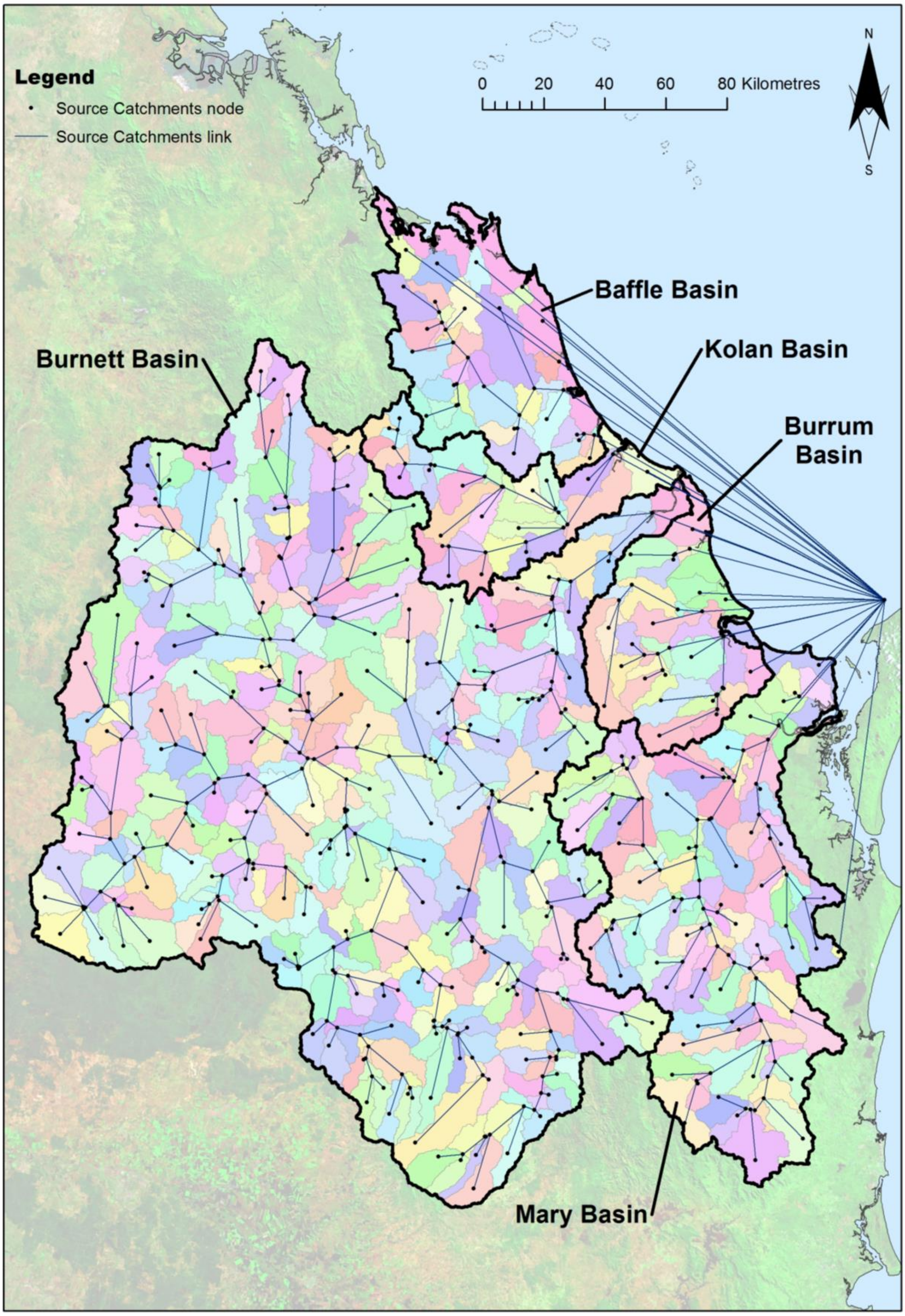

Figure 6 Burnett Mary region subcatchment, node and link network

3.1.3 Runoff generation

Six rainfall runoff models are available within Source. A comparison of the six models (Vaze et al. 2011) concluded that there is little difference between these six models for broad scale application. The SIMHYD rainfall runoff model was chosen due to its extensive application and proven performance to satisfactorily estimate streamflow across Australia (Chiew, Peel & Western 2002) and in particular for a large catchment in the GBR (Ellis et al. 2009). An investigation of the performance of a number of other models available in Source was undertaken (Zhang et al. 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. SIMHYD is a catchment scale conceptual rainfall runoff model that estimates daily streamflow from daily rainfall and areal potential evapotranspiration (PET) data (eWater Ltd 2013).

Each FU possesses a unique instance of the SIMHYD rainfall-runoff, and constituent generation models. 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 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 Limited 2012).

3.1.4 Constituent generation

In the GBR Source Catchments framework there is the ability to link to external models and add your own component models as specific 'plug-ins' to customise for the particular modelling objectives. This capability has been extensively used to incorporate the most appropriate constituent generation, filtering and routing models. SedNet/Annex 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 long-term average annual estimates of gully and streambank generation. 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 sub-annual resolution will yield results that are difficult to reconcile with observed events or data. Figure 7 shows the conceptual diagram of constituent balance in the GBR Source Catchments model.

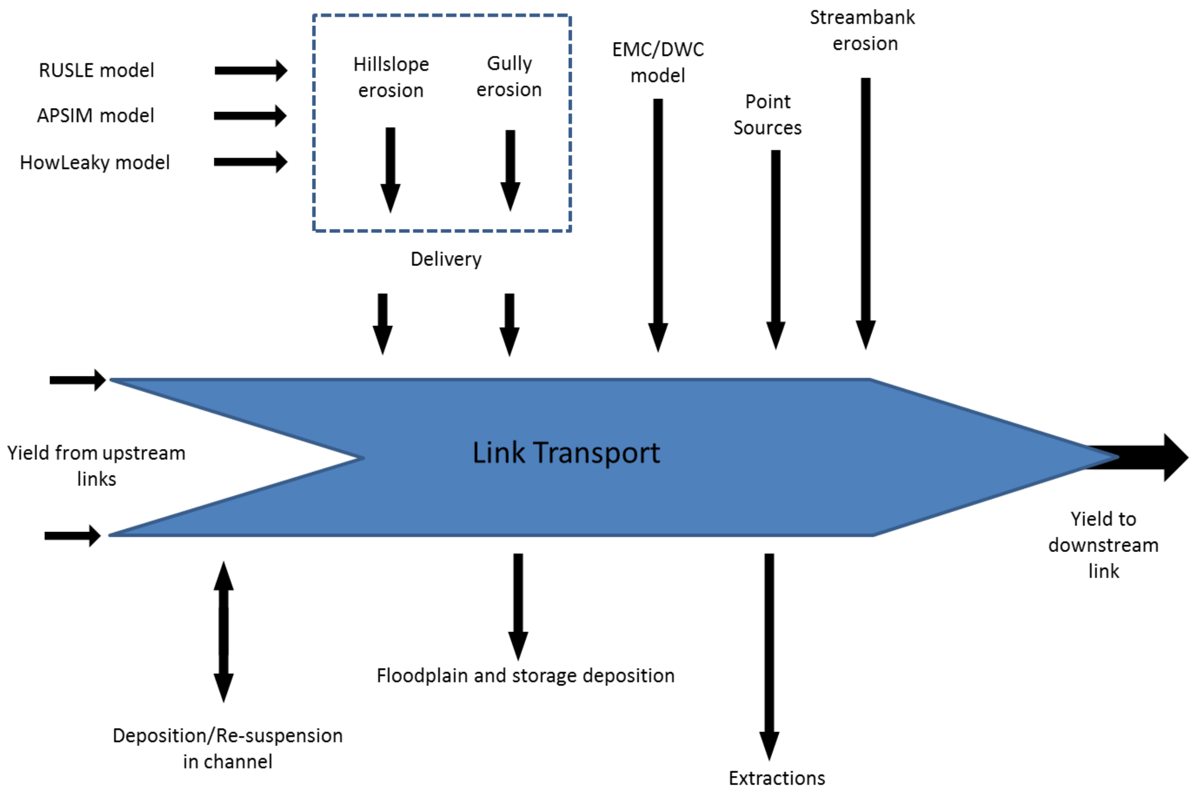

Figure 7 Conceptual diagram of GBR Source Catchments model

The APSIM (Agricultural Production Systems Simulator) model was chosen for modelling sugarcane (Keating et al. 2003), particularly for DIN in runoff. The HowLeaky model, with some enhancements, was used to model herbicides and phosphorus in sugarcane and all constituents for cropping areas (Robinson et al. 2011; Rattray et al. 2004). The paddock model outputs from changed management are then linked to Source Catchments to produce relative changes in catchment loads. It has been recognised that there will be an increasing demand to improve and re-interpret the models at sub-annual (seasonal, monthly and recognised event) temporal scale, and this is the reason the daily time-step of the GBR Source Catchments framework has been selected. Future work will look to examine the underlying concepts and available daily input data with the aim that these models become more robust at sub-annual time-steps.

3.1.5 Climate simulation period

A 23 year climate period was chosen (1/7/1986–30/6/2009). The modelling was constrained to this period for three reasons 1) it coincided with the availability of bare ground satellite imagery from 1986, 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 are used to calculate daily runoff. Rainfall and potential evapotranspiration (PET) inputs were derived from the Department of Natural Resource and Mines (DNRM) Silo Data Drill database (Silo - Queensland Department of Natural Resources and Water 1998). 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 this 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' (sub-surface seepage and low energy overland flow) 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 or link models.

3.2.1 PEST calibration

Hydrology calibration was undertaken using PEST (Doherty 2009), a model-independent parameter estimation tool. Parameter optimisation incorporated both the SIMHYD rainfall-runoff parameters of three lumped hydrologic response units and the 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 exceedance curves to achieve an optimum calibration. The monthly flow volume component works to ensure modelled volumes match measured volumes over long periods, the exceedance values work to ensure the flow volumes are proportioned well into base flows and event flows, while the log transformed daily flows work to obtain replication of the hydrograph shape (Stewart 2011). The three objective functions have been used successfully in other modelling applications (Stewart 2011). All three objective functions were weighted equally. For all observation groups the absolute value of a component will vary widely depending on the magnitude of the values contained within each component and the number of values in each time-series. This does not mean however, 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 32 BM gauges used in the calibration process. Performance was assessed for the entire calibration period 1/1/1970–31/3/2010. Most gauges had the full flow record for the 40 year calibration period.

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

- Daily Nash Sutcliffe Coefficient of Efficiency (>0.5 acceptable)
- Monthly Nash Sutcliffe Coefficient of Efficiency (>0.8 desirable)
- Percentage volume difference ± 20%

Double mass plots and flow duration curves (Figure 41–44, Appendix C) aided in assessing calibration performance. Further 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 total of 32 gauging stations were identified as suitable for PEST calibration, in the Burnett Mary region. The selection of gauges was based on the following criteria:

- Gauges located on the modelled stream network
- Had a minimum of 10 years of flow record (post 1970) with data meeting a minimum quality code.

Where gauges had been relocated over time, and there was less than 10% difference in contributing area, time-series data were merged into one continuous dataset. About 19% of the region was considered ungauged and hence not calibrated.

3.2.3 Rainfall runoff model parameterisation approach

The SIMHYD rainfall runoff model contains nine parameters. Of the nine parameters, seven 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 parameters were used as the starting values; see Table 28 (Appendix C). The final set of SIMHYD and Laurenson flow routing parameters used to generate runoff can also be found in Table 29 (Appendix C).

3.2.4 Model regionalisation

To further simplify the number of adjustable parameters considered by PEST during calibration, thereby reducing model run-time to an acceptable length, FU's deemed to have similar hydrologic response characteristics were grouped into three broad 'hydrologic response units': forest, grazing and cropping (Table 27, Appendix C). These broad groupings were selected based on previous research across 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. Functional units, 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 considered. This method of parsimony implies uniformity within, but not between, calibration regions.

Modelled subcatchments were divided into 32 calibrated regions (i.e. one region per calibration gauge) and one ungauged region given the code 99 (Figure 8). Regions were based on the contributing area to a gauge. Nested gauge regions had contributing areas minus the contributing area of the upstream gauge. The nearest neighbour approach was used to derive parameters for ungauged subcatchments (Merz et al. 2006; Merz & Blöschl 2004; Chiew & Siriwardena 2005). Ungauged catchments comprised 19% of Burnett Mary modelled area. Because of the lack of data to calibrate models, runoff modelling in ungauged catchments is one of the major problems facing hydrologists. To address the problem, modellers have typically been using regionalisation whereby model parameters for ungauged catchments are sourced from calibrated catchments. Spatial proximity, physical similarity and integrated similarity are three methods that have been commonly used to transfer parameters from donor (gauged) catchments to receiver (ungauged) catchments. Spatial proximity has been found to work well in previous modelling studies (Merz, Blöschl & Parajka 2006; Merz & Blöschl 2004; Chiew & Siriwardena 2005), as neighbouring catchments would have similar hydrologic response due to their climatic and physical similarity. Therefore, the spatial proximity approach, where parameters from a gauged donor catchment are assigned to the nearest receiver ungauged catchment, was chosen for this study.

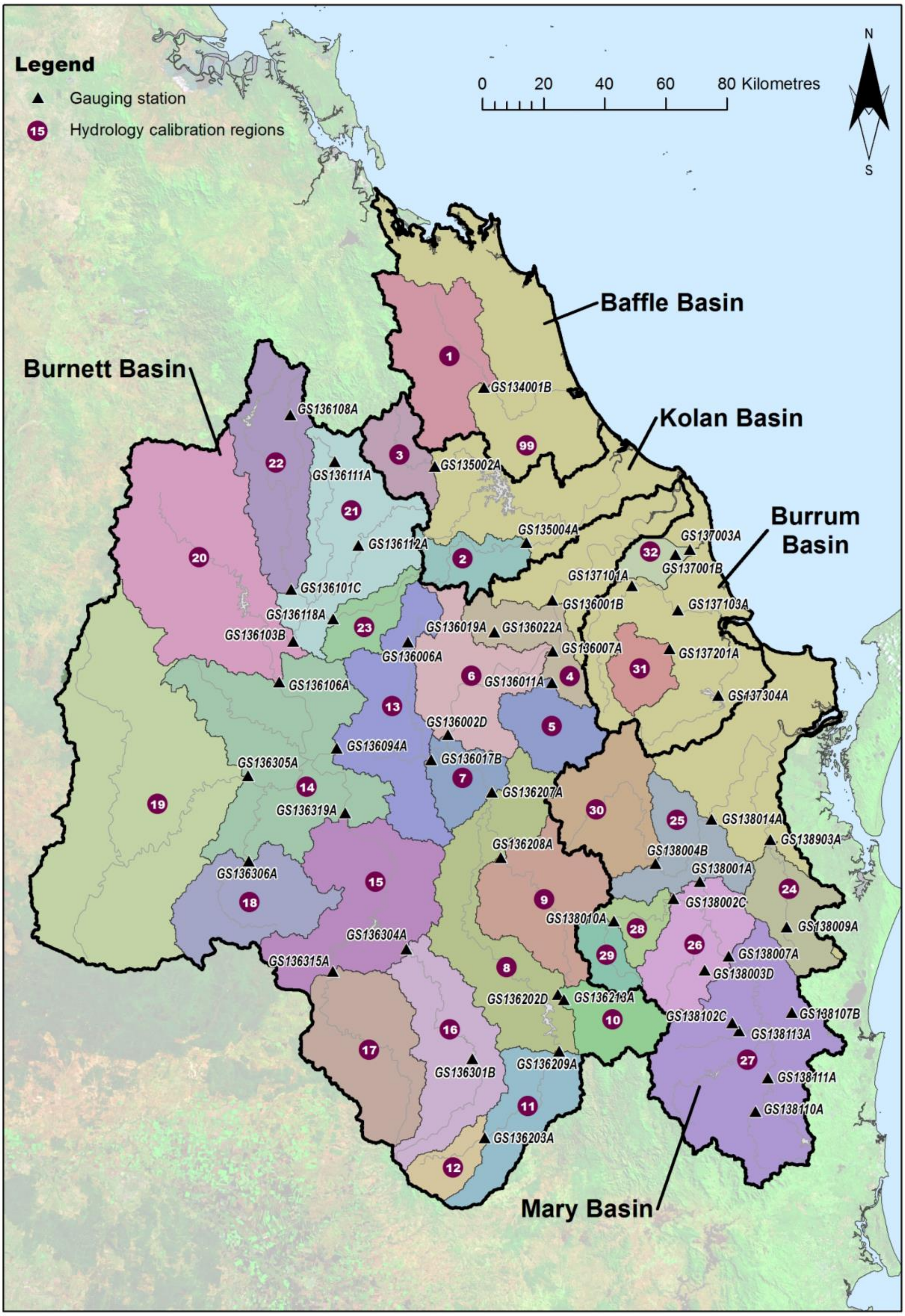

Figure 8 Spatial location of the 32 PEST hydrology calibration regions and the ungauged region in the Burnett Mary

3.3 Constituent modelling

The key water quality constituents modelled are outlined in Reef Plan shown in Table 5. 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 (Brodie et al. 2013). The choice of a <20 µm to determine the fine sediment fraction is also consistent with previous SedNet modelling studies, which used a clay percentage layer from the ASRIS database based on the International particle size fraction classification, to calculate particulate nutrient (PN and PP) loads. Moreover, Packett et al. (2009) found that for the in-stream sediment sampled for some subcatchments, and at the Fitzroy basin outlet, over 95% of the 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 four PSIIs, however due to the unavailability of application data elsewhere it was only modelled in the Fitzroy and Burnett Mary basin using estimated EMC values. 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.

Additional herbicides modelled but not required for reporting include the knockdown herbicides paraquat, glyphosate and 2,4-D, and the alternative residual herbicide metolachlor. These additional herbicides were included in the suite of compounds modelled to allow representation of the water quality impacts of a shift away from a reliance on residual herbicides, such as those listed as priority herbicides in Reef Plan 2009.

Table 5 Constituents reported

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)
PSIIs	
Atrazine, diuron, hexazinone, tebuthiuron	

The flexible nature of the Source Catchments framework allows a range of models to be applied to undertake the required constituent modelling objectives (Table 6). The paddock scale models used were APSIM (Keating et al. 2003) (with the HowLeaky model for pesticides and phosphorus) for sugarcane and Howleaky (Rattray et al. 2004) for cropping and RUSLE for grazing. In addition, SedNet (Wilkinson et al. 2004) functionality has also been incorporated to model the contribution of hillslope erosion in grazing, gully and streambank erosion. A detailed description of the models used at the FU and Link Scale can be found in the companion report '*Dynamic SedNet Component Model Reference Guide* (Ellis & Searle 2014), Shaw et al. (2013) and Shaw & Silburn (2014).

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

Constituents	Cropping-sugarcane	Cropping-dryland and irrigated	Grazing-open and closed
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 (Ellis & Searle 2014) 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 and ANNEX catchment scale water quality model (that is, gully, streambank and hillslope 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 style 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
- the data requirements of each of the component models
- the methodology used to simulate constituent generation and transport process for each functional unit (land use) 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 of the dominant factors impacting on hillslope runoff and erosion in the GBR. Previous studies suggest that gully erosion is also a significant source of sediment to the GBR (Dougall et al. 2006; Wilkinson et al. 2013). Given grazing occupies such a large area of the GBR it is important that the models chosen represent the dominant erosion processes occurring and the spatial variability observed across such a large area. ‘Dynamic SedNet’ incorporates daily rainfall, spatially and temporally variable cover to generate erosion.

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

3.3.1.1 Hillslope sediment, nutrient and pesticide generation

3.3.1.1.1 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). 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. The model is mathematically expressed as:

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

Where
A = soil erosion per unit area (t/ha/day)
R = Rainfall erosivity EI30 (MJ.mm/ha/h/day)
K = Soil erodibility (t.ha.h/ha/MJ/mm)
L = Slope Length
S = Slope Steepness
C = Cover management factor
P = Conservation practice factor (set to 1 in this study)

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 BM model are shown in Appendix D.

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 et al. 2006).

Slope 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) reprojected and resampled to 30 m. The use of a shuttle DEM 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 DEM's, covering floodplains in the Fitzroy catchment.

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.

Cover and management factor (C-factor) - can be applied in Source Catchments at three time-steps: monthly, annual and static. 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. Seasonal or daily cover estimates will be the ultimate goal when relevant satellite imagery is available. However, 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 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%). To minimise this effect, and improve the delineation of 'tree' areas the 2009 FPC coverage was used to represent the 'tree' coverage, for all years. The 2009 FPC coverage was used to represent the 'tree' coverage, for all years.

Where FPC <20%, C-factors (C_f) was derived as follows (Rosewell 1993):

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

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:

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

Conservation practice 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 proportion located in the ASRIS layers (the best data source available to generate this layer at the GBR scale). The clay and silt proportion 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 proportion 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 et al. 2004 & short term modelling refs). 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 31, Appendix D). The equation takes the form Equation 4:

$$TSS\ (kg/day) = \text{RUSLE sediment load (kg/day)} \times (\text{silt}_{\text{prop}} + \text{clay}_{\text{prop}}) \times \text{HSDR} \quad (4)$$

This estimates the TSS load (kg/day) which reaches the stream.

3.3.1.1.2 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 (Equation 5):

$$HPN\ load\ (kg/day) = \text{RUSLE sediment load}\ (kg/day) \times \text{Clay}_{prop} \times \text{SurfaceNutrient Concentration} \times \text{HSDR} \quad (5)$$

Where HPN = Hillslope particulate nutrient, ER = Enrichment ratio and NDR = Nutrient delivery ratio.

This estimates the total suspended nutrient load which reaches the stream. The surface soil nutrient layers were obtained from the Queensland ASRIS database.

For the dissolved nutrient load, an EMC/DWC value (mg/L) is multiplied by the quick and slow flow output. These models are described in more detail in the accompanying Model Reference Guide (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 given in Table 34 (Appendix D). Three rasters are required as inputs to these models, two nutrient rasters (surface nitrogen and phosphorus), as well as a surface clay (%) raster.

3.3.1.1.3 Herbicide generation models

Tebuthiuron is the predominant herbicide used in grazing lands to control re-growth. Tebuthiuron applications in grazing lands are to selected areas of land and are 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 has been used (Equation 6) 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.

$$\text{Daily Tebuthiuron load (kg/ha)} = \text{EMC} \times \text{quickflow} + \text{DWC x slow flow} \quad (6)$$

3.3.1.2 Gully – sediment, nutrient generation models

The gully modelling approach is based on the SedNet gully modelling methodology (Prosser et al. 2001) applied extensively across GBR (McKergow et al. 2005b; Dougall et al. 2009; Hateley et al. 2005).

Gully TSS 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 Functional Unit 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 average annual gully sediment supply (ASS) is given by:

$$\text{ASS (t/y)} = \left(\frac{\rho_s \times a_{xs} \times GD_{FU} \times A_{FU}}{\text{Age}}\right) \quad (7)$$

Where:
ρ_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 Functional Unit
A_{FU} = Area of Functional Units (m^2)
Age = Years of activity to time of volume estimation (e.g., year of disturbance to year of estimation)

Equation 7 gives total average annual gully sediment supply. In order to estimate the fine sediment supply, we multiply ASS by the silt plus clay proportion in the subsoil. 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 32, Appendix D). The National Land and Water Resources Audit (NLWRA) gully density layer was used as the input raster (km/km^2) for gully density in Burnett Mary. To date, much of the Australian literature 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 (Prosser & Winchester 1996; Hughes et al. 2001). To be consistent with previous modelling studies (e.g., Fentie et al. 2006), a 10 m^2 gully cross-sectional area has been applied in the BM model. The soil bulk density (g/cm^3) and B horizon clay and silt (%) raster 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 Burnett Mary model, a uniform value of 1900 was applied. The inference here is that major gully expansion started during this time (Silburn et al. 2012).

Similar to the hillslope nutrient generation, gully nutrients are derived as a function of the gully TSS load. Surface and subsurface nutrient concentrations are multiplied by the gully sediment load to provide an estimate of the gully nutrient contribution and the subsurface clay %. Three rasters are required as inputs to these models, two nutrient rasters (sub-surface nitrogen and phosphorus), as well as sub-surface clay (%).

3.3.2 Sugarcane constituent generation

For 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 *Cropping Sediment (Sheet & Gully)* model is setup specifically to collate all time-series loads of daily soil loss in t/ha from APSIM for a given modelling FU and subcatchment and combines this with the gully erosion calculated for sugarcane areas within the same subcatchment. Daily time series loads of fine sediment and DIN in runoff were supplied from APSIM model runs for sugarcane FUs.

3.3.2.1 Hillslope - sediment, nutrient, herbicide generation

Daily time-series loads of TSS and DIN were supplied from APSIM model runs for sugarcane FU's. Hillslope erosion was predicted in APSIM using the (Freebairn & Wockner 1986) form of the Revised Universal Soil Loss Equation (RUSLE) described in (Littleboy et al. 1989). Erosion estimates provided by APSIM were adjusted for slope and slope length before being run in Source Catchments. Slope and slope length were derived from the digital elevation model (DEM) and slope values were capped at 8%.

Runoff in APSIM was modelled using the Curve Number approach. Model runs were assigned to mapped soils in the BM based on similarity of surface texture and curve number in an effort to assign appropriate runoff estimates. Runoff drives the offsite transport of other constituents in APSIM and HowLeaky.

DIN loads modelled by APSIM were imported directly as supplied. Pesticide and phosphorus loads were modelled using HowLeaky functions based on the outputs of the APSIM model set up of cane systems for water balance and crop growth. The HowLeaky pesticide and phosphorus models are described for dryland and irrigated cropping below. Further details on the APSIM and HowLeaky models and the parameters used to define simulations of cane are provided in the paddock modelling technical report (Shaw & Silburn 2014).

There were differences between sugarcane areas reported in the first report card compared to the QLUMP derived cane area used for the modelling. An area correction factor was therefore applied in the model to align with the actual cane area. The correction factor was required to reduce the QLUMP cane areas to account for headlands not cropped and areas under fallow (assumed 20% under fallow).

3.3.2.2 Gully – sediment, nutrient generation - 'Dynamic Gully Model'

Gully modelling for cane lands follows the same methodology as for cropping and grazing lands. Similar 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 sub-surface soil nutrient concentrations.

3.3.3 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 Cropping Sediment (Sheet

& Gully) model is setup specifically to take time-series loads of daily soil loss in t/ha through hillslope erosion, as calculated by HowLeaky (Rattray et al. 2004) in this case, and combines it with the daily gully erosion estimate. Daily time series loads of fine sediment, phosphorus and herbicides in runoff 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 Wet Tropics were run in the HowLeaky model to represent unique combinations of soil groups, climate and land management.

3.3.3.1 Hillslope sediment, nutrient and pesticide generation

Daily time-series loads of TSS, nutrients and herbicides were supplied from HowLeaky model runs for the dryland and irrigated cropping FUs. Simulations of a range of typical cropping systems in the Burnett Mary were run in the HowLeaky model to represent each unique combination of soil, 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 daily within the HowLeaky model 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.

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. Dissolved P is not explicitly modelled for management practice change, however within the model, dissolved P changes with runoff, so less runoff results in less offsite transport of dissolved P. With regard to particulate P, management practices affect suspended sediment movement and thus affect PP runoff. This is because a) there is no GBR P management practice framework, and b) there is no reporting on P management practice adoption.

Herbicide mass balance and runoff losses were modelled using HowLeaky (Shaw et al. 2013), 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).

For a detailed description of the HowLeaky model and the parameters used to define simulations of dryland and irrigated cropping, refer to the paddock modelling technical report (Shaw and Silburn 2014).

3.3.3.2 Gully sediment, nutrient generation

Gully modelling for cropping lands follows the same methodology as for grazing lands (Section 3.61.1). As in 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.

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

For the remaining land uses (forestry, nature conservation, urban, 'other' and horticulture), Event Mean Concentration/Dry Weather Concentration (EMC/DWC) models were applied (see Table 34 and Table 35 for values). In comparison to grazing, cropping and sugarcane areas, these land uses had a small relative contribution to total region loads, except for nature conservation for some constituents. In the absence of specific models for these land uses, EMC/DWC models were applied to give an estimate of the daily load, where (Equation 8):

$$\text{Daily load (kg)} = (\text{EMC} \times \text{quick flow runoff}) + (\text{DWC} \times \text{base flow runoff}) \qquad (8)$$

Where quick flow runoff represents the storm runoff component of daily runoff and the remainder being base flow. A constituent EMC/DWC (mg/L) model was applied for a particular functional unit, a parameter value 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, Waters and Packett 2007) or from data collected recently from neighbouring subcatchments. When reliable long-term annual monitoring data was available (e.g. EMC values for horticulture from the Burnett paddock research monitoring data) 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 20th percentile of daily flows. 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.

We chose an EMC/DWC model for nature conservation, due to problems with the application of the USLE style model in past modelling efforts. Using the USLE to estimate soil erosion especially from steep rainforest areas has shown to overestimate sediment loss (Hateley et al. 2005; Armour, Hateley & Pitt 2009). In our case, we used EMC/DWC values from locally derived monitoring. However, a limitation of the current EMC/DWC approach is that erosion processes such as gully and hillslope erosion cannot be identified. Currently 26% of the Burnett Mary area was modelled using the EMC/DWC model and future modelling work will address this issue with the aim to separate out hillslope and gully erosion processes where EMC/DWC models are applied.

To derive an estimate for the total hillslope and gully contribution for this report, 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.

3.3.5 Point sources

Sewage treatment plants (STP's) were deemed a significant contribution to nutrient loads exported to the GBR. The larger STP's were included with an arbitrary criterion of a minimum 10,000 equivalent person's (EP) capacity. Table 7 shows details of STPs included in the BM model. STP details and data for the 2000–2004 were provided by DERM's (formerly Environment Protection Agency) Point Source Database (PSD).

Table 7 Sewage Treatment Plants with > 10,000 equivalent persons

Name of STP	Basin	Longitude	Latitude	DIN (kg/yr)	DON (kg/yr)	DIP (kg/yr)	DOP (kg/yr)
East Wastewater Treatment Plant	Burnett	152.369	-24.851	24,885	6,615	8,383	2,364
Gympie Sewage Treatment Plant	Mary	152.640	-26.183	33,047	8,785	7,051	1,989
Eli Creek Sewage Treatment Plant	Burrum	152.816	-25.273	6,822	1,813	1,319	372
Pulgul Creek Sewage Treatment Plant	Burrum	152.877	-25.331	1,787	475	1,122	316

The point source parameteriser 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 Total N, Total P and Ammonia (as N-NH3). Twelve STP's from Queensland with recorded concentrations of DIN, DON, DIP, DOP Total N and Total P were used to calculate the mean percentage of each constituent to the total. Of the 12 STPs, 8 were tertiary and 4 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. Data pairs were discarded where the speciation concentration added together was greater than the Total N or Total P concentration. The fixed percentages (Table 8) were applied to Total N and Total P 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 8 TN, TP speciation ratios

	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

3.3.6 In-stream models

The in-stream processes represented in the model are streambank erosion, decay, channel deposition and remobilisation, and floodplain deposition. The models that have been applied are: the *SedNet Stream Fine Sediment* model and *SedNet Stream Coarse Sediment* model. The Lewis model (described later) has been applied to deposit TSS and particulate nutrients in storages. Dissolved nutrients and herbicides were not generated at a link scale. For herbicides, decay models were applied see below.

3.3.6.1 Streambank erosion

The *SedNet Stream Fine Sediment model* calculates a mean annual rate of 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 (2013) and Ellis and Searle (2013), also see Table 36 (Appendix D) for parameter values. The *SedNet Stream Particulate Nutrient model* calculates PN and PP 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.

3.3.6.2 In-stream deposition, decay and remobilisation

The implemented in-stream model allows both the deposition and remobilisation of fine and coarse sediment. However, with limited data available to validate this component at the time of model development, remobilisation and in-stream deposition 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. Hughes et al. (2010) note that in-channel benches are an important store of large volumes of sediment in the Fitzroy catchment, however these benches are predominantly comprised of sand. A small fraction of fine sediment may be trapped in these coarse (bedload) deposits, however the time scale for fine sediment movement is much shorter and thus this fraction is ignored in the bedload budget (Wilkinson et al. 2004). For fine sediment it was assumed that there was no long-term fine sediment deposition in-stream, and that all suspended sediment supplied to the stream network is transported (Wilkinson et al. 2004). As new science becomes available on fine sediment in-stream deposition (and remobilisation) processes, applying these models will be investigated. Currently research is being undertaken in the Fitzroy, Burdekin and Normanby catchments (Brooks et al. 2013) which may help to validate this component. Furthermore, in-stream deposition and remobilisation are both influenced by stream flow energy, which itself is controlled by stream geometry parameters that are difficult to determine across a large model. 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 BM 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 2014). Half-lives were taken from the DT50 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; 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, pers. comm.). Where values were not available, 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 Table 37 (Appendix D).

3.3.6.3 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 2013; Prosser et al. 2001). The ‘sediment settling velocity’ parameter is applied in the SedNet Stream Fine Sediment Model.

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 modelled.

3.3.6.4 Node Models

Nodes, in the model, represent stream junctions or points in a stream network where catchment processes or behaviour can be represented at nodes. For example, water can be added to inflow nodes, extracted from observed extraction and/or time-series order nodes, lost from loss nodes, or recorded at gauge nodes. A node can be used to represent processes that may take place over a large physical area but that, for modelling purposes, occur at a single point, such as inflows from a catchment, or extractions from a group of off takes (eWater Ltd 2013).

3.3.6.4.1 Extraction, inflows and loss node models

To simulate the removal of water from storage 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 model (IQQM) runs. The BM model includes a total of 77 node models. Input data and locations of the nodes have been provided by the Surface Water Assessment Group, Department of Natural Resources and Mines (1999, 2001, 2002) which used IQQM for Water Resource Planning in the region using 11 models listed in Table 9. Whilst some aggregation has been done, we have tried to maintain the location of IQQM nodes included in the Source Catchments model.

Table 9 Details of IQQM models which were sources of input for the 77 node models

IQQM model	Start	Finish	Reference
Baffle	1/1/1889	30/06/2007	DNRM (2010)
Barker/Barmabah	1/1/1890	30/06/1997	DNRM (1999)
Boyne	1/1/1890	30/06/1997	DNRM (2001)
Bundaberg WSS	1/1/1890	30/06/1997	DERM (2010)
Burrum	1/1/1890	30/06/1999	DNRM (2005)
Elliot	1/1/1890	30/06/1997	DNRM (2002)
Gregory	1/1/1890	30/06/1997	DNRM (2002)
Isis	1/1/1890	30/06/1997	DNRM (2002)
Mary	1/1/1890	30/06/1999	DNRM (2005)
Three Moon Creek	1/1/1890	30/06/1997	DNRM (2002)
Upper Burnett	1/1/1890	30/06/1997	DNRM (2002)

The 77 node models include 22 Loss models, 41 Observed extraction models, 14 Time-series order models. The IQQM daily time series orders were only available to the year in the years in Table 9. To extend this data to match the model simulation period (1986–2009), the time series was extended by using the last year in the IQQM simulation for the reminder of the years of Source Catchments simulation.

3.3.6.5 Storage models

Demands or extractions from storages include town water supply and irrigation. 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) by replicating the last year IQQM outputs for years not covered by the IQQM modelling.

Storages (dams and weirs) with a capacity of >10,000 ML (Table 10) 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. As a result, fourteen storages have been included in the Burnett Mary Source Catchments model. Table 10 shows some of the details of these storages (more details are given in Table 38, Appendix D).

Figure 9 shows the location of the 14 storages included in the Burnett Mary model. Of the 14 storages, three were assigned no in-stream processing model on the bases that they were relatively small weirs and are therefore assumed not trapping much sediment or particulate nutrients. Three of the remaining 11 storages are downstream of other storages, which may be an issue with regard to the application of the trapping algorithm employed. A modified version of the algorithm for cascading storages will be used in future modelling.

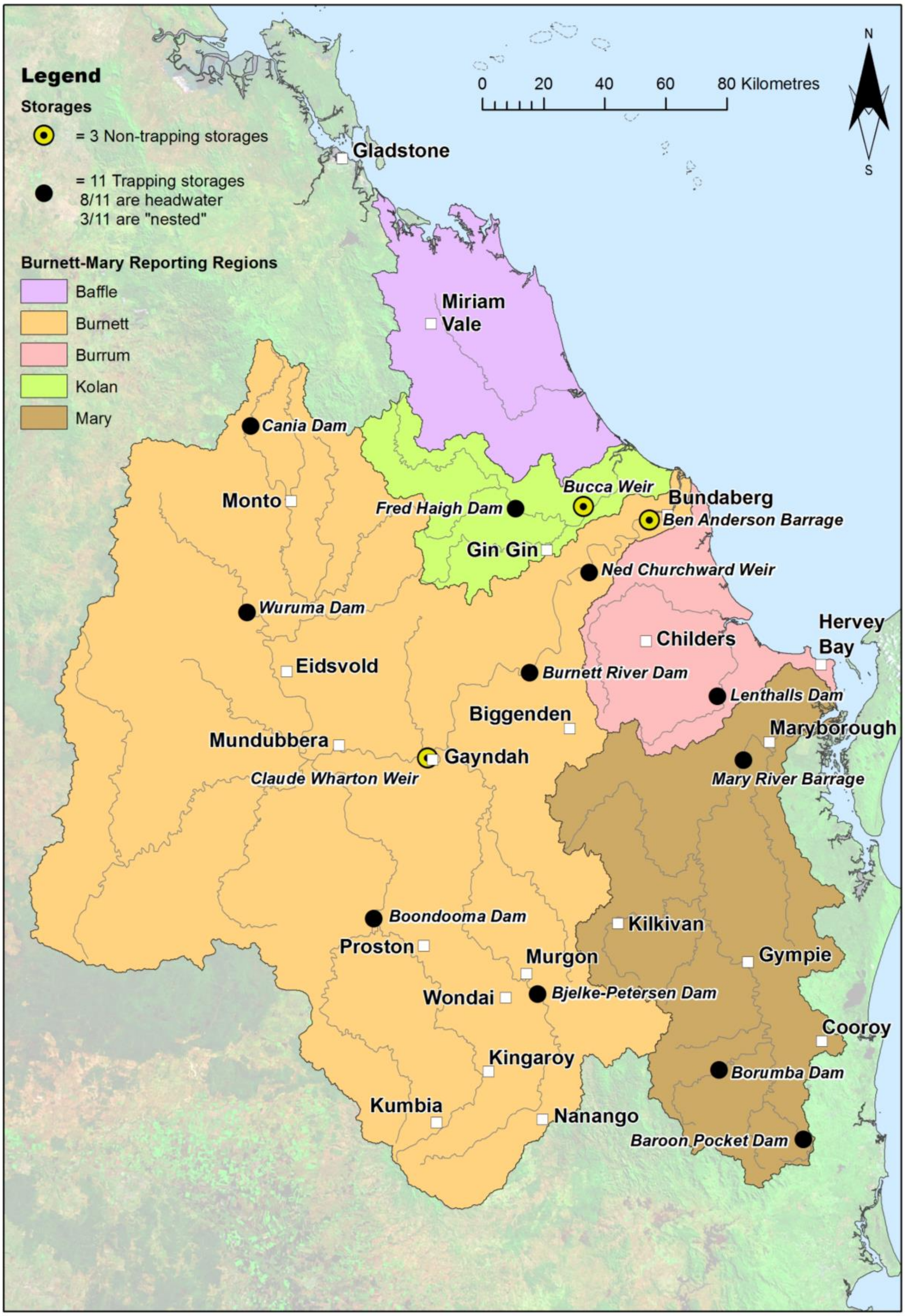

Figure 9 Location of storages included in the Burnett Mary model

Table 10 Details of storages

Storage	Catchment area (km^2)	Capacity (ML)	Year of completion
Baroon Pocket Dam	67	61,000	1988
Borumba Dam	465	33,300	1964
Wuruma Dam	2,318	165,411	1968
Ned Churchward Weir	32,760	29,500	1998
Ben Anderson Barrage	33,085	27,600	1983
Bjelke-Petersen Dam	1,670	125,000	1988
Boondooma Dam	4,200	212,000	1982
Claude Wharton Weir	23,490	12,600	1987
Lenthalls Dam	511	15,500	1984
Bucca Weir	2,385	9,780	1987
Fred Haigh Dam	1,310	586,000	1975
Mary River Barrage	7,343	11,700	1983
Cania Dam	280	89,000	1982
Burnett River Dam	30,785	300,000	2005

Trapping of TSS and particulate nutrients in storages is simulated by the *SedNet Storage Lewis* Model and the *SedNet Storage Particulate Nutrient Deposition* model, respectively. Here TSS 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 TSS trapping equation (Churchill 1948). An annual weighted version of this equation reviewed and tested against measured data for the Burdekin fall dam (Lewis et al. 2013) and storages in the U.S.A, 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.

3.4 Progress towards Reef Plan 2009 targets

Water quality targets were set under Reef Plan 2009 in relation to the anthropogenic baseline load (i.e., the estimated increase in human induced constituent loads from predevelopment conditions) (Figure 10, equation 10).

$$\text{Anthropogenic baseline load} = \text{total baseline load} - \text{predevelopment load} \qquad (9)$$

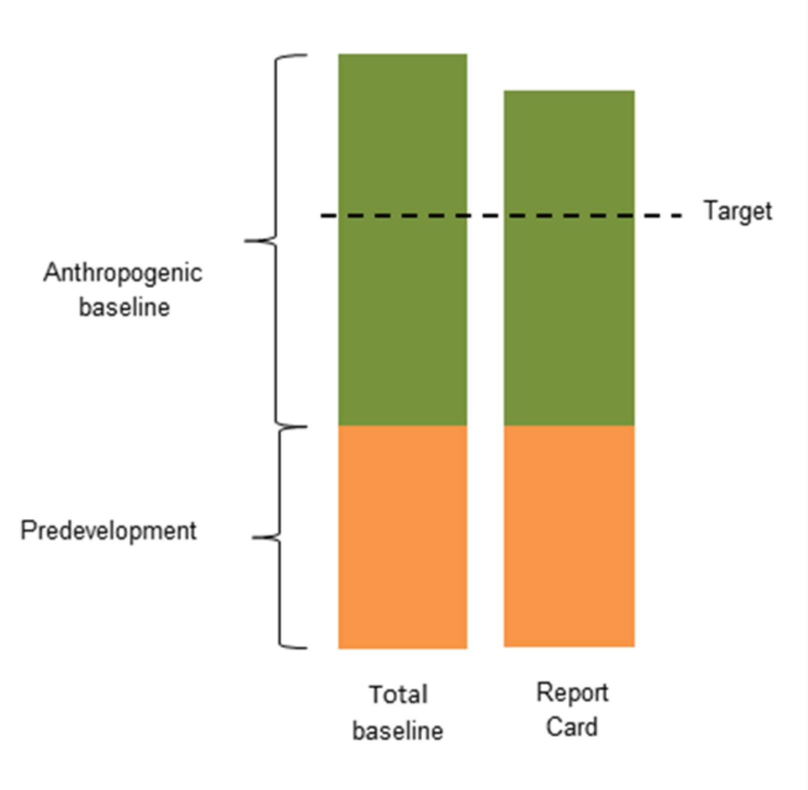

Figure 10 Example of how modelling results will be reported to demonstrate the estimated long-term load reduction as a result of improved management practice adoption for Report Cards 2010–2013 against the target

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

$$\text{Reduction in load (\%)} = \left(\frac{\text{Total baseline load} - \text{Report Card 2013 load}}{\text{Anthropogenic baseline load}}\right) \times 100 \qquad (10)$$

The progress made towards water quality targets due to adoption of 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, 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. The First Report Card was released in August 2011. 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 11 for details of the total and anthropogenic baseline scenarios and Report Card scenarios. Note that Report Card 2010 includes two years of management change. Report Card 2011 and beyond represent cumulative change up to and including the current report card.

Table 11 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 Reef Plan 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 off-site water quality. It is important to note that not all reported practice adoption was 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 summary of typical management practice changes attracting co-investment, refer to Table 39 (Appendix D).

To model management practice change, the baseline management practice was identified and incorporated into the total 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.

To represent the effects of A,B,C or D management practices for sugarcane daily timeseries files of loads in runoff per day per unit area were generated from the APSIM or HowLeaky model for combination of soil type, climate, constituent and management system. These daily loads were then accumulated into a single timeseries (per constituent) according to spatially relevant weights and loaded into the Source Catchments model for each subcatchment. This process allowed the inclusion of spatial (and management) complexity that the Source Catchments model was unable to represent. The impact of fertiliser and soil management practices on DON has not been modelled. For further details on this methodology see Shaw & Silburn (2014). For more information on the ABCD framework and associated management practices see the Reef Plan website: www.reefplan.qld.gov.au.

The proportion of each industry was established in A, B, C or D condition. The area of ABCD was then reflected in the total baseline model. The proportion of area of ABCD then changed each year between 2008 and 2013 (Report Cards 2010–2013) based on the adoption of improved practices.

The total baseline load was modelled using 2009 land use from the Queensland Land Use Mapping Program (QLUMP) and land management practices. Land use categories in QLUMP were amalgamated to represent broader land use classes including: nature conservation, forestry, open and closed grazing, cropping, and horticulture.

Grazing and sugarcane were the only major industries where improved practice adoption occurred in the BM, and there was a suite of specific management practices and systems defined under the ABCD framework relevant to soil, nutrient and herbicide management. The prevalence and location of management practice change is central to the modelling and reporting progress towards meeting reef water quality targets. The variety of sources of information collected in the baseline year 2008/2009 and adoption of improved management practices from industry and government investments are outlined in Reef Plan (Queensland Government Department of the Premier and Cabinet 2013).

Management practice adoption data for the 2008–2010, 2010–2011, 2011–2012 and 2012–2013, years was collated and compared to the baseline (2008–2009). Management changes funded through the Reef Rescue Caring for Our Country investment 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 12.

Table 12 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 Sugarcane

To represent the effects of ABCD management practice breakdown for sugarcane for the baseline year (and in years where improved practice adoption occurred), many daily time-series files of loads per day per unit area were generated from the paddock model for each combination of soil, climate, and constituent and management system. These daily files were then accumulated into a single time-series (per constituent) according to the area of each practice for a given land use within a specific subcatchment then loaded into the Source Catchments model for each subcatchment. This process allows the inclusion of spatial (and management) complexity that the Source Catchments framework is unable to represent. The paddock scale model APSIM was used to provide the matrix of time-series required for cane. For further details on this methodology, refer to the paddock modelling technical report Shaw & Silburn (2014).

In Report Card 2010, no management effect was incorporated for dissolved phosphorus and hence no reductions in DIP and DOP loads due to improved management. No management information was available for DON and therefore was not modelled. In Report Card 2011 and beyond, the effect of management practice changes on these constituents has been accounted for through the reduction of runoff, which is a direct input in the estimation of loads of these constituents.

For sugarcane nutrient management, the majority of the nutrient baseline management was B practice (45%), for soil and pesticide C practice (75%) and (48%) respectively (Figure 11). For Report Card 2010, there was a 16% shift to B practice mainly from C practice while there was a shift of about 6% to A practice with respect of nutrient management. The corresponding cumulative shift in nutrient management in Report Card 2011 is 17% shift to B practice and 10.58% shift to A practice while the respective corresponding shifts in Report Card 2012 are 20% and 11% to B and A respectively. In Report Card 2013, there is a cumulative shift of 18% in nutrient B practice, which is a less than in Report Card 2012 while the shift to A practice is 17%. For Report Card 2010, there was a 18% shift to B practice mainly from C practice while there was a shift of about 5.55% to A practice with respect of pesticide management. The corresponding cumulative shift in nutrient management in Report Card 2011 is 22% shift to B practice and 8% shift to A practice while the respective corresponding shifts in Report Card 2012 are 27% and 9% to B and A, respectively. In Report Card 2013, there is a cumulative shift of 31% in nutrient B practice while the shift to A practice is 12%. The extent of these shifts to B and A management practices both in nutrient and pesticides will determine the extent of nutrient and pesticide export reductions attributed to improved practice adoption.

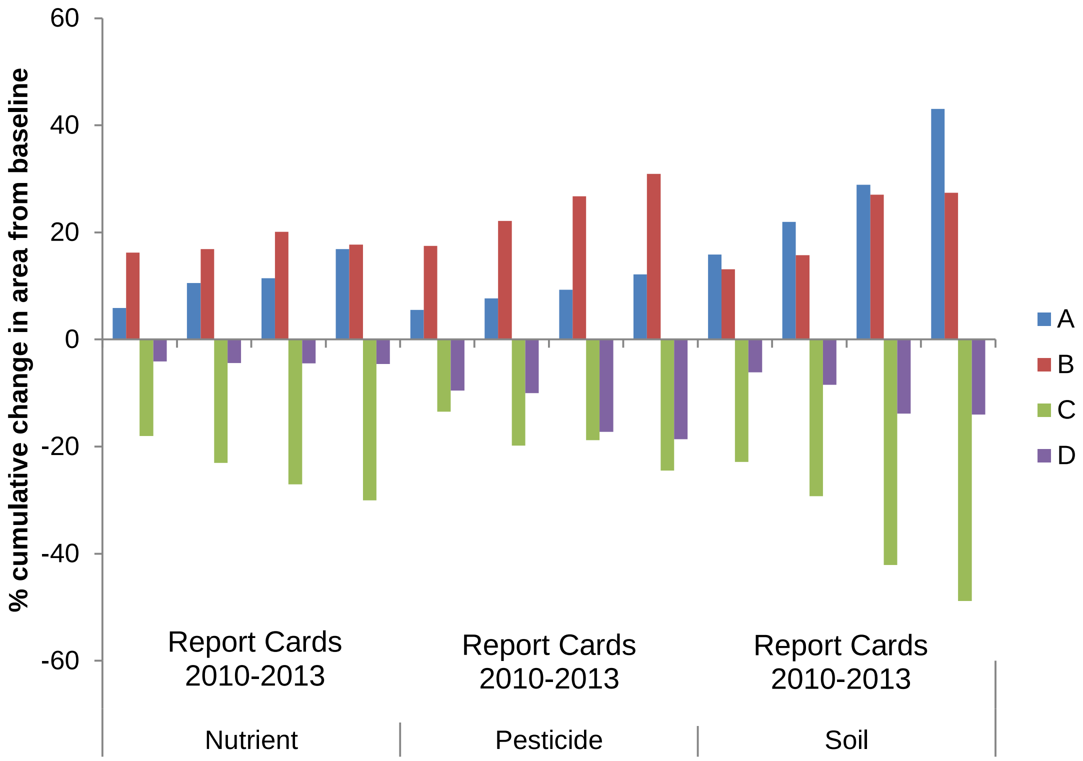

Figure 11 Summary of percent change in soil, nutrient and pesticide management areas for sugarcane areas

3.4.1.2 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 ground cover was then translated into a “C-factor”. The C-factor is required in the RUSLE equation 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 the paddock scale modelling technical report (Shaw & Silburn 2014). Percentage of grazing area under each management practice in the baseline and Report Cards 2010–2013 management change scenarios is shown in figure 12. There is a 0.73% increase in the area under A practice in Report Card 2011 by while areas under the other practices decreased. Similarly, the area under A practice in Report Card 2011 increased by 1.06% while the areas under the other practices decreased. In Report Card 2012, areas under A and B practices increased by 1.1% and 0.24% respectively. Similarly, in Report Card 2013 areas under A and B practices increased by 1.2 and 0.42%, respectively.

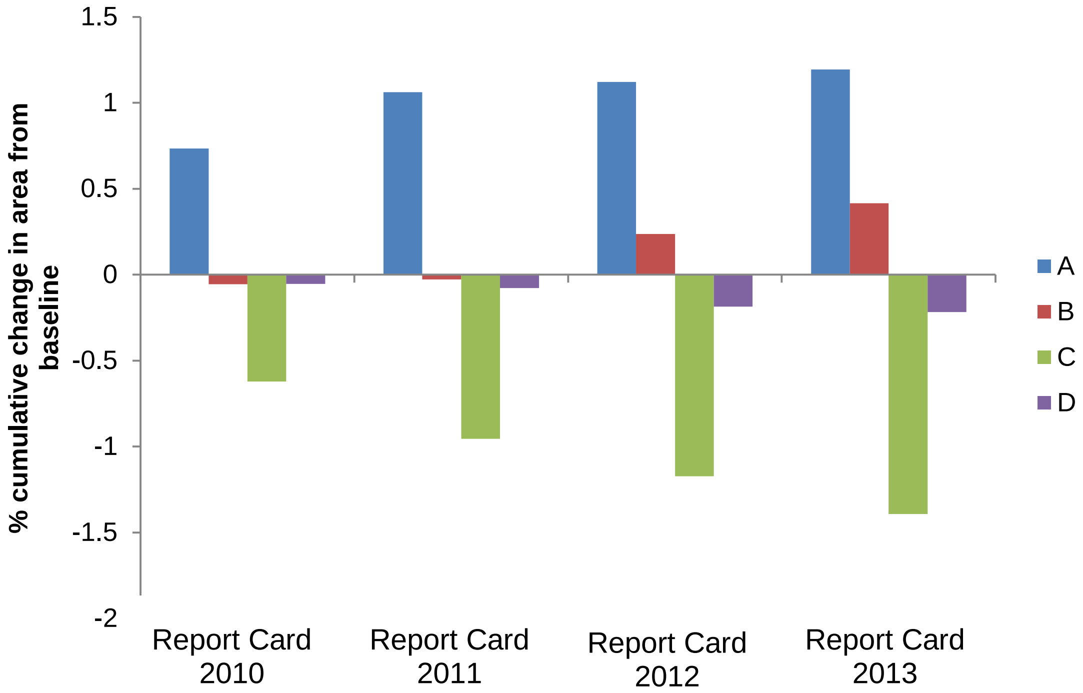

Figure 12 Summary of per cent change in management areas under grazing

3.4.1.2.1 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 and Wilkinson (2012), Table 13. 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. Data on riparian fencing was not provided for the BM and its effect has not therefore been modelled for this region.

Table 13 Gully and streambank erosion rates relative to C class practice (adapted from Thorburn and 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 the indirect effect of grazing management change 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 2011–2013 scenarios.

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. The assumptions made to represent predevelopment conditions were:

- Ground cover was increased to 95% on open and closed grazing
- Remaining land uses (FU’s) had a nature conservation EMC/DWC applied,
- A foliage projected cover (FPC) was created to represent 95% riparian cover in the Stream Parameteriser, and
- Gully cross-section area was reduced from 10 m^2 to 1 m^2 (90% reduction).
- Gully density was reduced to 10% of current.

To be consistent with previous catchment modelling undertaken in the GBR, the hydrology, dams and storages were left unchanged. Therefore, in the report progress on water quality targets is solely due to land management change. The predevelopment scenario was run from 1986 to 2009.

3.5 Constituent load model validation

It is important to note that the modelled loads are only indicative of actual measured loads. Land use and land management practices represent a static point in time therefore do not reflect the annual and seasonal variations in load as seen in the landscape. Therefore, model validation aims to demonstrate that the models are achieving a reasonable approximation of the loads derived from measured data. Validation therefore, is more appropriate at an average annual to annual timescales and any comparisons made at smaller time-steps than this should be considered to have a high degree of uncertainty.

Four sources of data have been used to validate the GBR Source Catchments modelling:

1. Firstly, modelled estimates were compared to previous load estimates in the Burnett Mary (Kroon et al. 2012).
2. Secondly , data from the GBR catchment load monitoring program, that commenced in 2006 in ten high priority catchments (Joo et al. 2012) was used to estimate actual loads from the observed concentration data (Turner et al. 2012; Turner et al. 2013a,b). Modelled loads were then compared to the observed load estimates for the same four year period where measured data and modelled data overlapped (2006–2009).
3. Thirdly, a regression approach was used to correlate measured water quality data to discharge for the model run period. Annual and average annual loads were then calculated and compared to modelled loads for all end of system gauges for the 23 year modelling period (Joo et al. 2014).
4. Fourthly, for the Burnett Mary basin, a range of event-based load estimates were made from measured data (Esslemont 2006a-g) collected at a number of sites

across the BM region. The load estimates from the model were then compared against corresponding modelling estimates.

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

Kroon et al. (2012) estimated current, predevelopment and anthropogenic baseline loads from the 35 reef catchments (in six NRM regions), using the most recent published and available loads data. The best estimates for BM catchments for the ‘current’ loads (except PSIIs) were from (Fentie et al. 2006) which was based on SedNet modelling. The Predevelopment loads described were from (McKergow et al. 2005a; McKergow et al. 2005b). Both of these studies also used the SedNet model, but with different input data sets and parameters to Fentie, et al. (2006) SedNet modelling. The PSII catchment load estimates reported in Kroon et al. (2012) were derived from the difference between the Kroon et al. (2012) current and predevelopment load provided an estimate of the anthropogenic baseline load for the first report card. Anthropogenic baseline loads from the different regions could not be compared due to differences in modelling periods and methodologies. This is further outlined in the discussion. The first Report Card loads are presented in Table 26 (Appendix A). It should be noted that any comparisons made with the first Report Card 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 GBR Catchment Loads Monitoring Program – (2006 to 2010)

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 EOS of 10 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 are: diuron, atrazine, hexazinone, ametryn and tebuthiuron are tested for. However, organochlorine and organophosphate insecticides (e.g. Endosulfan, chlorpyriphos) as well as fungicides are also tested for in laboratory analysis. 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). For model validation in the Burnett Mary, the modelled loads for the Burnett EOS are compared with the GBRCLMP estimates for the 2006 to 2010 for all modelled constituents except herbicides (Joo et al. 2012, Turner et al. 2012).

3.5.3 Long-term FRCE loads (1986 to 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 average and average annual loads for a range of 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; Marsh & Waters 2009; Richards 1999). 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 a lack of representative data (Joo et al. 2014, Marsh and Waters 2009). Joo et al. (2014) has collated all appropriate data sets to generate estimates of daily, monthly, annual and average annual loads for all end of system gauging stations. They 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) FRCE load for all modelled constituents except herbicides across 23 water years (1/7/1986–31/6/2009).

Limited guidance was available to facilitate model evaluation in terms of the accuracy of modelled loads compared to constituent loads derived from measured data (Joo et al. 2014). 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: Nash-Sutcliffe coefficient of efficiency (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.

Table 14 General performance ratings for recommended statistics for a monthly time-step (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

3.5.4 Other datasets

In addition to the Paddock to Reef catchment monitoring at four sites in the Burnett basin (3.7.1), water quality data was collected previously at a number of different sites across the BM and compiled by Esslemont (2006a-f) as part of the National Action Plan (NAP) for Salinity and Water Quality. This data set will only be used as indicative validation given the many sources of uncertainty associated with any load estimate at an event scale (sub-monthly time step).

Table 15 shows the details of the gauges where event load comparisons between modelled and measured constituents have been made. Six out of the eight gauges are in the Mary and the Burnett and the Baffle with one gauge each.

Table 15 Description of gauges and events used for model calibration

Gauging station	Event duration	Basin	Location
134001B	17/12/1988–30/12/1988	Baffle	Baffle Creek (Mimdale)
134001B	01/01/1991–15/01/1991	Baffle	Baffle Creek (Mimdale)
134001B	05/02/2003–12/02/2003	Baffle	Baffle Creek (Mimdale)
136207B	17/12/1988–31/12/1988	Burnett	Lower Barambah (Ban Ban)
138110A	13/02/1995–20/02/1995	Mary	Mary River (Bellbird)
138110A	29/04/1996–12/05/1996	Mary	Mary River (Bellbird)
138110A	07/02/1999–15/02/1999	Mary	Mary River (Bellbird)
138014A	28/03/1989–16/04/1989	Mary	Mary River (Home Park)
138001A	26/06/2005–12/07/2005	Mary	Mary River (Miva)
138004B	15/10/2005–30/10/2005	Mary	Munna Creek (Marodian)
138107B	27/10/2005–04/11/2005	Mary	Six Mile Creek (Cooran)
138903A	10/04/1988–18/04/1988	Mary	Tinana Creek (Bauple East)
138903A	28/06/2005–10/07/2005	Mary	Tinana Creek (Bauple East)

4 Results

This section is separated into hydrology and water quality (modelled loads) subheadings. Under the hydrology section, the results of the calibration process will be presented, in addition to a general presentation of the hydrology of the GBR regions. The water quality results section includes modelled total baseline sediment, nutrient and herbicide loads, and the anthropogenic baseline and predevelopment loads. Water quality improvements due to improved practice adoption for the 2008–2013 period (Report Cards 2010–2013) are reported against the anthropogenic baseline load. The validation of the BM results are then presented using previous measured and modelled data.

4.1 Hydrology

4.1.1 Calibration performance

A complete list of parameters included in the calibration and their final values for each calibration region and land use is shown in Table 29 (Appendix C). Model performance was assessed for the 32 BM gauges used in the calibration process. Performance was only assessed for the calibration period 1970–2010. Table 16 provides the calibration results for all 32 gauges, which have varying catchment areas. With the exception of three gauges, all gauging stations have about 15 years of record.

As outlined in the Methods section, a 'traffic light' colour scheme in Table 16 shows that values highlighted in green for each objective function meet the calibration criterion for that particular objective function while those highlighted in red failed to do so.

Out of the 32 gauges used in the hydrology calibration for BM, eight met all three performance criteria, 18 met two of three criteria, and six gauges meet only one of the three criteria. Out of the 32 calibration gauges 29 (91%) met the monthly Nash-Sutcliffe criterion (>0.8), 25 (78%) met the monthly percentage volume error criterion (±20%). Monthly modelled flow volumes at 84% of the gauges were within 20% of the observed monthly volumes. However, only 10 out of 32 gauges (31%) met the daily Nash-Sutcliffe criterion (>0.5).

Table 16 Burnett Mary hydrology calibration (1970-2010)

Gauge	Gauge name	Catchment	Years of	Daily	Monthly	Total
134001B	Baffle Creek at Mimdale	1,402	15	0.07	0.95	-9
135004A	Gin Gin Creek at Dam Site	531	15	0.5	0.92	-20
135002A	Kolan River at Springfield	551	15	0.17	0.96	2
136001B	Burnett River at Walla	32100	9	0.34	0.68	-23
136011A	Degilbo Creek at Coringa	687	15	0.52	0.94	3
136007A	Burnett River at Figtree Creek	30,712	8	0.11	0.51	3
136002D	Burnett River at Mount Lawless	29395	15	0.09	0.44	6
136207A	Barambah Creek at Ban Ban	5,563	15	-0.04	0.54	-35
136208A	Boonara Creek at Ettiewyn	1,391	15	0.21	0.72	12
136202D	Barambah Creek at Litzows	681	15	-0.58	0.83	-4
136209A	Barker Creek at Glenmore	1367	15	0.23	0.94	-1
136203A	Barker Creek at Brooklands	249	15	0.25	0.61	-36
136017B	Burnett River at Gayndah Flume	23,311	15	0.01	0.11	19
136094A	Burnett River at Jones Weir Tailwater	21,700	15	0.57	0.91	26
136319A	Boyne River at Cooranga	5,205	11	0.23	0.61	1
136304A	Stuart River at Proston Rifle Range	1,546	15	0.39	0.91	-9
136315A	Boyne River at Carters	1,617	15	-0.39	0.88	14
136306A	Cadarga Creek at Brovinia Station	1,233	15	0.11	0.62	52
136305A	Auburn River at Glenwood No 2	5,330	15	0.19	0.7	12
136106A	Burnett River at Eidsvold	7,117	15	0.58	0.97	-8
136103B	Burnett River at Ceratodus	3,892	15	0.59	0.99	9
136101C	Three Moon Creek at Abercorn	1,539	15	0	0.94	10
136118A	Eastern Creek at Lands End	450	15	0.26	0.93	-9
138903A	Tinana Creek at Bauple East	783	15	0.63	0.86	7
138014A	Mary River at Home Park	6845	15	0.51	0.97	1
138001A	Mary River at Miva	4,755	15	0.66	0.98	3
138007A	Mary River at Fishermans Pocket	3,068	15	0.77	0.98	-3
138002C	Wide Bay Creek at Brooyar	655	15	0.36	0.95	6
138010A	Wide Bay Creek at Kilkivan	322	15	0.06	0.87	23
138004B	Munna Creek at Marodian	1,193	15	-0.05	0.87	-10
137201A	Isis River at Bruce Highway	446	15	0.57	0.97	-4
137003A	Elliott River at Dr Mays Crossing	251	15	-0.14	0.96	4

Green = 3 criteria met, Orange = 2 criteria met and Red = 1 criteria met. NSE (Nash Sutcliffe coefficient of Efficiency)
^ Years of record = number of years of flow data that was within the hydrology calibration period (1970-2009)

Figure 13 shows a map of per cent differences between measured and modelled volumes across the region. The grey area was not gauged and hence not calibrated. However, nearest neighbour calibrated parameter values were assigned to this area (refer Section 3). The volumetric errors are within the 15% limit in the majority of calibration regions.

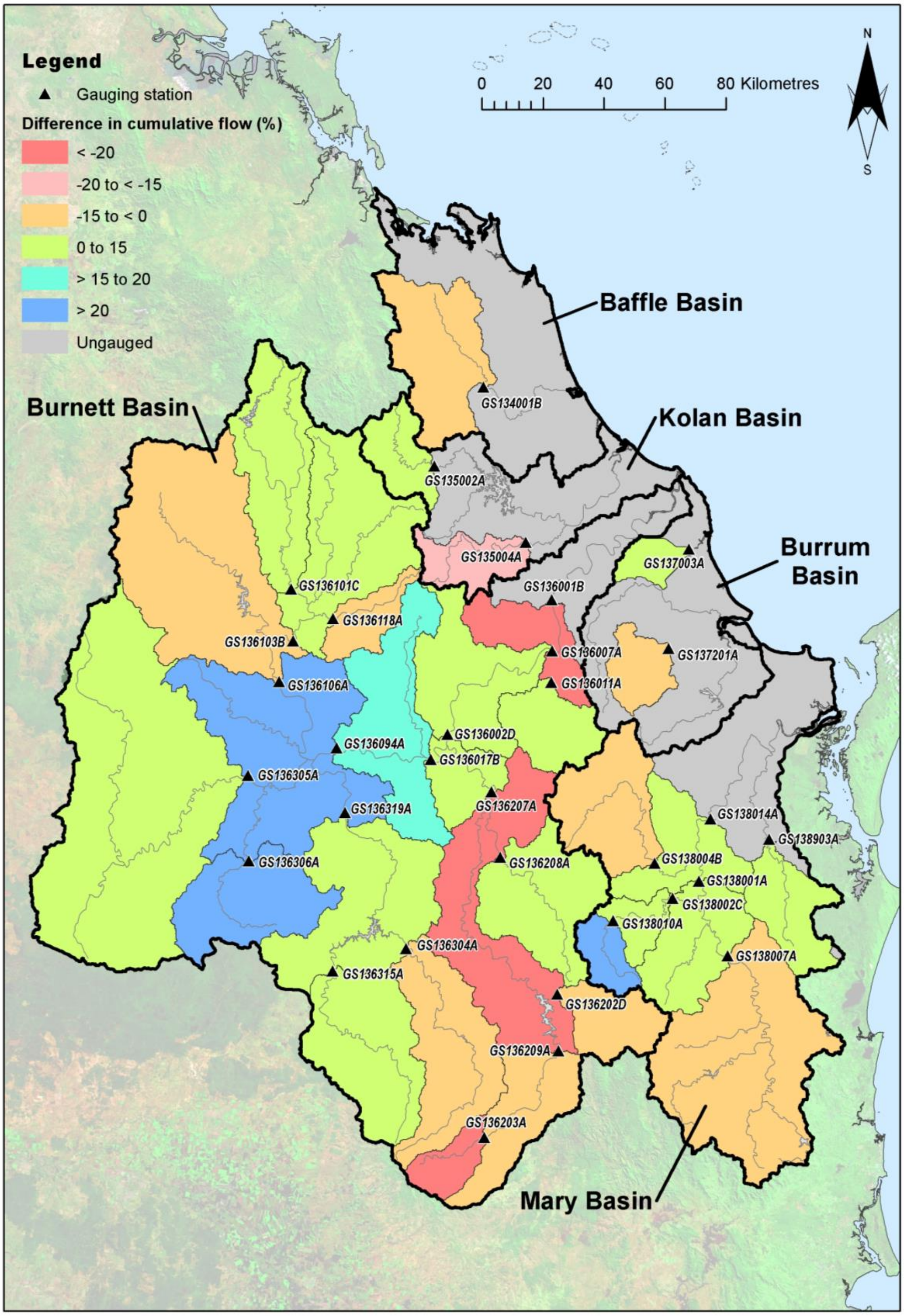

Figure 13 Percentage volume difference for calibration regions

Figure 14 shows that with the exception of four regions where the difference between measured and modelled total flows is greater than 15%, there is strong agreement between modelled and measured average annual flows.

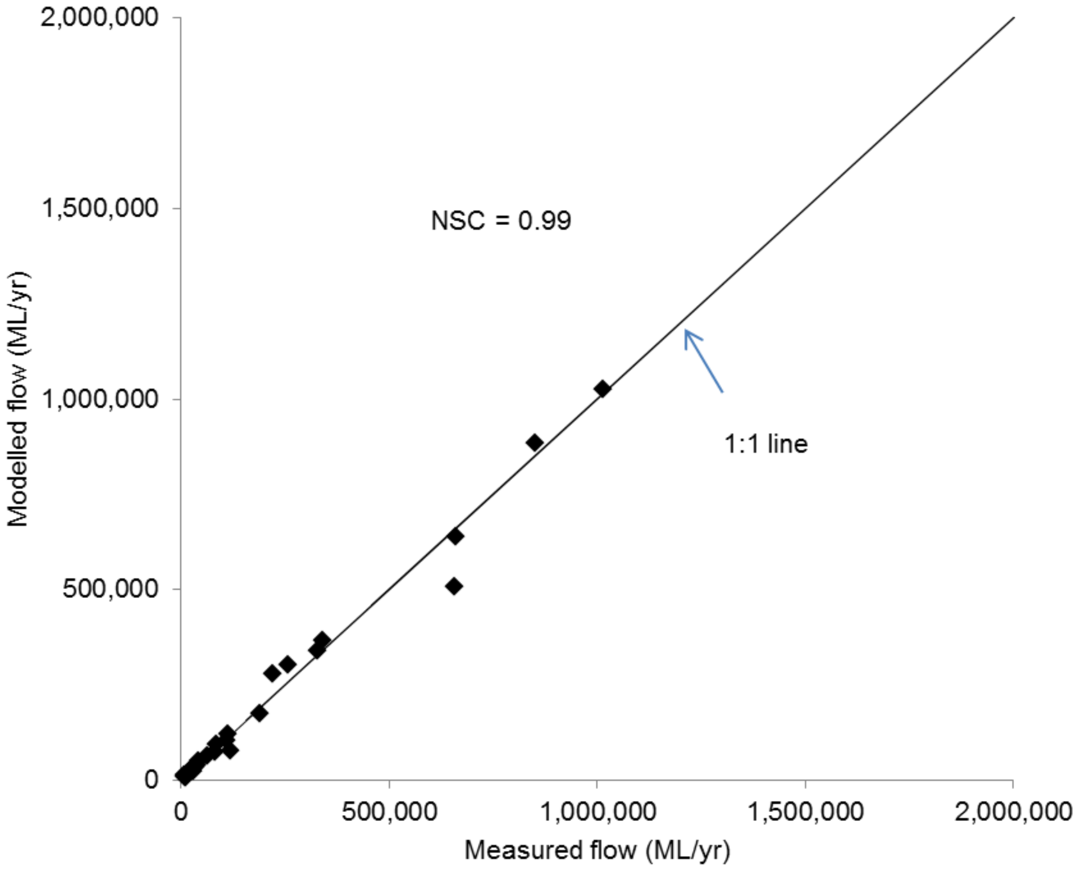

Figure 14 Modelled versus measured annual flows at all 32 calibration gauging stations

A comparison of measured and modelled annual flows at gauging station (136094A) in Figure 15 shows that both wet (high flows) and dry years (low flows) are modelled satisfactorily indicating that the model is representing extreme flow conditions, with the exception of two dry years (2001 and 2002) where measured flows were considerably less than modelled flows.

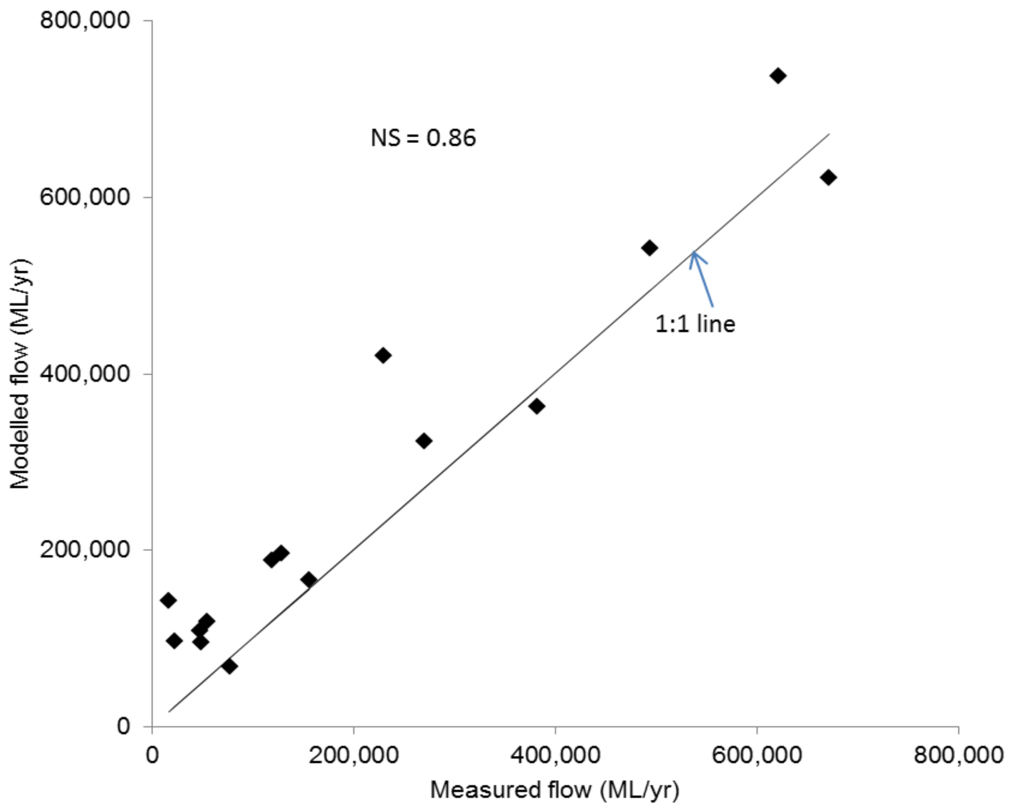

Figure 15 Comparison of modelled and measured annual flows at gauging station 136094A

The model also performed well at the monthly time-step for the three wettest years (Figure 16) and three driest years (Figure 17) at gauging station 136094A, although there seems to be a tendency for the model overestimating flows in the three driest years. The fact that the model performed well in the wettest years is encouraging given constituent export is proportionally the highest during these years compared to the dry years.

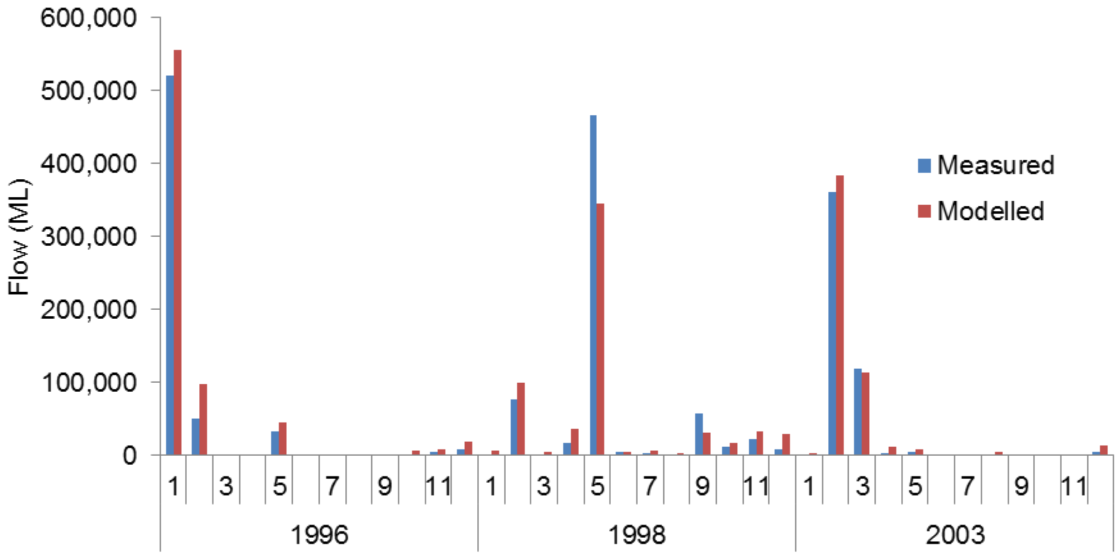

Figure 16 Comparison of modelled and measured monthly flows at gauging station 136094A for three wet years

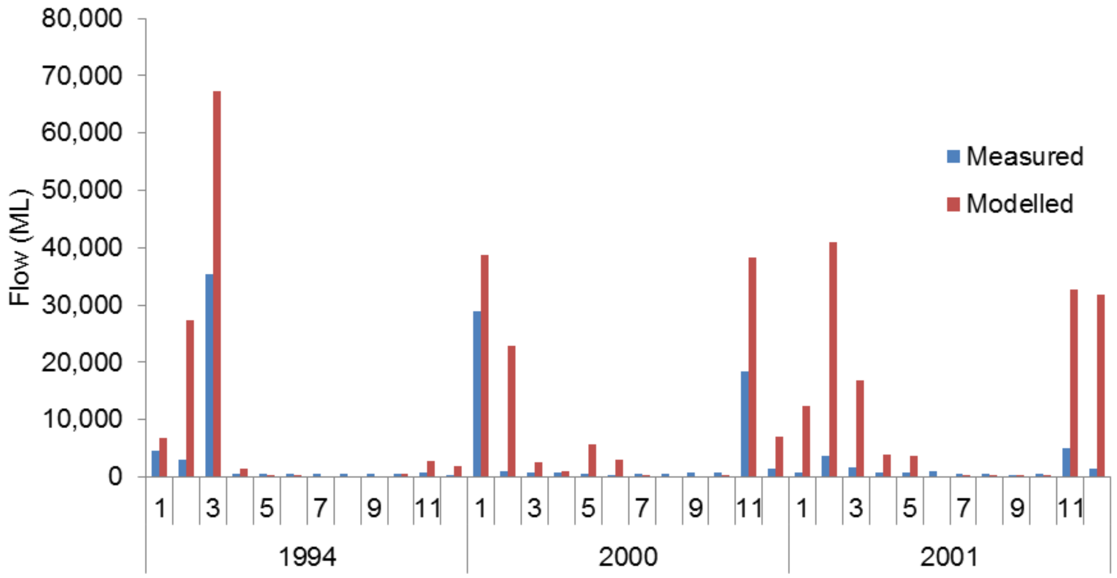

Figure 17 Comparison of modelled and measured monthly flows at gauging station 136094A for three dry years

Comparison of daily flows at gauging station 136094A shows that the model generally under-predicts high flows at this time-step. This indicates that, although the modelling is done at a daily time-step, caution should be exercised when interpreting results at sub-annual time steps.

4.1.1. Base flow comparison

Modelled quick and slow flow components for each of the 597 modelled subcatchments were used to produce some statistics of the base flow index (BFI) calculated as base flow as a percentage of total flow. For the BM region, BFI varied from 12.34 to 86.51% with a mean of 41.44 and median of 37.93%.

4.1.2. Regional discharge

The modelled average annual flow for Burnett Mary is 2,417,715 ML/yr, which is 3.8% of the total GBR average annual flow. The Wet Tropics has the biggest average annual flow for the modelled period compared to the five other GBR regions (Figure 18).

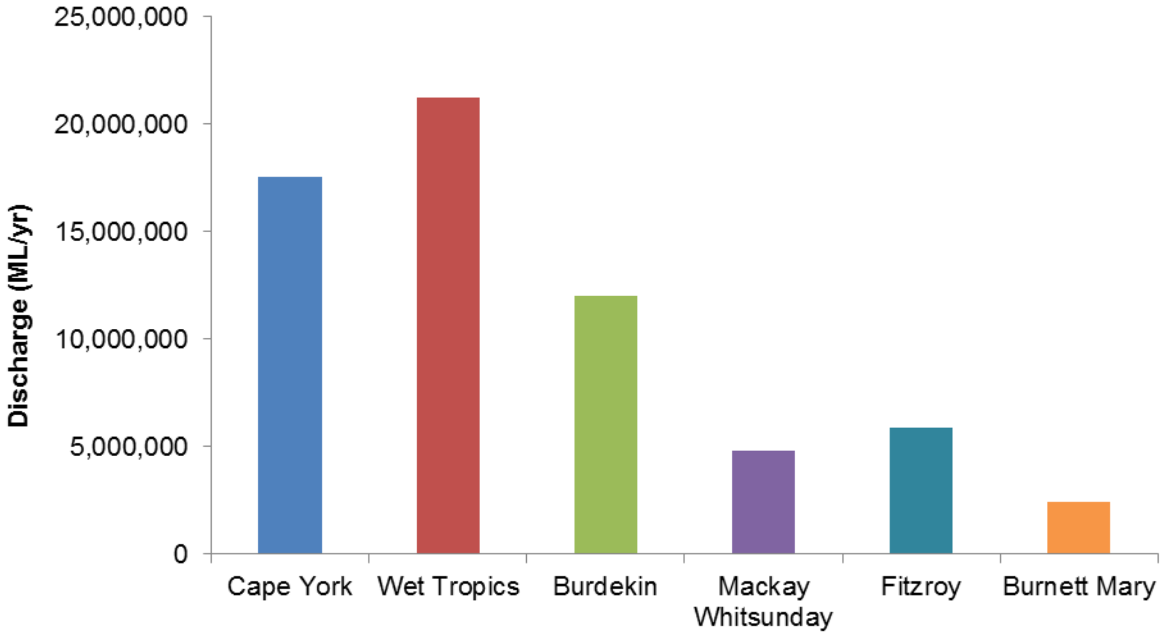

Figure 18 Average annual discharge from the six GBR NRM regions (1986–2009)

Within the Burnett Mary region, the Mary basin has the highest average annual flow (1,400,239 ML/yr), followed by the Baffle (491,201 ML/yr) and Burrum (258,813 ML/yr) basins (Figure 19). In terms of contribution of flow per unit catchment area, the Burnett has the lowest runoff per unit area (6 ML/km^2/yr), while the Mary and Baffle basins have the highest runoff per unit area (150 ML/km^2/yr and 122 ML/km^2/yr respectively).

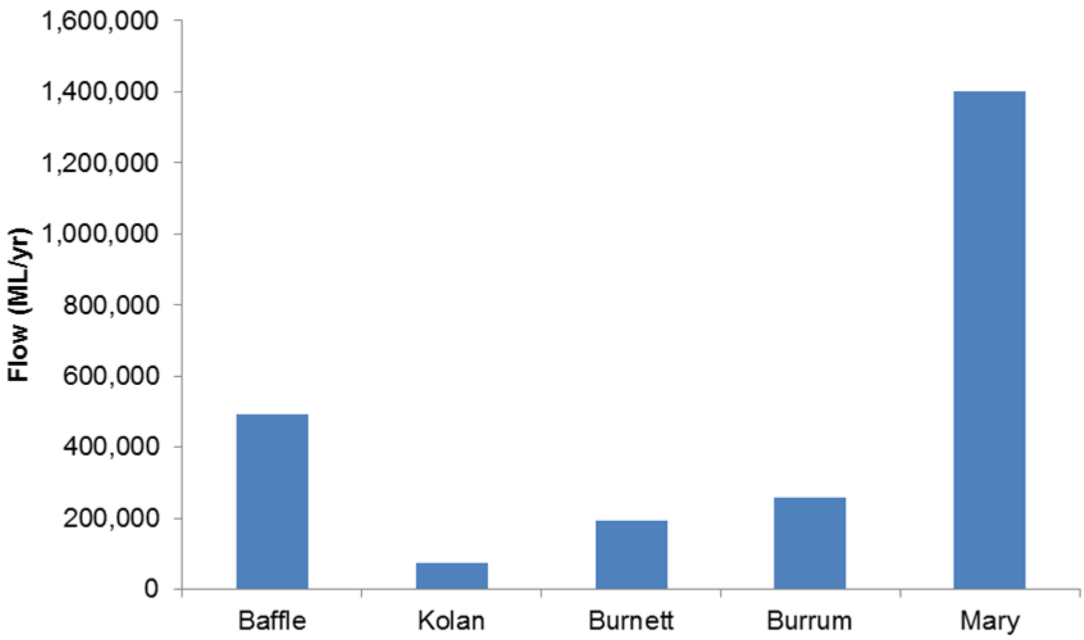

Figure 19 Annual discharge from the five basins in the BM region

Table 17 shows average PET, rainfall and runoff in mm/yr for each of the five basins in the Burnett Mary region.

Table 17 Rainfall and modelled runoff (mm/yr) by basin

Basin	Area (km^2)	Rainfall (mm/yr)	Runoff (mm/yr)	Runoff coefficient (%)
Baffle	4,035	994	125	13
Kolan	2,955	831	73	9
Burnett	33,038	652	33	5
Burrum	3,450	862	89	10
Mary	9,340	1,021	174	17

4.2 Modelled loads

It is estimated that 8,545 kt/yr of TSS is exported from the six GBR NRM regions (total baseline load) of which 5,613 kt/yr is the anthropogenic baseline load. Table 18 presents the total constituent load for all regions, while Table 19 presents this data as a per cent contribution, highlighting the lowest (shaded green) and highest (shaded red) contributors across the GBR.

The Burdekin region is the greatest contributor for most constituents excluding PSII inhibiting herbicides, for which the Wet Tropics is the largest source. The Burdekin is the largest contributor due to the size of the region and the large flows, as well as the predominant soil types, prevalence of gullies and terrain. Grazing is the predominant land use in the Burdekin. With regard to PSII inhibiting herbicides, the Wet Tropics has the greatest load (8,596 kg/yr) which is a function of land use, especially the large areas of sugar cane and other irrigated crops within the region, such as bananas. The Wet Tropics supplies 51% of the total PSII export from the GBR catchments, and is considerably higher than the second greatest contributor, Mackay Whitsunday, with 3,944 kg/yr (24% of GBR total).

Table 18 Total baseline constituent loads for all 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	579
Burnett Mary	53,021	462	2,202	554	873	775	392	78	35	278	1,528
Total	**423,134**	**8,545**	**36,699**	**10,532**	**14,320**	**11,847**	**6,294**	**1,155**	**606**	**4,532**	**16,740**

The Burnett Mary contributes 5.4% of TSS and 5.3% of the DIN load to the GBR. Within the Burnett Mary Region, the Mary basin contributed 79% of the TSS and 46% of the DIN anthropogenic baseline load. In relation to the total baseline load exported to the reef, 80 % of the suspended sediment load, 78% of the DIN load and all of the PSII export is due to anthropogenic (human-induced) activities.

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

NRM region	Area	Flow	TSS	TN	DIN	DON	PN	TP	DIP	DOP	PP	PSII
	(%)											
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 Burnett Mary region, the Mary basin is the greatest contributor to export of all constituents, with the exception of PSIIs for which the Burrum basin is the largest contributor (Table 20). Detailed modelling results from the five basins in the Burnett Mary are given in Table 40 (Appendix D). Due to its close proximity to the reef lagoon, absence of storages and relatively higher average rainfall, the Baffle basin is the second highest contributor of TSS, TP, TN and particulate nutrients.

Table 20 Export of constituent loads for each subcatchment in the BM region

Region	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)
Baffle	50	55	44	7	4	238	105	31	101	23
Kolan	11	14	9	4	1	83	22	21	40	257
Burnett	24	37	18	14	5	258	38	123	96	271
Burrum	24	43	27	12	4	308	64	119	124	531
Mary	352	242	181	41	20	1,316	546	260	510	445
Total	**462**	**392**	**278**	**78**	**35**	**2,202**	**462**	**554**	**873**	**1,528**

4.2.1 Predevelopment loads

Constituent export loads to the reef lagoon from the BM region in the predevelopment scenario are presented in Table 21. Once again, the Mary basin dominates the contribution to export of all constituents while the Baffle basin contributes the second most TSS, TP, PP, TN and PN export. Obviously, there is no export of PSII inhibiting herbicides in the predevelopment scenario.

Table 21 Constituent export from the predevelopment scenario by reporting region

Basin	TSS (kt/yr)	TP (t/yr)	PP (t/yr)	TN (t/yr)	PN (t/yr)	DIN (t/yr)	DIP (t/yr)	DOP (t/yr)	DON (t/yr)
Baffle	19.8	30.4	25.0	126.7	62.9	11.9	3.4	2.1	51.9
Kolan	2.3	4.0	3.0	20.1	8.1	2.2	0.6	0.4	9.8
Burnett	3.2	21.1	7.7	82.0	18.8	30.8	10.1	3.4	32.3
Burrum	6.8	15.0	8.1	81.9	26.8	16.9	4.8	2.1	38.3
Mary	60.8	97.7	73.2	468.0	210.1	59.6	15.8	8.6	198.3
Total	**92.9**	**168.3**	**117.0**	**778.6**	**326.6**	**121.3**	**34.7**	**16.6**	**330.7**

4.2.2 Anthropogenic baseline loads

As outlined in the Methods section, anthropogenic baseline load is calculated by subtracting the predevelopment (or natural) load from the total baseline load. Anthropogenic baseline loads of constituents exported to the reef lagoon are presented in Table 22, while Figure 20 shows predevelopment and anthropogenic baseline loads for TSS for each of the five basins in Burnett Mary region. The contribution to anthropogenic baseline load export of each basin within the BM region is similar to its contribution to export in the total baseline and predevelopment scenarios.

Table 22 Anthropogenic baseline export by reporting region

Basin	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)
Baffle	30	25	19	4	2	111	42	19	49	23
Kolan	9	10	6	3	1	63	14	19	31	257
Burnett	21	16	10	4	2	176	20	93	64	271
Burrum	17	28	19	7	2	226	37	102	86	531
Mary	291	145	108	25	12	848	336	200	312	445
Total	**369**	**224**	**161**	**43**	**19**	**1423**	**449**	**433**	**542**	**1,528**

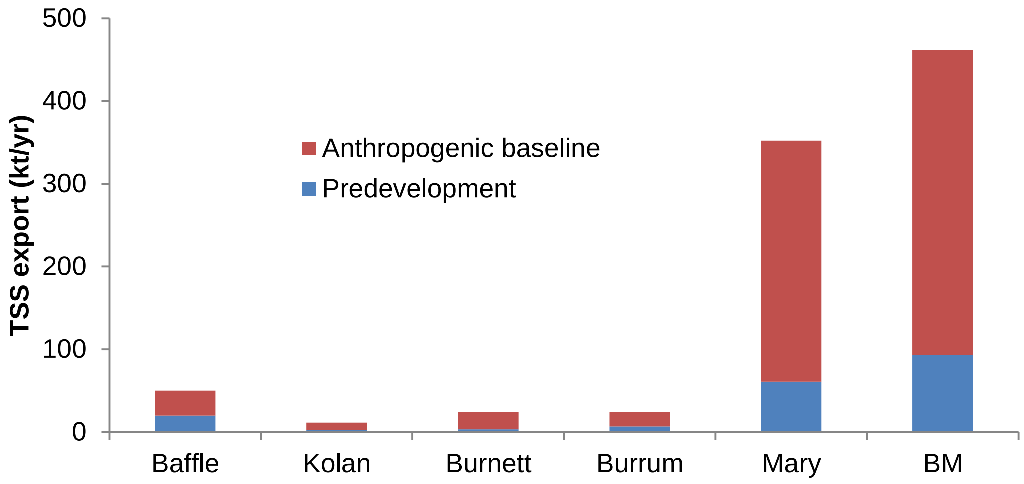

Figure 20 Stacked chart of anthropogenic baseline and predevelopment TSS export by catchment in the BM region

The Mary River contributes 79% of baseline TSS load in the BM region, and has increased five-fold from predevelopment conditions. The Baffle River contributes 8% to the regional TSS anthropogenic baseline load with a two-fold increase from predevelopment condition, while the remaining regions combined contribute 15%. TSS export has increased 2.5 fold in the Baffle to 7.6 fold in the Burnett basin with an overall 5.01 fold increase for the Burnett Mary region since European settlement.

In Figure 21, the anthropogenic baseline and predevelopment contributions to total nitrogen (TN) load for each catchment are presented. The Mary, Burrum and Burnett basins contribute 60%, 14% and 12% of the baseline load, respectively. The Kolan shows the highest anthropogenic baseline load to predevelopment load ratio of TN of 4.1 while the Baffle shows the lowest ratio of 2.0 indicating relatively low anthropogenic effects.

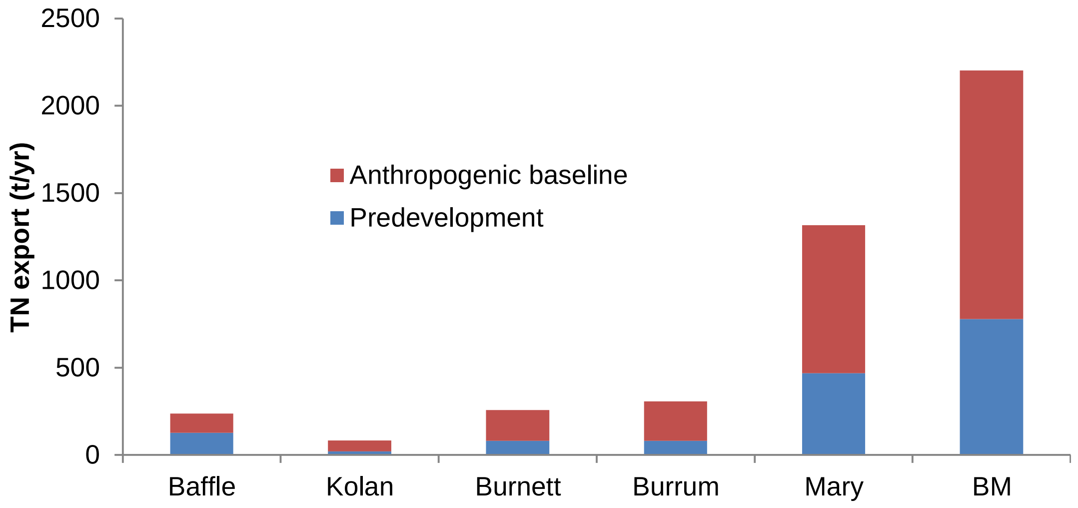

Figure 21 Stacked chart of anthropogenic baseline and predevelopment TN export by catchment in the BM region

In Figure 22 the anthropogenic baseline and predevelopment scenarios to total phosphorus (TP) load for each catchment are presented. The Mary, Burnett and Baffle basins contribute 65%, 12% and 11% of the anthropogenic baseline load, respectively. The Kolan shows the highest anthropogenic baseline load to predevelopment load ratio of TP of 3.5 while the Baffle shows the lowest ratio of 2.0 indicating relatively low increase in TP load from predevelopment conditions.

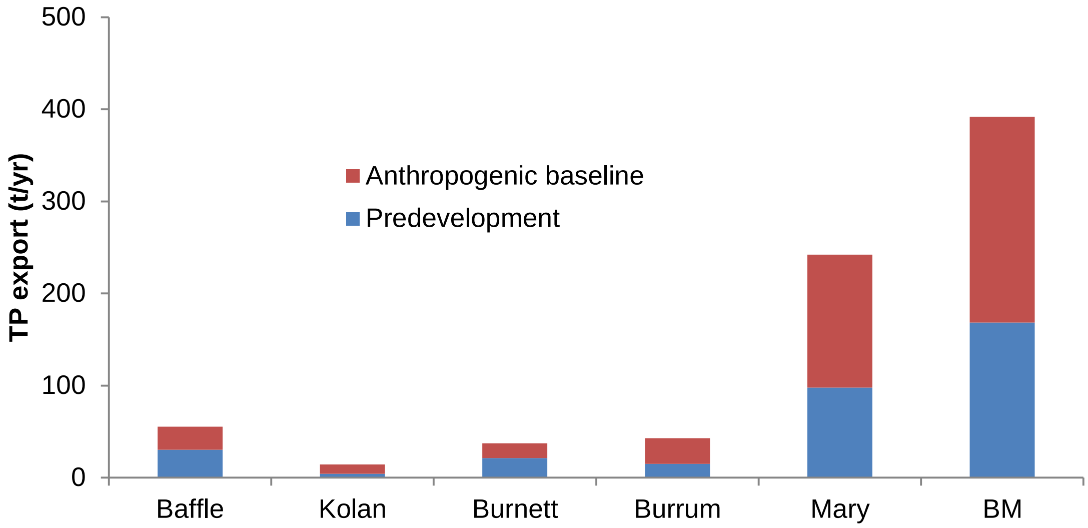

Figure 22 Stacked chart of anthropogenic baseline and predevelopment TP export by catchment in the BM region

DIN export increased 2.6 fold in the Baffle to 9.4 in the Kolan basin, with an overall 4.6 fold increase for the Burnett Mary region since European settlement. TN export increased 1.9 fold in the Baffle to 4.1 fold in the Kolan basin with an overall 2.8 fold increase for the Burnett Mary region since European settlement. TP export increased by 1.8 fold in the Baffle and Burnett to 3.5 fold in the Kolan basin with an overall 2.3 fold increase for the Burnett Mary region since European settlement. As there was no PSII inhibiting herbicide application predevelopment, all the total baseline PSII export is attributed to anthropogenic activities.

4.2.3 Contribution by land use and streambank erosion

Figure 23 to Figure 25 show the relative contribution of different land uses (from both hillslope and gully erosion) and streambank erosion in the Burnett Mary region to constituent export. It is evident that accounting for 56% of the baseline (51% from the Mary basin) TSS export, streambank erosion is by far the dominant source of this constituent which also accounted for 17% of the toal baseline (16% from the Mary basin) TP export. About 65% of the total baseline export (27% from the Mary basin) DIN export is from sugarcane which also contributed about 26% of the TN baseline export (10% from the Mary basin). Sugarcane contributed about 98% of the (anthorpogenic baseline) PSII export 35% of which was from the Burrum basin.

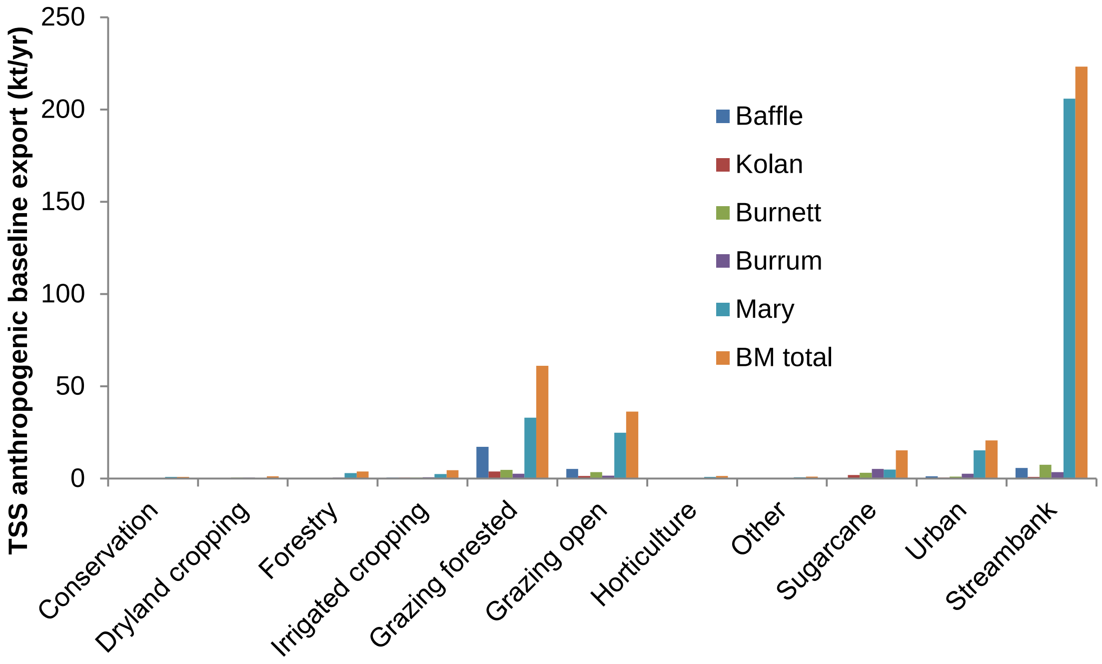

Figure 23 Relative contribution to TSS export by land use and streambank erosion in the Burnett Mary region

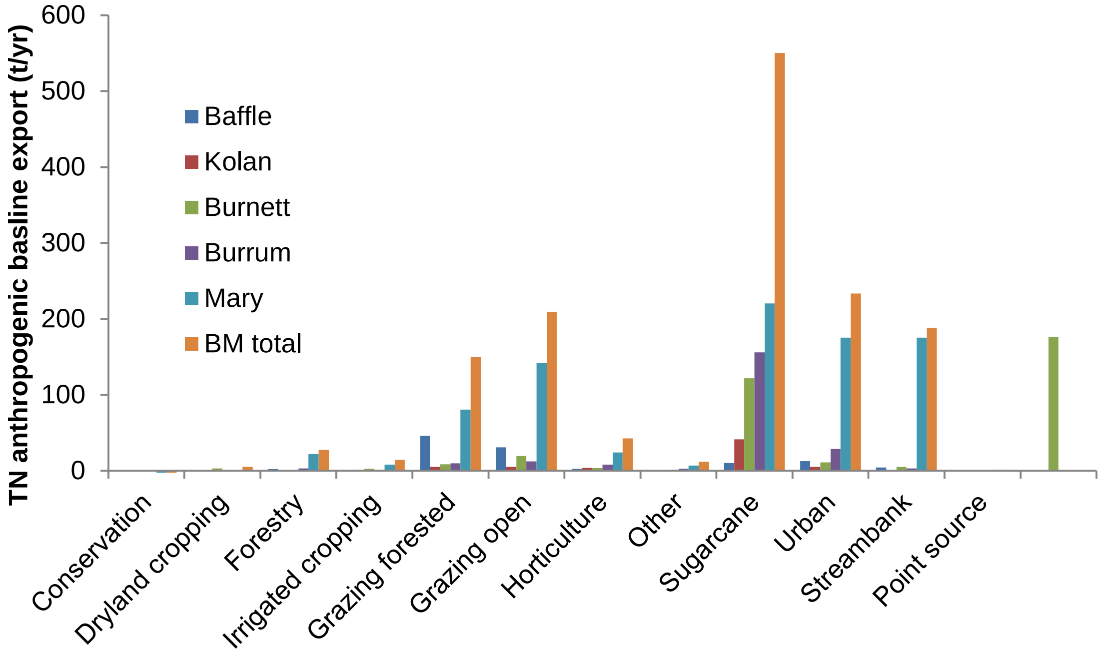

Figure 24 Relative contribution to TN export by industry in the Burnett Mary region

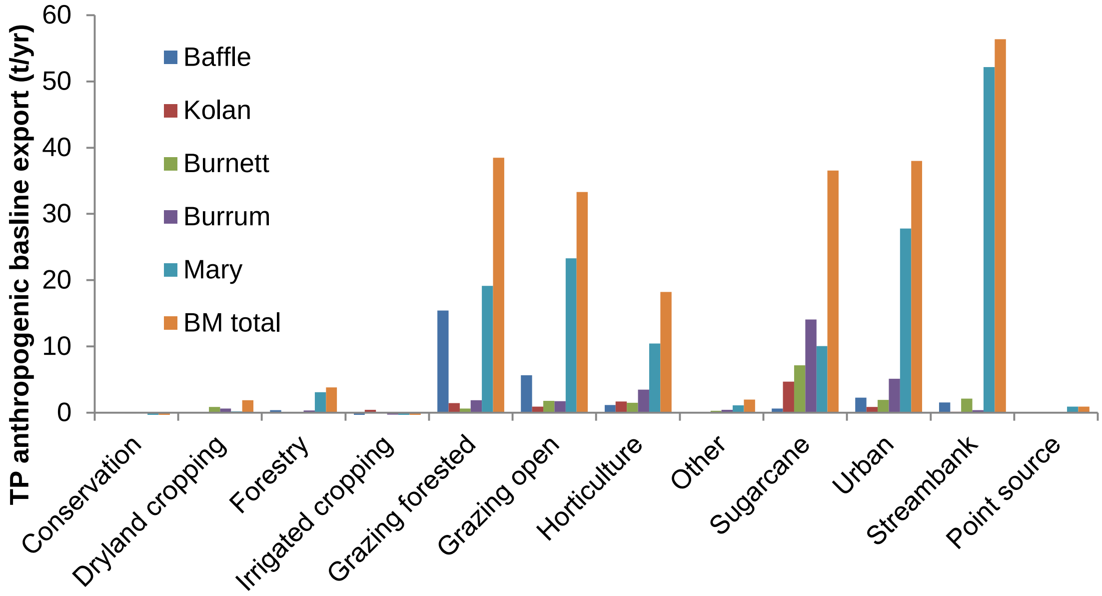

Figure 25 Relative contribution (% of export) to TP export by industry in the Burnett Mary region

Grazing forested and grazing open contributed 27% of the TSS export from the Burnett Mary region. Sugarcane and point sources contributed 65% and 10% of the DIN export, respectively, with grazing open and grazing forested accounting for 6.0% and 2.5% of the DIN export, respectively. Sugarcane and grazing industries contributed 64% of the TN exported. About 98% of the PSII inhibiting herbicides exported to the reef lagoon is sourced from sugarcane fields. Grazing, streambank erosion and the urban land use contributed 30%, 24% and 16% of the TP export, respectively.

4.2.4 Constituent budget (sources and sinks)

The relative contribution of TSS sources to constituent export from each of the five basins and the Burnett Mary region as a whole is shown in Figure 26. As a first approximation, TSS and particulate nutrients from EMC/DWC based estimates have also been separated into hillslope and gully erosion as outlined in the Methodology section. The Mary basin is the highest contributor of TSS export followed by the Baffle basin, which despite being perceived as relatively undisturbed contributes more than the other three basins due to the absence of storages, its proximity to reef lagoon and relatively high rainfall (and runoff).

The relative contribution of processes to constituent export varies from catchment to catchment. For example, hillslope erosion is the dominant contributor of TSS export in the Baffle, Kolan, Burnett and Burrum basins while streambank erosion is by far the most dominant contributor of TSS in the Mary basin and the BM region as a whole. Diffuse dissolved sources are the dominant contributors of TN (Figure 27) and TP from the BM region as a whole (Figure 28).

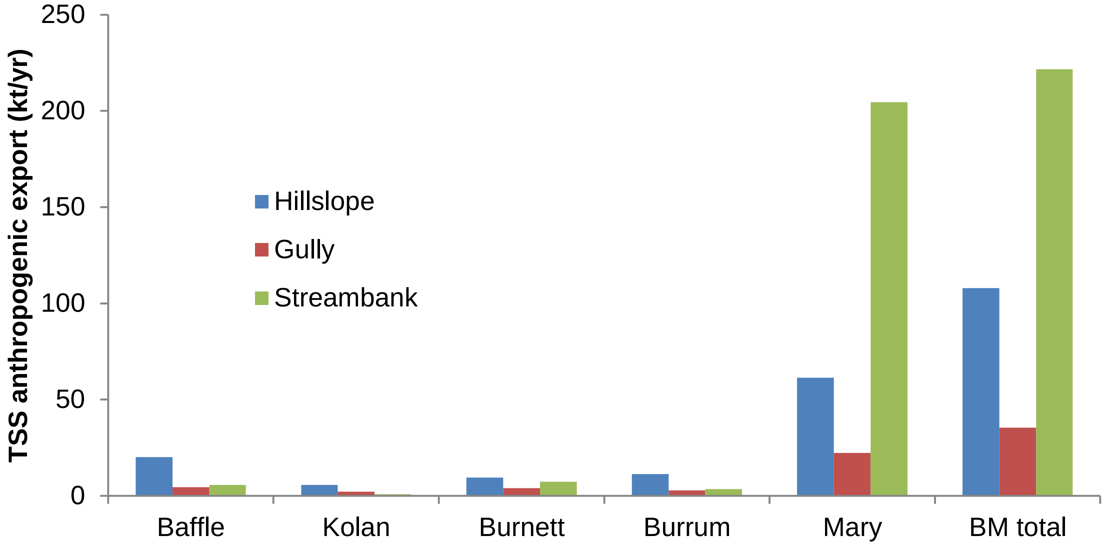

Figure 26 Contribution of source processes to TSS export

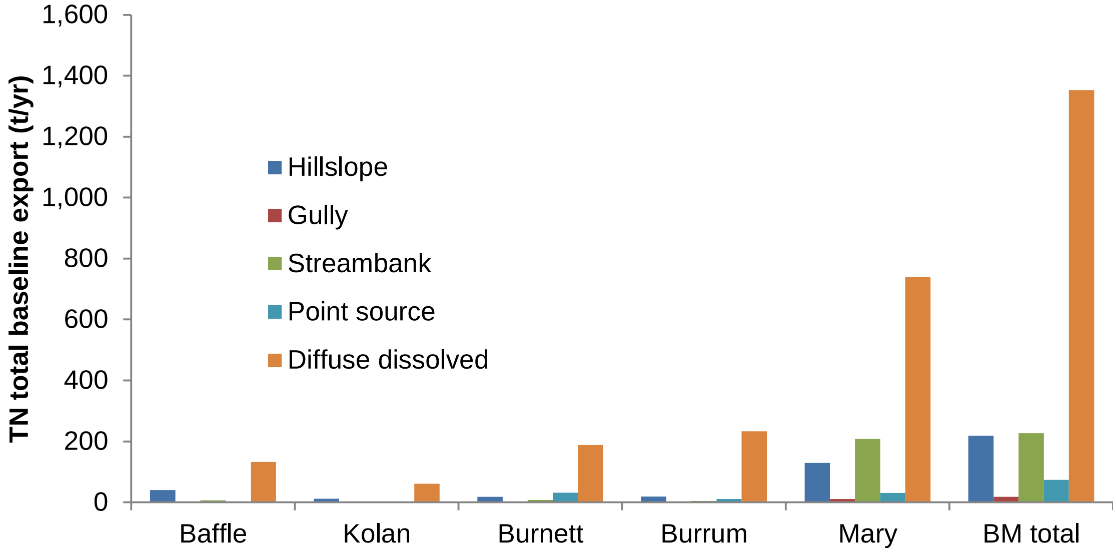

Figure 27 Contribution of source processes to TN export

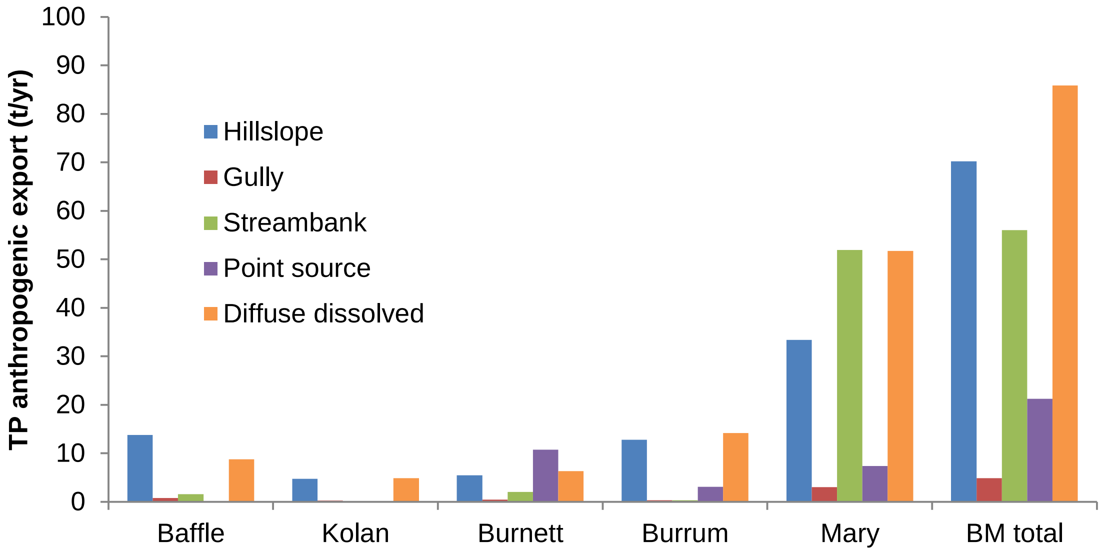

Figure 28 Contribution of source processes to TP export

Fentie et al. (2013) have reported the Report Card 2011 constituent budgets. Table 23 shows the load for each of the main constituent budget elements from the baseline scenario for Report Card 2012 and Report Card 2013. Similar tables of constituent budget for each of the five basins in the Burnett Mary region are included in tables 42-46, (Appendix E). Considering only constituents for which targets are set (i.e., TSS, TN, TP and PSII and DIN) Table 23 indicates:

- Only 39 % of the TSS supplied to the stream network is exported to the outlet while 42% is trapped in storages, 17% is lost through water extraction and only 0.8% is deposited on the floodplain. Hillslope erosion generated 42% of the TSS supply followed by streambank erosion (39%) and gully erosion (19%).
- About 55% of the TN supplied to the stream network is exported to the outlet while 25% is lost due to water extractions, 19 % is trapped in storages and the remaining 1% deposited on the floodplain and accounted for as residual. Diffuse-dissolved sources generated most of the TN supply followed by hillslope erosion and streambank erosion.
- Only 42% of the TP supplied to the stream network is exported to the outlet while 22% is lost due to water extractions, 35 % is trapped in storages and the remaining 1% deposited on the floodplain and accounted for as residual. Hillslope erosion generated most of the TP supply followed by diffuse sources (undefined plus diffuse dissolved) and streambank erosion.
- About 66% of the PSII supplied to the stream network is exported to the outlet while 25% is lost due to water extractions and about 9% lost through stream decay. Diffuse dissolved sources generated all PSII supply.
- About 68% of the DIN supplied to the stream network is exported to the outlet while the rest is lost due to water extractions. Diffuse and point sources, respectively, contribute 92% and 8% of the DIN load supply.

Table 23 Detailed constituent budget summary

Budget element	TSS (kt/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TN (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	TP (t/yr)	PSII (kg/yr)
SOURCES	**1,176**	**819**	**1,301**	**1,890**	**4,009**	**117**	**54**	**755**	**925**	**2,302**
Hillslope	495	0	0	1,312	1,312	0	0	554	554	0
Gully	221	0	0	183	183	0	0	67	67	0
Streambank	461	0	0	394	394	0	0	133	133	0
Point source	0	67	18	0	84	18	5	0	23	0
Diffuse dissolved	0	752	1,283	0	2,035	99	49	0	148	2,302
SINKS	**715**	**265**	**428**	**1,114**	**1,807**	**39**	**18**	**476**	**534**	**774**
Extraction	205	261	415	339	1,014	38	18	148	203	568
Floodplain deposition	9	0	0	11	11	0	0	5	5	0
Reservoir deposition	497	0	0	758	758	0	0	321	321	0
Reservoir decay	0	0	0	0	0	0	0	0	0	0
Residual link storage	4	4	13	6	24	1	1	2	4	4
Stream decay	0	0	0	0	0	0	0	0	0	202
Stream deposition	0	0	0	0	0	0	0	0	0	0
EXPORT	**462**	**554**	**873**	**775**	**2,202**	**78**	**35**	**278**	**392**	**1,528**
Hillslope	165	0	0	508	508	0	0	201	201	0
Gully	39	0	0	41	41	0	0	9	9	0
Streambank	258	0	0	227	227	0	0	68	68	0
Point source	0	56	17	0	73	17	13	0	30	0
Diffuse dissolved	0	498	856	0	1,353	62	22	0	83	1,528

Figure 29 shows the contribution of each of the five basins to constituent export. Figure 29 indicates:

- Most of the TSS is exported from the Mary and Baffle basins, accounting for 76% and 11% of the export, respectively.
- Most of the TN is exported from the Mary and Burrum basins, accounting for 60% and 14% of the export, respectively.
- Most of the TP is exported from the Mary and Burnett basins, accounting for 62% and 14% of the export, respectively.
- Most of the PSII is exported from the Burrum and Mary basins accounting for 35% and 29% of the export, respectively.

- Fertilised agricultural lands are a key source of nutrient runoff, particularly dissolved forms of nitrogen from sugarcane. The load of DIN exported from the Burnett Mary region is 554 t/yr, of which 436 t/yr is due to human activity.

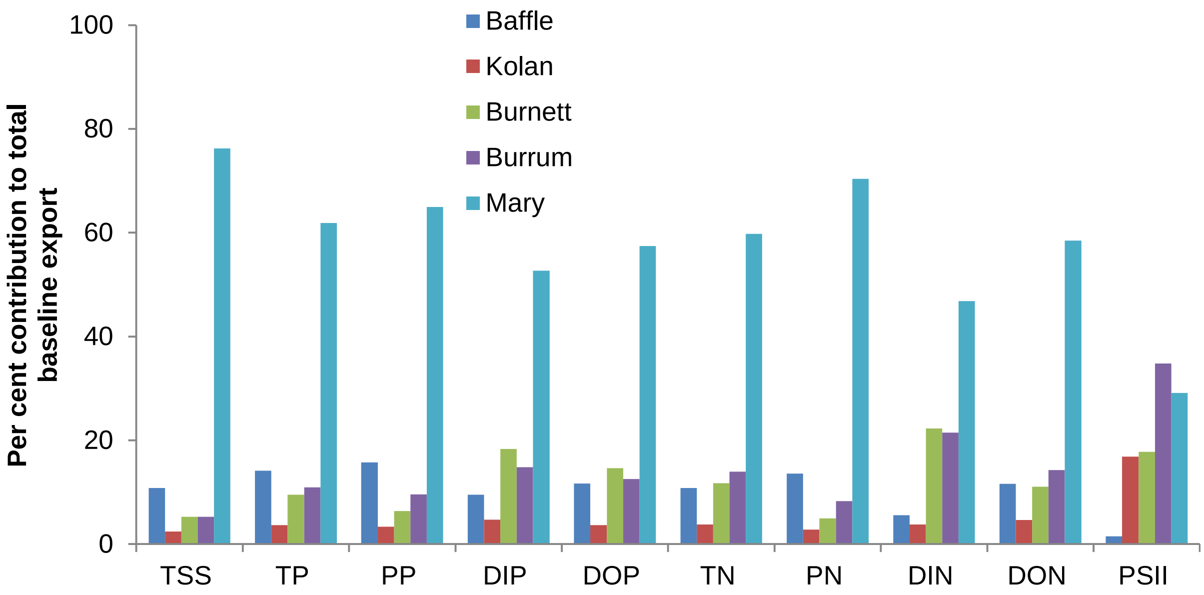

Figure 29 Contribution of each basin to export as per cent of total regional export

4.3 Progress towards Reef Plan 2009 targets

Suspended sediment load reduction due to the four years of improved management practice adoption in the Burnett Mary was about 3% compared to GBR wide reduction of 11%. The Mary basin accounted for 41% of the regional reduction in TSS export followed by the Burrum basin with 26%. The Burnett, Kolan and Baffle basins accounted for only 16%, 10% and 7% of the regional reduction in TSS export, respectively. Almost all the TSS export reduction is due to Reef Rescue funded management practice changes.

Figure 30 shows the contribution of each basin to the total reduction in constituent export resulting from four years (Report Cards 2010–2013) of improved practice adoption.

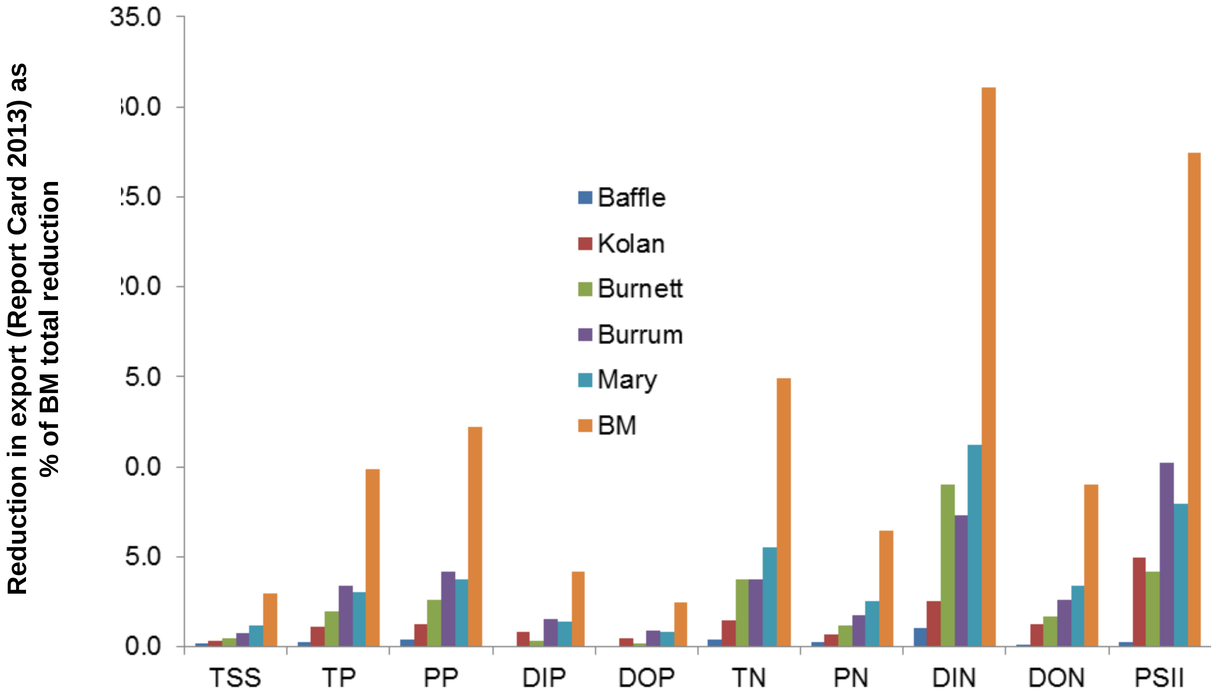

Figure 30 Reduction in constituent export as the result of management intervention

The greatest reductions in DIN and PSII were achieved in cane areas. There was moderate reduction of 15 % and 10% respectively of total nitrogen and total phosphorus across the Burnett Mary compared to GBR wide reductions of 9.9% and 13% respectively. The greatest reductions in TN were achieved through a reduction of DIN. The majority of DIN is lost in runoff following fertiliser application in sugarcane growing areas. Adoption of the six easy steps for nutrient management in these areas has had major contribution to the reduction. The PSII inhibiting herbicides reduction in the BM of 28% was very similar to the GBR-wide reduction of 28% with the major reductions attributed to improved pesticide application techniques in cane growing areas. The reductions in DIN and PSII inhibiting herbicides export is almost exclusively due to management changes in sugarcane.

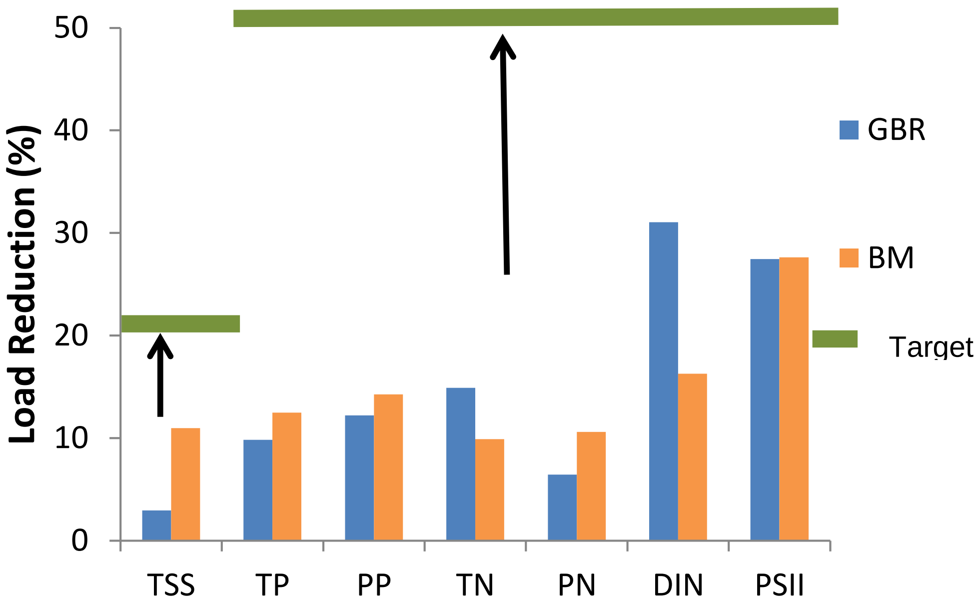

Figure 31 Percentage reduction in TSS, TP, TN, PN, DIN and PSII for BM and whole of GBR compared to the reductions targets of 20% for TSS by 2020 and 50% for the remaining constituents

Figure 31 shows TSS, TP, TN and PSII % export reductions due to the four years (Report Cards 2010–2013) investment in management change in the Burnett Mary region compared to GBR-wide reductions and against Reef Plan reduction targets for these constituents (50% reduction in TN, TP, and PSII by 2013 and 20% reduction in TSS by 2020). The per cent redcutions in TSS and TP export from the Burnett Mary region are less than the corresponding reductions from the GBR as a whole. On the other hand there is a higher per cent reduction in TN from the Burnett Mary region than reduction from the whole of the GBR while % reductions in PSII across both BM and the GBR as a whole are similarIn terms of the 50% reduction targets by 2013, TN and TP and PSII, the reductions from the four year investments may be considered quite modest, while reductions in PSII are relatively better. Assuming the same annual reduction of 2% from 2010 to 2020 to meet the Reef Plan target of 20% reduction by 2020, the 3% reduction in TSS for the two years of improved practice adoption is also modest.

Tables 49 to 51 show predevelopment, baseline and management change results for Report Card 2011, Report Card 2012 and Report Card 2013 while Figure 32 shows progress made in constituent export due to improved practice adoption at the end of each of the four report cards. Note that for Report Card 2011 reductions to be compared to Report Cards 2012-2013 reductions, it was necessary to re-run this management scenario and the corresponding baseline scenario with the same parameters and the same version of Dynamic SedNet. As the result, the reductions for Report Card 2011 presented here are different from those reported previously.

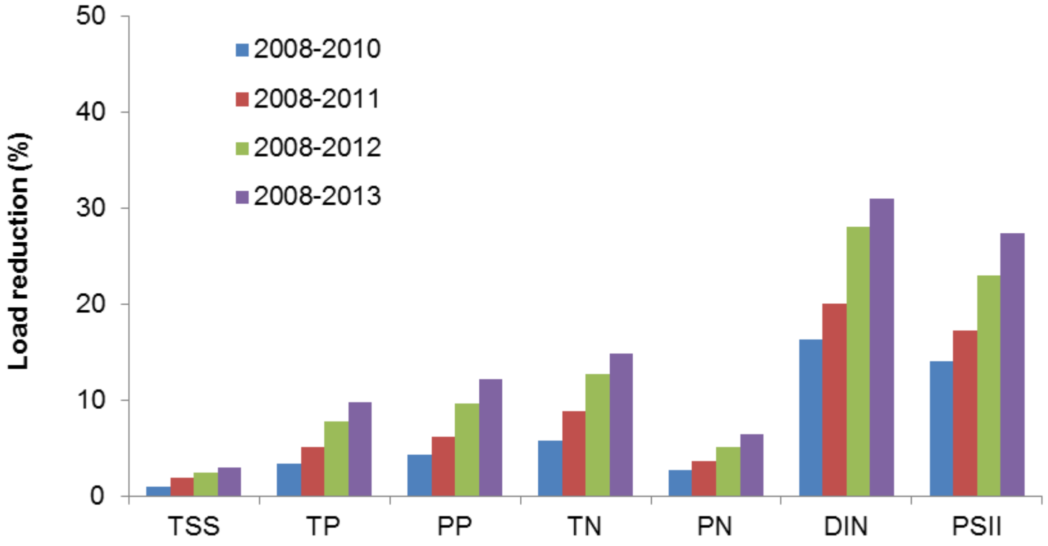

Figure 32 Cumulative reduction in constituent export for the four reporting periods

The results presented in Figure 33 can be explained in terms of percentage changes in area under each of the sugarcane management practices in each report card. For example, the relatively high jump in DIN export reduction from Report Card 2011 to Report Card 2012(Figure 32) compared to the reduction from Report Card 2012 to Report Card 2013 is due to the corresponding jump in percentage of area under B practice from Report Card 2011 to Report Card 2012 while it actually declined from Report Card 2012 to Report Card 2013. Although there is a relatively high jump in percentage of area under A practice from Report Card 2012 to Report Card 2013, this was partly due to a conversion of B practice to A practice which does not result in a as much DIN export reduction as the same amount of area change from D or C to B practice.

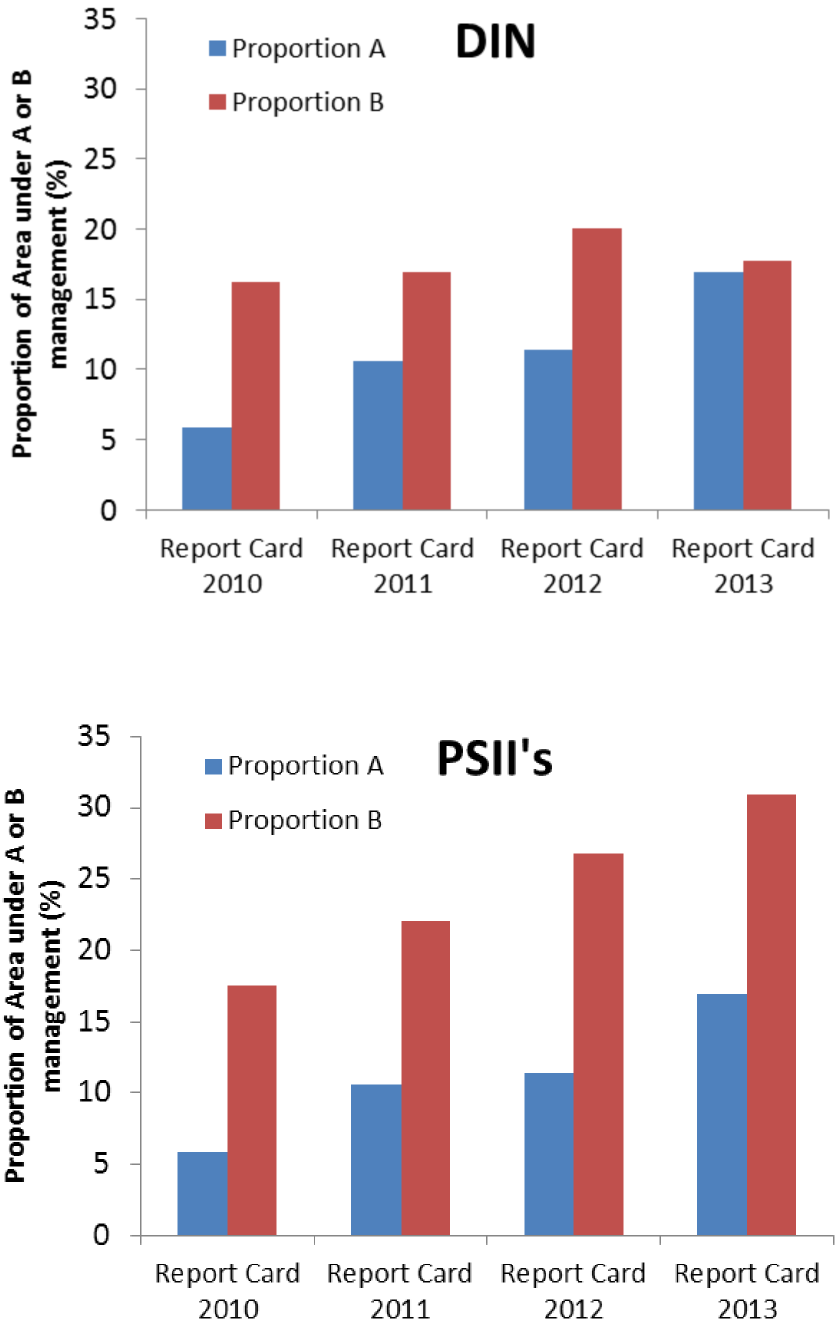

Figure 33 Percentage of sugarcane area under A and B class management practice (top for nutrients and bottom for pesticides) for the BM region across the four reporting periods

The reduction in TSS and particulate nutrients in the BM region could be considered conservative as the management practice changes did not include streambank rehabilitation and gully stabilisation, which contribute most of the TSS and particulate nutrients.

4.4 Model validation

4.4.1 Previous best estimates

The Burnett Mary Source Catchments model TSS, TN and TP load results are considerably less than the (Kroon et al. 2012) and (Brodie et al. 2009) estimates (Table 24). On the other hand, PSII loads estimated by the model are higher at Baffle, Kolan, Burrum and Mary basins than those estimated by both (Kroon et al. 2012) and (Brodie et al. 2009). The Kroon et al. (2012) estimate is sourced from the short-term modelling report (Fentie et al. 2006) which used a constant ground cover of 50%, included fewer dams and did not account for constituent losses associated with water extraction. These differences may explain the lower Source Catchments loads.

Table 24 Previous modelling estimates against Source Catchments modelling results

TSS (kt/yr)	Brodie et al. (2009)	Kroon et al. (2012)		Source Catchments	
	Current	Natural	Current	Predevelopment	Total baseline
Baffle	300	35	280	20	50
Kolan	100	22	130	2	11
Burnett	200	99	1,400	3	24
Burrum	100	9	94	7	24
Mary	1,200	98	1,200	61	352
Region total	**1,900**	**263**	**3,100**	**93**	**462**
TN (t/yr)	**Brodie et al. (2009)**	**Kroon et al. (2012)**		**Source Catchments**	
	Current	**Natural**	**Current**	**Predevelopment**	**Total baseline**
Baffle	800	203	1,500	127	238
Kolan	350	104	620	20	83
Burnett	1,700	396	5,200	82	258
Burrum	500	133	770	82	308
Mary	1,850	627	5,100	468	1,316
Region total	**5,200**	**1,463**	**13,000**	**779**	**2,202**
TP (t/yr)	**Brodie et al. (2009)**	**Kroon et al. (2012)**		**Source Catchments**	
	Current	**Natural**	**Current**	**Predevelopment**	**Total baseline**
Baffle	138	28	220	30	55
Kolan	54	14	97	4	14
Burnett	385	50	1,500	21	37
Burrum	86	19	110	15	43
Mary	375	92	1,200	98	242
Region total	**1,038**	**203**	**3,100**	**168**	**392**
PSII (kg/yr)	**Brodie et al. (2009)**	**Kroon et al. (2012)**		**Source Catchments**	
	Current	**Natural**	**Current**	**Predevelopment**	**Total baseline**
Baffle	20	0	19	0	23
Kolan	100	0	100	0	257
Burnett	300	0	320	0	271
Burrum	400	0	400	0	531
Mary	150	0	160	0	445
Region total	**970**	**0**	**1,000**	**0**	**1,528**

4.4.2 Catchment load monitoring – (2006 to 2010)

A comparison was made between the mean GBRCLMP loads (averaged over three and four years between 2006 and 2010) and the modelled loads (Source Catchments) at Burnett EOS (136014A) and three other sites (136002D, 136094A and 136106A). As shown in Figure 34 and Figure 35 for the three year average loads (2006-2009), the model is generally overestimating constituent loads at all sites with the exception of DIN at 136002D and DIN and DON at 136106A. On the other hand, over the four years (2006-2010), the model is underestimating loads of all constituents at EOS site. On the other hand, it overestimates loads of all constituents except PP at 136002D. At a third site (136094A) the model overestimates TSS, TP and PP while it overestimates the other constituents. At a fourth site (136106) it overestimates TSS, TN, PN, TP and PP while it underestimates the other constituents as shown in Figure 35. Differences between modelled and monitoring estimates at the 136002D gauging station range from 6% in PP to 52% in DON.

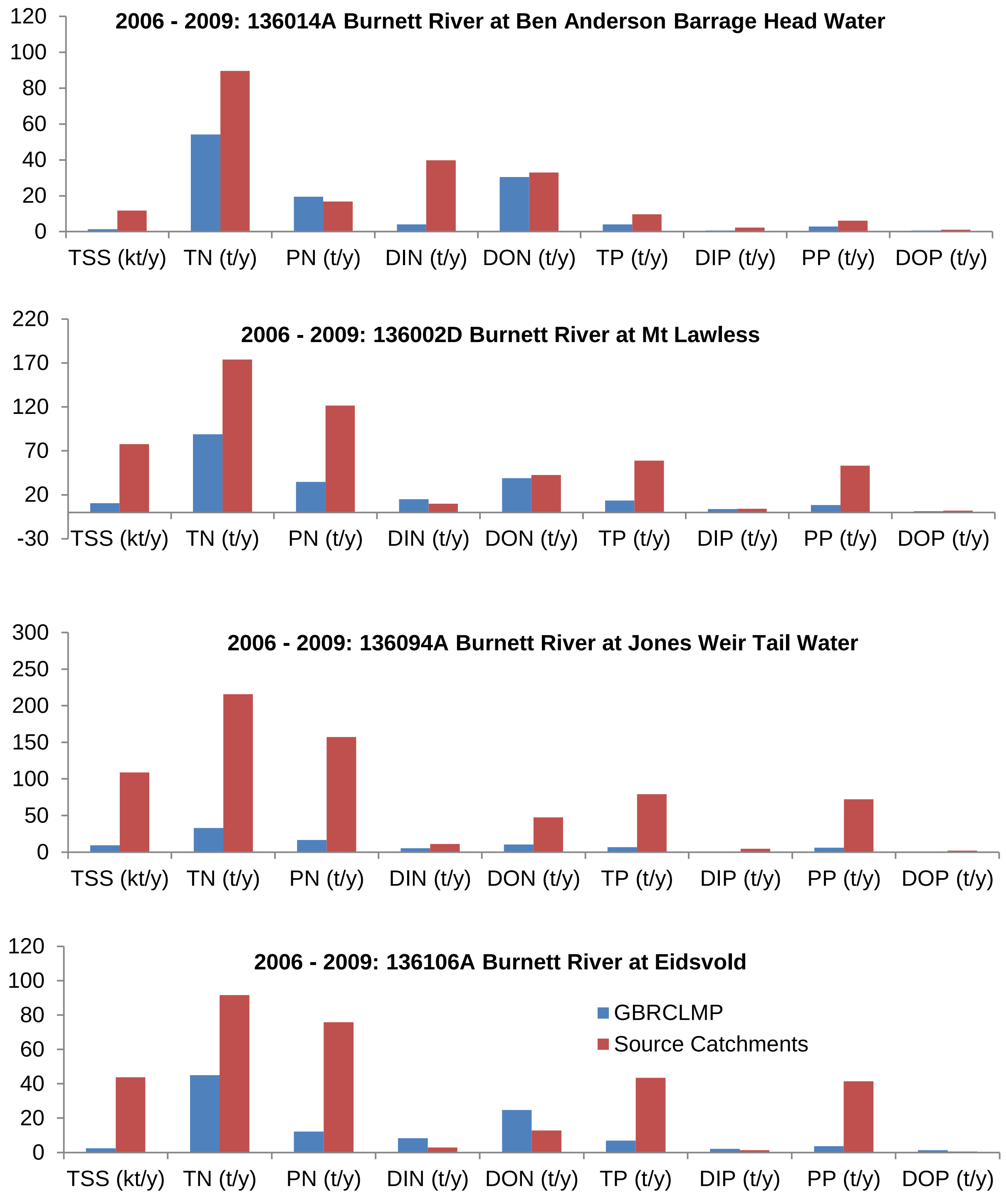

Figure 34 Constituent export load estimates (average annual over three years of monitoring, 2006–2009) versus Source catchments modelled export load

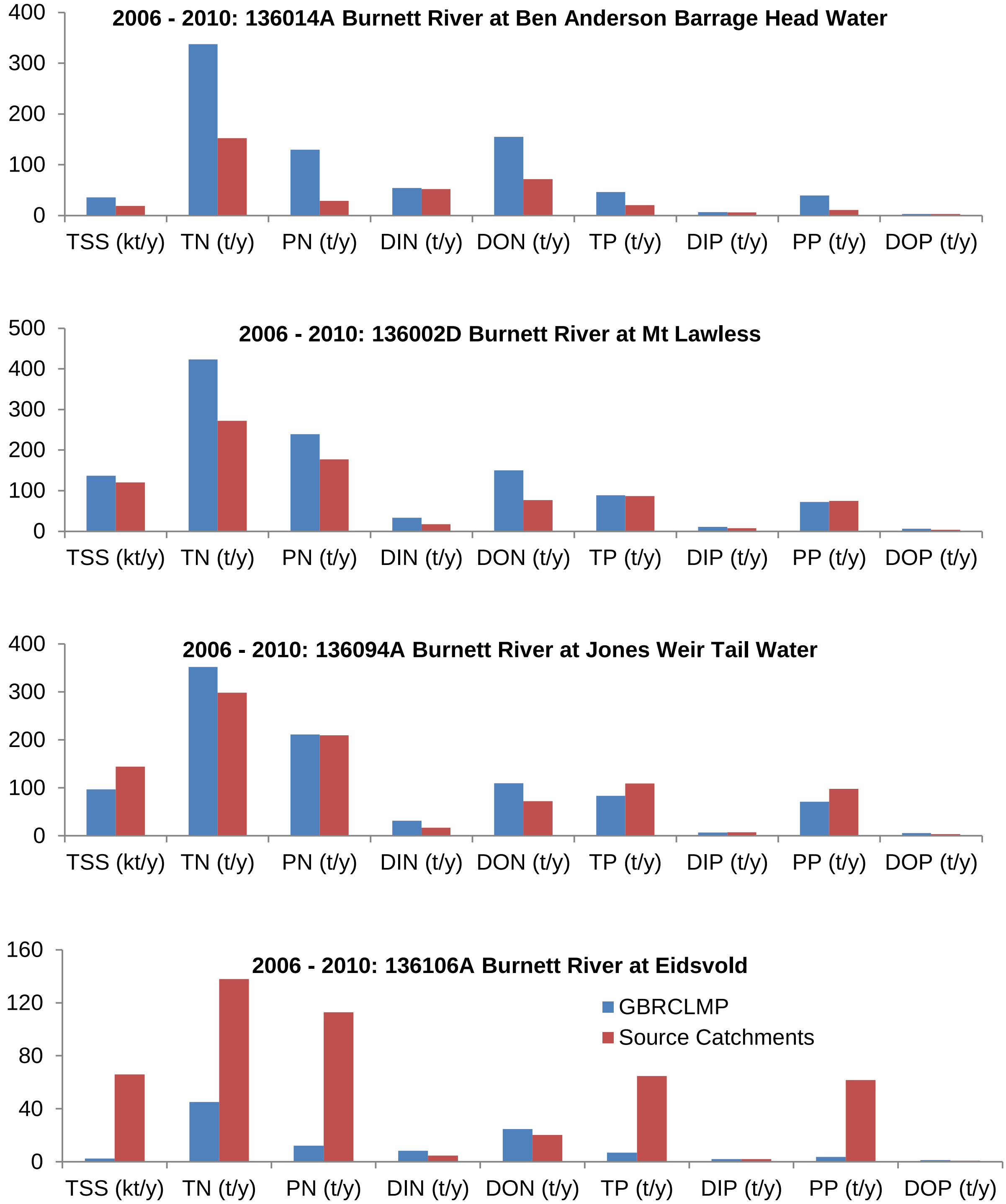

Figure 35 Previous constituent export load estimates (average annual over four years of monitoring, 2006–2010) versus Source catchments modelled export loads

Model performance was better at 136094A followed by 136014A and 136002D. The model performed poorly at 136106A reflecting the poor data quality rating assigned to this site by Joo et al. (2012) as indicative only.

4.4.3 Catchment load estimates (1986 to 2009)

Modelled load for the full modelling period have also been compared with estimates for the same period using flow and measured concentration data (Joo et al. 2014) as presented in Figure 36 and Table 25. According to the recommended ranges of model performance measures presented in Table 15, results presented in Table 25 indicate that the modelling of TSS can be considered satisfactory against the NSE and RSR performance measures of Moriasi et al. (2007) while it was unsatisfactory against the PBIAS performance indicator. The modelling of TN and TP falls in the satisfactory category against PBIAS and unsatisfactory against the other two performance measures. Due to lack of measured flow data at the site where loads have been estimated (Joo et al. 2014), mainly arising from in the use of this dataset, FRCE loads in the region are more uncertain than in other regions. Therefore, while still useful, these loads may not be legitimate for a model validation exercise in the Burnett Mary and are only included here for completeness and consistency with other regions and should be considered as indicative only rather than realistic model validation.

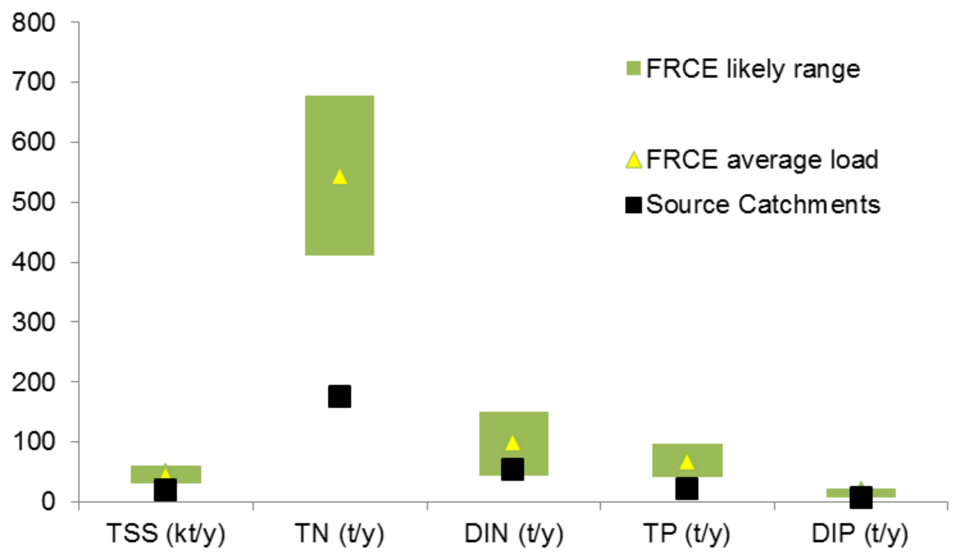

Figure 36 Comparison of modelled constituent export against estimates by Joo et al. (2014)

Table 25 Results of model evaluation according to Moriasi et al. (2007)

	NSE		RSR		PBIAS	
Constituent	**Value**	**Result**	**Value**	**Result**	**Value**	**Result**
TSS	0.60	Satisfactory	0.63	Satisfactory	56	Unsatisfactory
TN	0.47	Unsatisfactory	0.73	Unsatisfactory	68	Satisfactory
TP	0.49	Unsatisfactory	0.71	Unsatisfactory	70	Satisfactory

4.4.4 Other data sets

Figure 37 compares event modelled loads and loads estimated from monitoring at a number of gauging stations (see Table 15 for details). Loads estimated from monitoring were compiled and reported for the NAP project (Esslemont 2006a–g). For the same constituent, modelled and measured values are in closer agreement at some gauges than others. In general, the model estimates more TSS in seven out of 11 gauges, more TP at five out of seven gauges and less TN at three out of five gauges. It appears that there is a stronger agreement between modelled and observed values for TN than for TSS and TP.

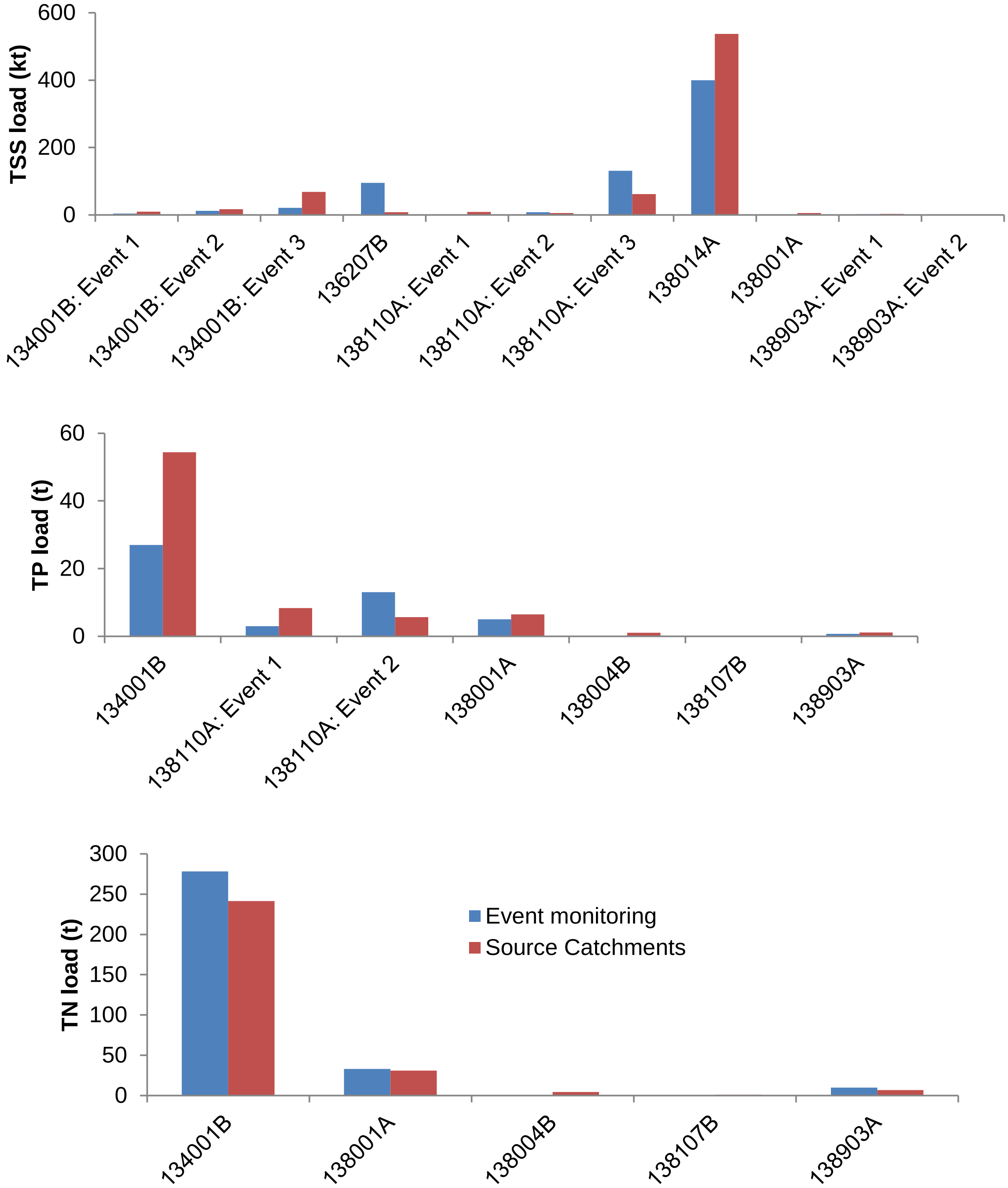

Figure 37 Comparison of loads estimated from event monitoring and the corresponding modelled loads at various sites in the BM for TSS (top), TP (middle) and TN (bottom)

5 Discussion

In the Paddock to Reef program a consistent modelling approach was adopted using the Source Catchments modelling framework to generate predevelopment loads and subsequent anthropogenic baseline loads for key constituents for the 35 reef catchments (including small coastal catchments), for the six NRM regions. In addition SedNet/ANNEX modelling functionality was incorporated to provide estimates of the contribution of hillslope, gully and streambank erosion, along with improved: hydrology, spatial and temporal resolution of remotely sensed ground cover, riparian vegetative cover, soils information, representation of land management practices, and water quality data to validate model outputs. These collective enhancements have resulted in a comprehensive improvement in modelling constituent loads and reporting on changes of loads discharging from GBR catchments.

5.1 Hydrology

An improved spatial and temporal representation of hydrology compared to previous modelling at a similar scale has been a critical enhancement of the catchment modelling undertaken. In the Burnett Mary region, the hydrology modelling calibration produced very good agreement with gauged flow data, particularly for monthly and annual flows. Out of the 32 gauges used in the hydrology calibration for the region, 91% met the monthly Nash-Sutcliffe criterion (>0.5), 25 (78%) met the monthly per cent volume error criterion (± 20%). This can be regarded as an extremely good calibration result given that a global review of hydrology calibrations rated Nash Sutcliffe E values > 0.75 as “very good” performance (Moriasi et al. 2007).

However, most of the calibration gauges failed to satisfy the daily Nash-Sutcliffe criteria. Some factors that may explain some of the discrepancy between measured and modelled daily flow include:

- The uneven spatial distribution of the limited rain gauges used to generate the daily rainfall surfaces
- Accuracy of the node model time-series and functions obtained from a series of IQQM projects in the region and their spatial location
- Limitations of the rainfall and runoff model

The accuracy of the SILO rainfall grid is generally expected to be lower in areas where there is a low density of rainfall gauges (Zhang & Chiew 2009) relative to the climate gradients (Chiew et al. 2008). The SILO climate database is continually expanding and updated through time. Therefore, future calibration should be based on the latest climate data when and where it is available.

Future hydrology calibration will look into the use of additional flow gauging stations with shorter periods than the current calibration period in order to investigate the possibility of further improvements to the hydrology calibration. The current regionalised hydrology calibration used a limited number of gauging stations that had a suitable length of time-series flow data. In addition, future calibration should explore the possibility of using different weightings and the use of additional objective functions. All three objective functions used in the current calibration were equally weighted. It is possible that giving more weight to peak flows will improve the modelling results of constituent loads, which are mainly generated during high flow events.

Whilst SIMHYD has been chosen due to its relatively wide application in previous modelling projects and its relatively small number of parameters, future modelling will explore the possibility of a more suitable model. An example of this exploration has been that conducted by (Zhang, Waters & Ellis 2013).

Therefore, future hydrology calibration will look into improving these inputs and explore different objective function options to address under-predicted peak flows, and discrepancy between measured and modelled flows. Whilst it has been shown to be acceptable (Zhang & Chiew 2009), the transfer of parameter values from calibrated regions to ungauged parts of the region based on proximity may be avoided if appropriate flow data could be obtained through future monitoring in these currently ungauged parts of the region.

5.2 Constituent loads

5.2.1 Load validation

The GBR Source Catchments loads for the Burnett Mary region were validated against four other load estimates to determine the performance of the model. Firstly, current model outputs were compared against previous catchment modelled estimates reported by Kroon et al. (2012) and Brodie et al. (2009). Secondly, a short-term catchment monitoring data for 2006 to 2010 (Turner et al. 2013a,b) compared to the equivalent 4 year modelled loads. Thirdly, a regression approach that used a correlation between available measured water quality data to discharge to produce average annual loads for the 23 year model period (Joo et al. 2014). Fourthly, Source Catchments loads were compared against a range of event-based load estimates from (Esslemont 2006a-g) collected at a number of gauged sites across the region, and compared with corresponding modelled estimates for the particular event time period.

Generally, loads estimated by the current model are considerably less than loads estimated by the previous model estimates while being in better agreement with loads estimated from monitoring. This is attributed to improved input datasets and model components in the current model. Moreover, previous estimates do not cover the same period as the Source Catchments modelling period considered in this study.

The Source Catchments modelling estimated TSS, TP and TN exported loads from the Burnett Mary region have increased 5.0, 2.3, and 2.8 fold respectively from predevelopment loads. The estimated increase in loads is much smaller than (Kroon et al. 2012) previous modelled estimated increases of 11.8, 15.3, and 8.9-fold for TSS, TP and TN. This difference may partially be explained by the lack of representation of major water storages in the load estimates captured by Kroon et al. (2012), while the current modelling includes all major water storages in the region and a comprehensive representation of removal of constituents due to water extraction.

The Source Catchments modelled loads compared favourably with the estimated short-term catchment monitoring loads (2006–2010) from three upstream gauges and the end of system gauge in the Burnett basin; but not that strongly with the average annual load estimated for the 23 year modelled period (Joo et al. 2014). In both cases, the modelled loads tended towards the expected lower load ranges, particularly with TN loads. Given the uncertainty in the FRCE loads mainly arising from the lack of measured flow data at the site where loads have been estimated (Joo et al. 2014), the use of this dataset, while still useful, may not be legitimate for a model validation exercise in the Burnett Mary. However, it is included here for completeness and consistency with other regions and should as such be considered only as indicative only rather than realistic model validation. There was also a promising agreement between monitored event loads and modelled loads. However, 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 modelled catchment loads. Therefore model validation aims to demonstrate that the models are achieving a reasonable approximation of the loads derived from measured water quality data. Validation therefore, is more appropriate at an average annual to annual timescale and any comparisons made at smaller time-steps should be treated cautiously and be considered to have a higher degree of uncertainty.

At a monthly time-step, a per cent difference between measured and modelled loads for sediment and nutrients of 55% and 70% respectively is considered satisfactory (Moriasi et al. 2007). Model simulations are typically poorer for shorter time steps than for longer time steps (e.g. daily versus monthly or yearly) (Engel et al. 2007), however we calculate there is no change in the per cent difference between monthly and annual time-steps. The modelled annual fine sediment load when compared to GBRCLMP load at the Burnett basin outlet is within 45%, while for TN and TP at the annual time-step the modelled load difference is 53% and 46% respectively. Using the percent error performance rating of Moriasi et al. (2007), the modelling results rate as satisfactory for TSS, TN, and TP.

5.2.2 Anthropogenic baseline loads

Reef Plan water quality targets look to reduce the anthropogenic baseline load that is the loads contribution caused by human induced development and management practice activities. Therefore, the anthropogenic load is determined by the difference between the total baseline load and predevelopment load. The Mary and the Baffle basins are the dominant contributors of anthropogenic baseline TSS export loads while the Mary and the Burrum basins are dominant sources of DIN anthropogenic baseline load. The Mary and Burnett basins contribute most of TP, PP and PN anthropogenic baseline load export. The DIN and PSII inhibiting herbicides anthropogenic baseline export is associated with the prevalence of sugarcane land use in each catchment in the region.

Whilst prioritisation of management actions would be based on socio-economic in addition to bio-physical factors, it can be argued that catchments (or areas within catchments) that are dominant sources of anthropogenic baseline export of constituents should be targeted for maximum reduction in export due to management intervention.

5.2.3 Constituent generation and export

Despite being the third largest GBR regional area, the BM region exports the second lowest TSS and TP, and third lowest TN and PSII inhibiting herbicides to the reef lagoon. The relatively low contributions in TSS, TP, PP, TN and PN export are attributed to constituent trapping in the 11 storages included in the constituent model compared to the other five regions. Catchment monitoring data (Turner et al. 2013a,b) suggested TSS trapping efficiency for the Burnett River Dam was approximately 73% while the model estimated over 95% trapping. It is recommended that future verification and investigation is conducted on the trapping efficiency algorithm for the regions dams.

Within the BM region, the Mary basin is the greatest contributor to export of TSS and particulate constituents due mainly to the high rate of streambank erosion in this catchment (Fentie et al. 2013) and the relatively small number of storages. The Burrum basin exports the largest load of PSII inhibiting herbicides. The Baffle, due to its close proximity to the reef lagoon, absence of storages and relatively higher average annual rainfall, is the second highest contributor of TSS, TP, PP, TN and PN exported from the region.

The BM Source Catchments modelling estimates the TSS contribution exported from the region to the coast is 36% from hillslope erosion, 9% gully, with the largest contribution 55% from streambank erosion. This is in contrast to model outputs from Fentie et al. (2006) where hillslope was the major contribution to exported TSS (55%), gullies (20%), with streambank erosion 27%, half the amount estimated from this study. Nevertheless, in both studies the Mary basin had the greatest contribution of streambank erosion from the region, and this was also the case from earlier modelling undertaken by DeRose et al. (2002) and the National Land and Water Audit (NLWRA 2001). The Mary basin accounts for more than 70, 47 and 29%, respectively, of the TSS, DIN and PSII export loads. Most of the TSS from the Mary basin is sourced from streambank erosion, which is the dominant source of sediment in this catchment accounting for 67% of the sediment export from the basin and 59% of the regional export.

The presence of fewer and smaller water storages can explain the large contribution of streambank erosion exported from the Mary basin. Unlike the Burnett, the Mary basin has just two upland water storages (Baroon Pocket Dam and Borumba Dam) with small catchment areas that have little effect on the reduction of the overall sediment export budget. Plus the Mary River Barrage in the lower section of the catchment has the lowest sediment trapping efficiency of all the regional storages (27%), with the result 76% of regional TSS is exported from the Mary basin.

In contrast, the larger Burnett basin generated almost 51% of the regional TSS delivered to the stream network, with just 4% exported from the region. The small TSS per cent contribution from the Burnett basin is a result of the high sediment trapping efficiency of six of the 11 sediment water storages in the lower reaches of the catchment, particularly the Burnett River Dam, and losses associated with water extractions. In terms of the overall constituent budget, it is worth noting that sediment deposition in storages is the major sink of TSS within the region. Losses associated with water extraction and export account for almost all the sink budget elements of dissolved constituents as zero decay and no storage deposition of dissolved constituents are assumed in the current modelling. The very high trapping efficiency of most of the storages included in the model explains the relatively small contribution to TSS export from the Burnett basin to the GBR lagoon.

The fact the model underestimated TSS load compared to loads estimated from the GBRCLMP in the Burnett basin end of system site indicates that trapping and/or extraction losses are probably overestimated by the model. Future modelling needs to investigate and address this potential issue.

The main sources of TSS, particulate nutrients, dissolved nutrients and PSII inhibiting herbicides have been identified. Streambank erosion in the Mary basin is the major source of TSS and particulate nutrient generation and export and substantial reduction in TSS export needs to target bank erosion reduction in this catchment. Most of the DIN export is associated with fertiliser losses in sugarcane growing areas. Adoption of the six easy steps for nutrient management is expected to result in major contribution to reduction in DIN export. Similarly, most of the PSII export is due to the application of these chemicals to control weeds in sugarcane farms. The sugarcane industry in the Burrum and Mary basins contributes most of the PSII export. Therefore, management actions to reduce PSII export from this region should focus in the sugarcane industry in those basins.

The Burnett Mary region contributes a relatively small amount of constituents to the GBR lagoon, with 5.4, 5.3 and 9.1% of the TSS, DIN and PSII baseline load export and 4% of the end of system flow to the GBR lagoon. Nevertheless, there is a large anthropogenic generated load of TSS, DIN and PSII (80%, 78% and 100% of the total baseline load respectively) exported from the region, indicating the need to target investment to reduce loads through improved land management activities from key land uses.

5.2.4 Contribution by land use

Tables 47 and 48 (Appendix E) show the contributions of land uses to TSS, TN and TP export loads. Grazing contributed 29% of the TSS export from the region. Most of this is from the Mary basin followed by the Baffle basin. Therefore, on ground management intervention to reduce export of TSS to the GBR lagoon from grazing should target these two basins. Streambank erosion in the Mary basin dominates the contribution to TSS load, and is supported by earlier modelling studies (Fentie et al. 2006; DeRose et al. 2002); and is a consequence of relatively high channel capacity and stream power, as a result of large historical channel incision and widening coupled with localised clearing of riparian vegetation. Sugarcane land use followed by streambank erosion and urban land use in the Mary contribute most of the TN export. Most of the TN export from sugarcane is attributed to the high DIN export from this land use in the Mary, Burrum, and Burnett basins. Therefore, management intervention to reduce DIN and TN export should target the sugarcane land use and streambank erosion.

Streambank erosion from the Mary is also the major source of TP export followed by urban and grazing land uses in the same catchment, making these land uses and streambank erosion in the Mary basin potential targets for management intervention to reduce TP export.

Almost all of the PSII inhibiting herbicides export is from the sugarcane land use, predominantly in the Burrum and Mary basins followed by the Burnett and Kolan basins. Therefore, management actions to reduce export of PSII habiting herbicides should target sugarcane management in these basins.

The constituent budget presented in Table 23 for the whole BM region and tables 42-46 (Appendix E) for each catchment show that the proportional contribution of the different process to constituent load supplied to the stream network can be different from their contribution to export to the reef lagoon. For the BM region as a whole, hillslope erosion contributes 42% and 36% of the TSS supply and export, respectively. Gully erosion contributes 19% and 8% of the TSS supply and export, respectively. In contrast, streambank erosion contributes 39% and 56% of the TSS supply and export, respectively. This means that given two processes that supply similar amounts of TSS, it is processes that export high proportions of TSS that should be targeted for maximum reduction in TSS export to the reef lagoon. These percentage differences in supply and export contributions by a particular process is attributed to the extent and location of losses and sinks in relation to the location of TSS generation from the process of concern. For example, hillslope erosion is the dominant contributor to TSS supply while streambank erosion contributes most of the TSS export, because of where they occur. Therefore, other factors may need to be considered in management intervention prioritisation, more reduction in TSS end-of-system export is likely to be gained by targeting streambank erosion than hillslope erosion or gully erosion.

The constituent budget also shows that 42% of the TSS supplied to the stream network is trapped in storages and 17% is taken out of the stream network through water extractions for different uses. Amounting up to 25%, 22% and 25%, respectively, with losses associated with water extraction are even higher for TN, TP and PSII inhibiting herbicides. Given the significance of these terms in the constituent budget, it is important that these losses are verified by future monitoring data which has been lacking to date in the region.

5.3 Progress towards Reef Plan 2009 targets

Compared to GBR-wide reductions and reef targets, there has been moderate progress towards meeting the reef targets following first five years of improved practice adoption (2008–2013) in the BM region. Whilst the percentage reductions in TSS and TP exports in the BM region are less than the GBR-wide percentage reductions, percentage reductions in TN export from the BM is higher than the GBR-wide reductions with percentage reduction in PSII export from the BM region being about the same as the GBR percentage reduction of about 27.6%. Across the GBR TSS has 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 27.6%. The modelling shows that good progress has been made towards reaching the 2020 target of a 20% reduction in sediment load from the GBR. However, the target of a 50% reduction by 2013 as outlined in Reef Plan 2011 for nutrients and herbicides has not been met. The timeline for meeting this target has been revised in Reef Plan 2011, and Report Card 2014 and beyond will report against this. The relative difference in reductions of DIN and PSII export is attributed to the distance of sugarcane farms from the coast. Since most sugarcane farms are in close proximity to the coast, DIN and PSII export and reductions due to management interventions are greater than TSS and particulate nutrients which are predominantly trapped upstream of cane growing areas in storages. The disproportionately higher percentage reduction of DIN and PSII export in the Mary and Burrum basins is attributed to the prevalence of more sugarcane properties in these basins compared to others. However, sugarcane management practice change data is supplied by mill area, with three mills in the region: Burnett, Isis and Maryborough that tend to straddle across basins (Figure 38). Hence, there is the potential to either over or under estimate reduction in loads for a particular catchment when management practice change is equally distributed within a mill area. This emphasises the need for spatially explicit land management change data to improve estimated load reductions of the regional basins.

About 85% of the regional reduction in TSS export can be attributed to sugarcane management changes in the Mary (30%), Burrum (26%), Burnett (18%), and Kolan (11%)

basins. Changes in grazing management and reduction in streambank erosion as the result of improved grazing management changes contributed 11% and 3% of the total regional TSS export reduction, respectively.

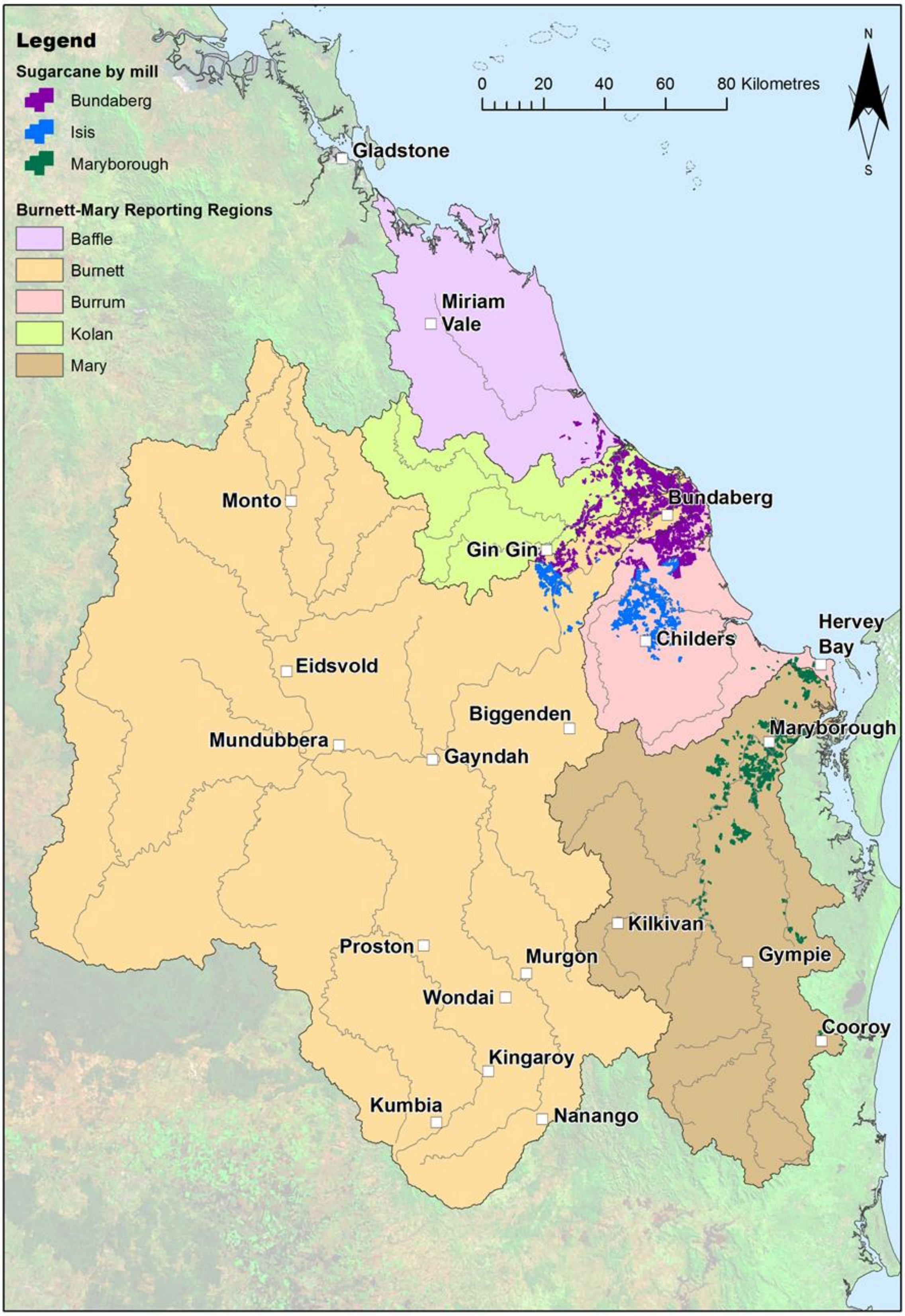

Figure 38 Map of sugarcane properties by mill and reporting region and their close proximity to the coast

The higher per cent reduction in TSS export due to sugarcane management changes is attributed to the proximity of the sugarcane industry to the coast and the relatively higher investment in sugarcane management changes. The generally high ground cover in grazing lands (as interpreted from remotely sensed data) resulted in only minor reductions in TSS export from grazing management changes.

DIN and PSII herbicide reductions are all due to changes in sugarcane management, except tebuthiuron, which is exclusively from grazing management practice change and is a minor component of PSII herbicides.

There have also been modest reductions in TN (9.3%) and TP (5.2%) loads as the result of cumulative management practice changes in the region. The 17% regional reduction in PSII export is higher than the GBR-wide reduction of 15%. Similarly, for nitrogen and phosphorus there was moderate progress.

Continual improvement is an important aspect of numerical modelling to simulate natural systems. A number of improvements are planned for future GBR Source Catchments models. The two priority areas for further model development are improving the model hydrology (to better match high flows) and better representation of sediment sources that is, determination of hillslope, streambank and gully supply. In addition, more spatially explicit management practice change data is critical to potentially improve the relative change in exported constituent loads from the regional basins.

As with all numerical modelling projects used to simulate natural systems, model outputs would be enhanced by improving input data and model processes. As part of the P2R Program's continual improvement process major modelling enhancement will take place for Reef Plan 2013; including the use of the Sacramento hydrology model to better match to high flows and to align with other QG water planning modelling; incorporation of seasonal rather than annual dry season cover; improved spatial allocation of specific management practice information and an updated ABCD management framework. These changes will provide an enhanced GBR Source Catchments total baseline load and load reductions to that for Reef Plan 2009. Consequently, the outcomes for the Reef Plan 2013 reporting period should not be directly related to the outcomes reported in Reef Plan 2009. The current modelling framework is flexible and has improved the capacity to model management practice change when compared to previous GBR catchment modelling approaches. It is a substantial improvement on previous GBR load modelling applications utilising a consistent methodology across all NRM regions. The model has shown that it is an appropriate tool for assessing load reductions due to on-ground land management change across the GBR.

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 Appendix F. 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 targets. Investment in improved land management practices across Report Cards 2010–2013 has resulted in a reduction in fine 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 27.6%. The reduction in sediment, nutrient and pesticide loads is positive progress towards meeting the overall Reef Plan targets. Specifically in Burnett Mary, sediment was reduced by 3%, TN reduced by 14.9% and TP also by 9.8%. The biggest reduction in the Burnett Mary thus far has been for DIN and PSII with a reduction of 31.1% and 27.5%, respectively.

Modelled outputs for the total baseline scenario indicate that approximately 462 kt/yr of TSS is exported to the GBR from the BM NRM region. The estimated regional TSS load is a 4.7 fold increase from predevelopment loads. PP (278 t/yr) is the greatest contributor to TP load (392 t/yr). TP has increased 2.6 times from the predevelopment load. PN (775 t/yr) accounts for the majority of the TN load (2,202 t/yr) while, DIN exporting 554 t/yr, the BM is the fourth highest contributor of DIN across the six GBR NRM regions. The total baseline TN load is estimated to be 3.1 times the predevelopment load. The Mary basin is the greatest contributor for all constituents except PSII inhibiting herbicides for which the Burrum basin is the dominant contributor closely followed by the Mary basin. Moderate progress towards reef plan targets was made for all constituents in areas where management practice changes have been implemented in sugarcane and grazing in the BM region.

The loads estimated from this project are somewhat lower than previous estimates for sediment and nutrient loads from the BM 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, inclusion of more storages and loss of constituents associated with water extraction for irrigation and other water uses. 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 new input information and water quality monitoring data.

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; Carroll et al. 2013). 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.

There are numerous successes of the GBR wide modelling project. Firstly, progress towards the water targets has been quantified. This project has also developed the first temporally and spatially variable water quantity and quality model for BM. In addition, the use of a consistent methodology across whole of GBR enables the direct comparison of loads across regions. Furthermore, due to 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 EMC approaches. The benefit of this approach is to enable 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 true integration of monitoring and modelling, and using modelling outputs to inform the monitoring program. Overall, the project can be considered a significant improvement on past models built for the GBR catchments; however, there will always be scope for improvement. It follows that the better the modelling performs spatially and temporally, the greater the confidence and possible sophistication in targeted management actions.

A process has been identified, and is in place, to improve the model as a whole. Major improvements in the Burnett Mary model that can be made include the re-calibration of the model hydrology to better match high flows; testing and re-parameterising the storage trapping algorithm; possible improvements in K and C-factor inputs of the Revised Universal Soil Loss Equation, improved estimates of predevelopment and anthropogenic loads. The greatest priority is to continue on-ground research and water quality monitoring. This data is the key information against which the catchment scale models can be calibrated, and validated against. These changes will provide an enhanced GBR Source Catchments total baseline load and load reductions to be used for Report Card 2014 and beyond. It should be noted, that due to the proposed model enhancements, the outcomes for the Reef Plan 2009 reporting period should not be directly related to the outcomes reported for the Reef Plan 2013 reporting period.

Overall, the catchment scale water quality modelling has successfully reported progress towards Reef Plan targets. The results show that land managers are on track towards meeting the overall sediment, nutrient and pesticide reduction targets for Reef Plan 2013.

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Appendix A - Previous estimates of pollutant loads

Table 26 Kroon et al. (2012) predevelopment (natural), total baseline and anthropogenic loads for the Burnett Mary NRM region

Basin Name	TSS (kt/yr)			DIN (t/yr)			DON (t/yr)			PN (t/yr)			TN (t/yr)		
	Natural	Baseline	Total	Natural	Baseline	Total	Natural	Baseline	Total	Natural	Baseline	Total	Natural	Baseline	Total
Baffle	35	250	285	96	44	140	97	83	180	10	1200	1,210	200	1,300	1,500
Kolan	22	110	132	48	72	120	49	2	51	7	140	147	100	520	620
Burnett	99	1,300	1,399	180	160	340	190	220	410	30	4,400	4,430	400	4,800	5,200
Burrum	9	85	94	61	160	221	69	51	120	3	440	443	130	640	770
Mary	98	1,100	1,198	280	260	540	310	390	700	33	3,900	3,933	630	4,500	5,130
BM	260	2,900	3,160	670	700	1,370	720	750	1,470	83	10,000	10,083	1,500	12,000	13,500

Basin Name	DIP (kt/yr)			DOP (t/yr)			PP (t/yr)			TP (t/yr)			PSII (kg/yr)		
	Natural	Baseline	Total	Natural	Baseline	Total	Natural	Baseline	Total	Natural	Baseline	Total	Natural	Baseline	Total
Baffle	4	28	32	10	1	11	14	190	205	28	190	219	0	19	20
Kolan	1	6	7	5	2	7	8	83	93	14	83	99	0	100	102
Burnett	3	27	30	18	41	59	29	1,500	1,529	50	1,500	1,550	0	320	320
Burrum	6	6	12	6	0	6	7	91	98	19	91	110	0	400	400
Mary	9	120	129	30	34	64	53	1,100	1,153	92	1,100	1,192	0	160	160
BM	23	190	213	69	72	141	110	3,000	3,110	200	3,000	3,200	0	1,000	1,000

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, taken from Kroon et al. (2012).

Appendix B – PEST calibration approach

The process of coupling PEST and Source Catchments is presented in Figure 39. 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 the returns to running the model in E2CommandLine, with the new parameter set.

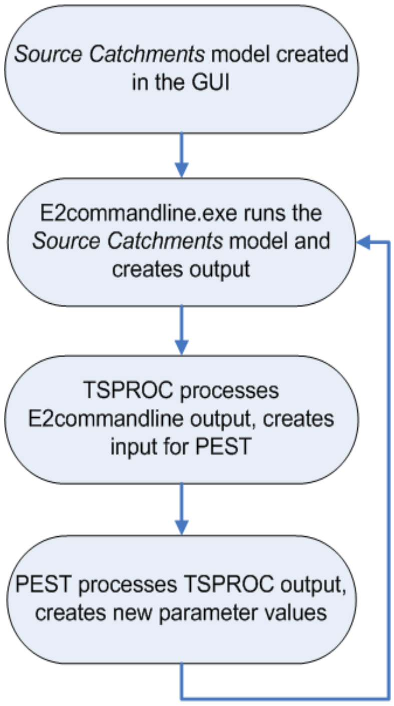

Figure 39 PEST - Source Catchments Interaction (Stewart 2011)

A detailed description of 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).

The PEST SVD-assist Super Parameter Definition was used to derive initial parameter sets and calibration results based on the initial 38 regions. The main benefit of using SVD-assist is the number of model runs required per optimisation iteration. SVD-assist does not need to equal or exceed the number of parameters being estimated. 150 super parameters were defined from the possible 874 parameters. The SVD-assist calibration was stopped once phi started to level out (Iteration 4). Due to IT limitations as stated above, the number of calibration regions was then reduced to 21. A full PEST run using all estimable parameters was then employed. Iteration 4 parameters were used as the starting values for the full 21 region PEST run. PEST was instructed to use E2 commandline to perform the model runs. Given the size of the Burnett Mary 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 40.

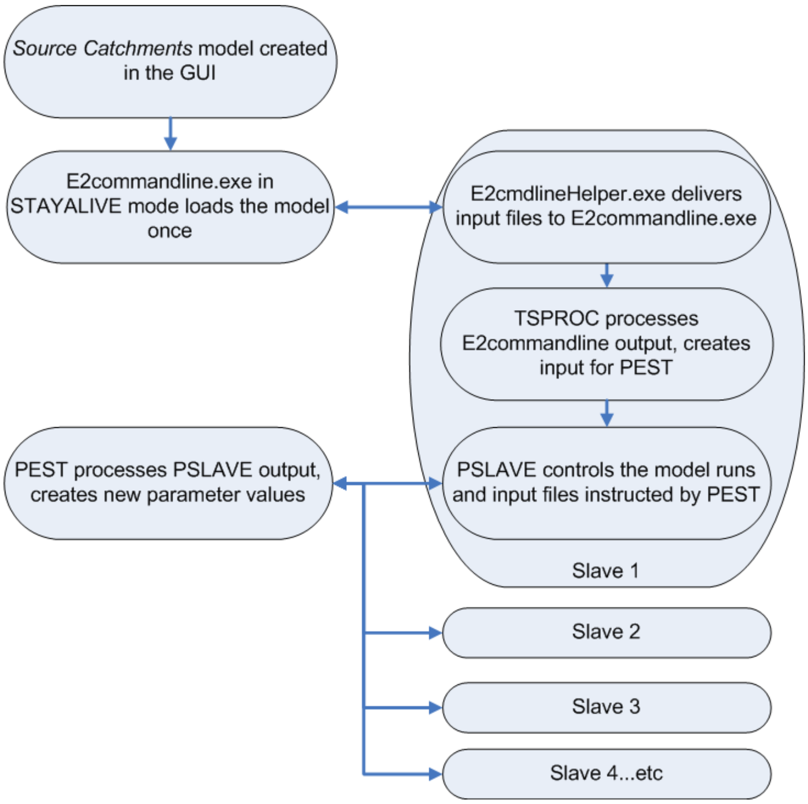

Figure 40 PEST operation (Stewart 2011)

Appendix C - SIMHYD model structure and parameters for calibration

The re-classification of the full set of land uses into three Hydrological Response Units (HRUs) is presented in Table 27. Default SIMHYD and Laurenson parameters were used as the starting values for the calibration process. The calibrated parameter values for three hydrological response units (HRUs) in 32 regions are provided in Table 29.

Table 27 Reclassification of FU's for hydrology calibration

Functional Unit (FU)	HRU
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 28 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)	300		
SIMHYD	Pervious fraction (fixed at 1)	1		
Laurenson	Routing constant (k)	2.25	1.0	864,000
Laurenson	Exponent (m)	240	0.6	2

Table 29 Calibrated SIMHYD and Laurenson parameter values for three HRU's across 32 BM calibration regions

Forest	**Calibration region**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
BASE	0.25	0.59	0.42	0.23	0.62	0.37	0.34	0.24	0.42	0.22	0.33	0.35	0.29	0.19	0.12	0.33
INFC	400.00	116.37	224.86	128.52	187.21	135.25	169.98	161.23	239.45	262.27	158.79	199.90	223.66	121.71	208.19	219.84
INFS	1.78	2.85	2.39	6.28	1.63	5.89	4.01	4.76	3.60	3.07	4.34	3.01	2.77	3.87	2.16	2.46
INTE	0.06	0.05	0.08	0.08	0.09	0.11	0.10	0.12	0.07	0.13	0.10	0.09	0.08	0.13	0.07	0.10
RECH	0.05	0.08	0.08	0.13	0.12	0.20	0.18	0.39	0.09	0.09	0.16	0.16	0.55	0.11	0.44	0.17
RISC	2.73	4.19	3.34	1.53	3.64	1.52	1.63	1.21	2.78	1.53	1.49	1.68	1.86	1.34	1.51	1.62
SMSC	153.57	457.75	183.53	418.48	181.33	257.65	291.23	218.22	421.15	282.21	312.74	299.26	414.06	500.00	500.00	293.69
Grazing	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
BASE	0.27	0.30	0.30	0.27	0.89	0.38	0.33	0.30	0.56	0.16	0.34	0.81	0.29	0.27	0.11	0.34
INFC	400.00	170.02	187.57	158.84	106.18	163.96	172.42	126.63	170.27	197.09	247.71	318.02	231.00	193.22	145.64	177.57
INFS	2.42	2.51	4.10	4.20	2.10	5.06	3.93	6.93	3.22	3.71	3.45	0.51	2.76	3.43	1.21	3.45
INTE	0.06	0.10	0.09	0.09	0.09	0.11	0.10	0.15	0.07	0.09	0.10	0.09	0.22	0.15	0.06	0.01
RECH	0.05	0.17	0.13	0.15	0.11	0.19	0.18	0.47	0.12	0.11	0.10	0.08	0.50	0.22	0.32	0.07
RISC	2.42	1.87	1.73	1.68	4.22	1.58	1.61	1.11	2.86	1.97	2.24	2.10	2.00	1.21	1.84	1.53
SMSC	175.42	262.92	185.96	500.00	126.54	279.12	293.32	176.19	123.53	239.77	301.69	366.88	482.67	437.20	500.00	318.85
Agriculture	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
BASE	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.32	0.29	0.30	0.30	0.30	0.30	0.30	0.30
INFC	200.00	200.00	200.00	199.96	198.93	200.00	199.20	169.70	222.71	204.12	200.00	200.00	200.64	197.63	232.20	200.45
INFS	3.00	3.00	3.00	3.00	3.00	3.00	3.02	3.79	2.45	2.92	3.00	3.00	3.00	3.07	2.42	2.99

INTE	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
RECH	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.25	0.20	0.20	0.20	0.20	0.20	0.19	0.20	0.20
RISC	1.50	1.50	1.50	1.50	1.51	1.50	1.50	1.37	1.58	1.49	1.50	1.50	1.52	1.52	1.53	1.51
SMSC	320.00	320.00	320.00	320.01	319.11	320.00	319.83	255.06	336.41	324.52	320.00	320.00	325.99	320.17	363.15	319.84
Flow Routing	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
K	34905.6	49239.9	32488.0	44046.7	17789.4	35747.8	41049.1	51037.4	36911.5	46928.3	67378.0	59992.8	40957.3	66805.6	175187	29094.7
M	0.66	0.93	1.35	0.50	1.21	0.55	0.76	1.14	1.27	0.35	0.58	1.29	0.47	0.71	0.55	1.12
Forest	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
BASE	0.37	1.00	0.34	0.13	0.15	0.35	1.00	0.20	0.27	0.18	0.21	0.37	0.63	0.53	0.44	0.23
INFC	213.45	162.85	97.88	177.37	252.07	358.48	113.70	244.16	194.40	203.91	295.52	206.05	139.70	226.63	184.16	326.27
INFS	2.79	4.23	1.76	1.00	2.91	3.68	3.26	3.87	3.63	3.19	3.53	2.50	2.17	2.38	5.04	2.24
INTE	0.08	0.06	0.03	0.09	0.03	0.06	0.06	0.08	0.12	0.17	0.18	0.09	0.07	0.08	0.09	0.11
RECH	0.13	0.03	0.04	0.11	0.13	0.04	0.02	0.21	0.23	0.59	0.41	0.15	0.05	0.08	0.08	0.25
RISC	2.16	4.73	2.85	1.07	0.97	2.90	3.17	1.16	1.20	0.68	1.21	2.16	4.30	2.24	2.54	1.31
SMSC	333.10	463.69	314.42	499.03	340.53	318.91	287.57	369.24	342.54	172.13	318.85	177.80	149.89	174.95	347.66	231.26
Grazing	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
BASE	1.00	0.50	0.43	0.25	0.13	0.24	0.83	0.35	0.28	0.09	0.16	0.38	0.78	0.53	0.28	0.28
INFC	303.37	187.48	400.00	196.36	234.03	140.13	181.78	153.37	182.92	155.09	260.10	220.03	165.20	280.35	182.08	331.76
INFS	4.40	3.50	1.41	0.72	5.29	1.27	2.43	2.68	3.48	4.97	5.16	2.85	1.43	4.01	3.91	2.70
INTE	0.02	0.06	0.13	0.04	0.04	0.04	0.09	0.06	0.10	0.13	0.12	0.09	0.06	0.08	0.08	0.11
RECH	0.06	0.06	0.03	0.20	0.05	0.06	0.12	0.20	0.22	0.38	0.37	0.15	0.04	0.08	0.13	0.25
RISC	5.00	1.65	3.43	2.76	1.55	1.97	1.46	1.58	1.35	0.34	1.47	2.05	4.28	3.62	1.74	1.47

SMSC	173.69	241.43	500.00	500.00	256.89	240.22	394.67	316.57	308.01	399.82	500.00	149.42	178.21	124.33	234.52	240.70
Agriculture	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
BASE	0.31	0.31	0.30	0.30	0.19	0.40	0.30	0.25	0.30	0.30	0.28	0.30	0.31	0.30	0.25	0.22
INFC	207.26	199.55	200.10	200.13	208.56	322.53	200.00	198.60	199.20	198.75	203.18	200.91	205.14	200.00	210.07	400.00
INFS	2.89	3.01	3.00	3.00	2.89	1.85	3.00	3.37	3.01	3.03	2.92	3.00	2.83	3.00	3.01	2.37
INTE	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.12
RECH	0.19	0.19	0.20	0.20	0.22	0.34	0.20	0.20	0.20	0.21	0.22	0.20	0.19	0.20	0.15	0.34
RISC	1.59	1.48	1.51	1.50	1.45	1.06	1.50	1.30	1.50	1.45	1.41	1.51	1.56	1.50	1.57	1.42
SMSC	319.68	315.13	320.24	322.23	335.30	500.00	320.00	324.46	318.46	328.00	310.61	315.83	323.18	320.00	277.45	230.71
Flow Routing	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
K	10468.5	12472.5	29691.0	78976.3	17630.0	49083.0	34824.1	109402.6	75516.6	138307.2	46451.8	32773.5	18419.4	33910.9	74003.7	35903.2
M	2.00	2.00	1.31	0.76	0.96	1.44	2.00	0.98	0.40	0.52	0.91	1.43	2.00	0.77	0.70	0.30

Flow duration curves

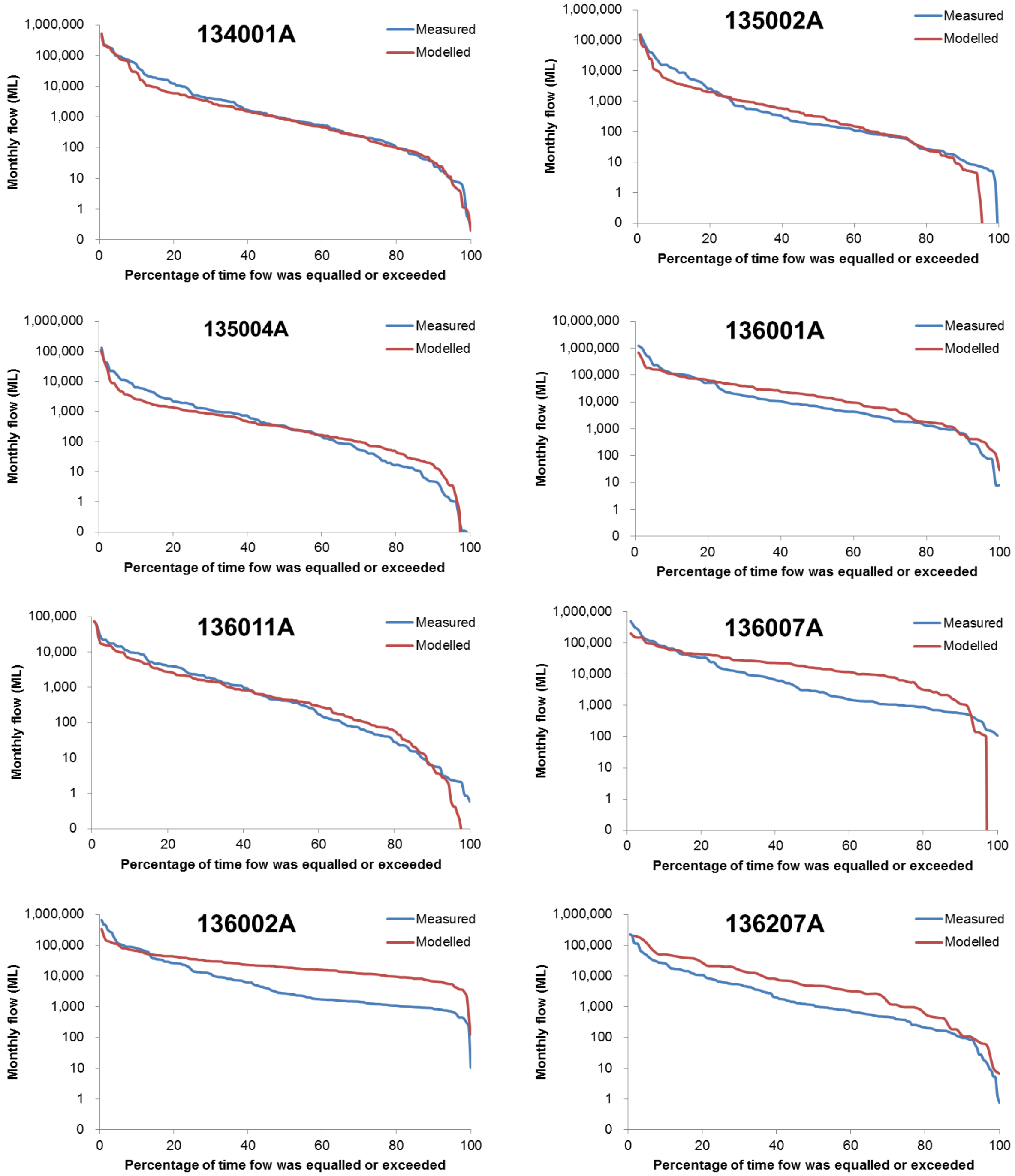

Figure 41 Flow duration curves

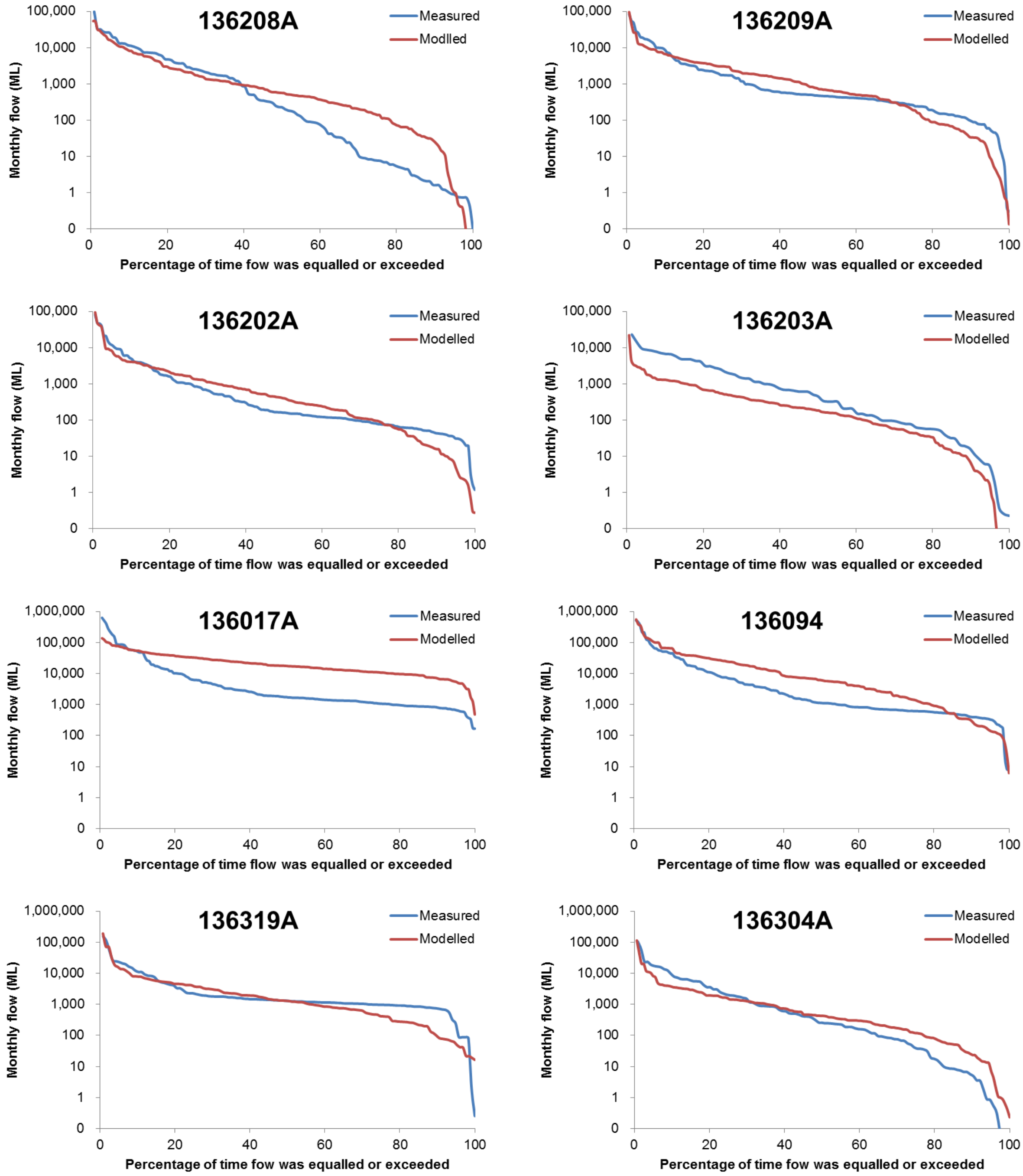

Figure 42 Flow duration curves (continued)

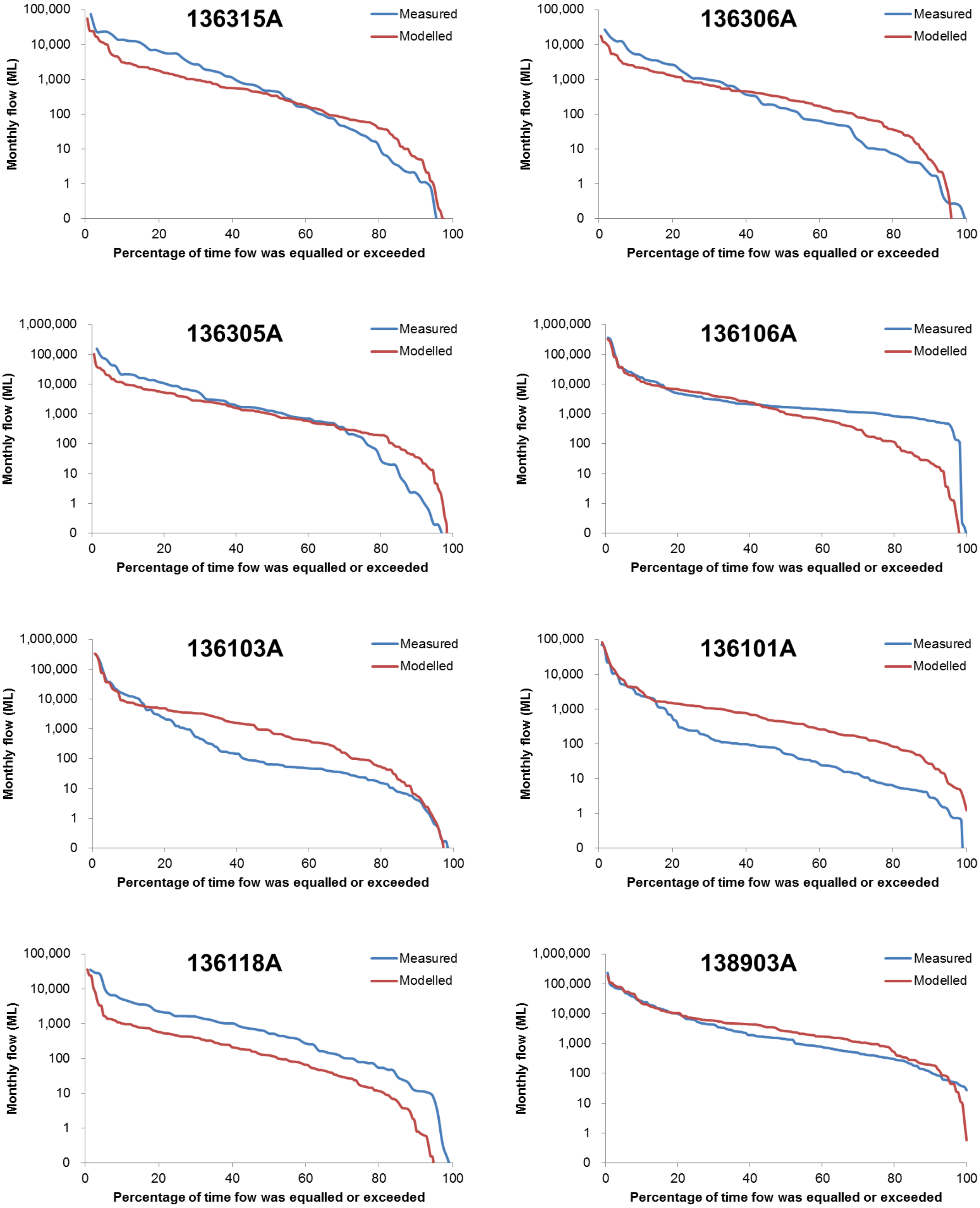

Figure 43 Flow duration curves (continued)

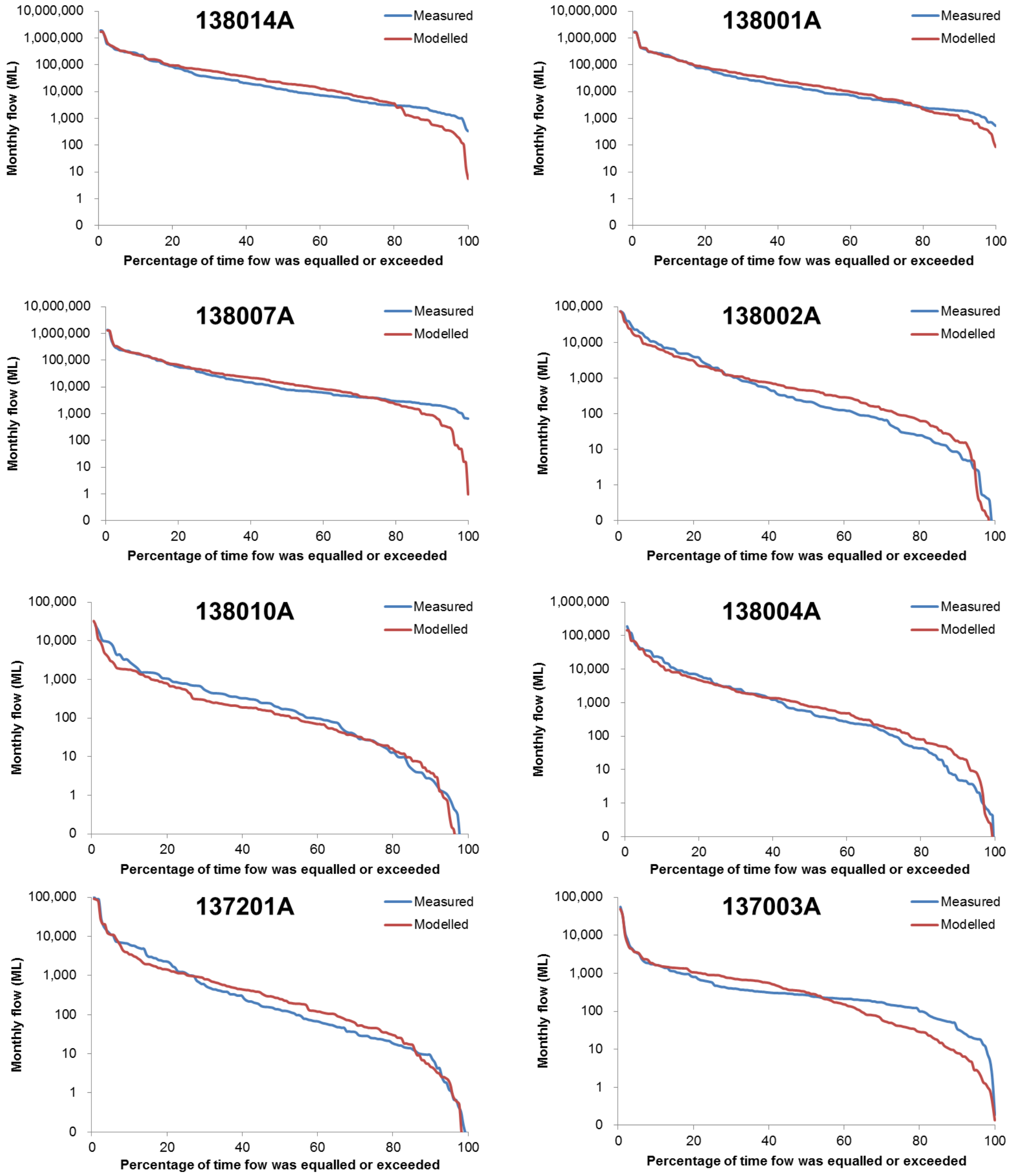

Figure 44 Flow duration curves (continued)

Appendix D – 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 your 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

Land use area by basin

Table 30 Land use area (km^2) by basin in the BM region

Basin	Conservation	Dryland cropping	Forestry	Grazing forested	Grazing open	Horticulture	Irrigated cropping	Other	Sugarcane	Urban	Water	Total
Baffle	754	1	281	2,125	589	16	5	8	8	72	176	4,035
Kolan	265	2	265	1,499	536	32	7	3	149	98	99	2,955
Burrum	721	4	765	956	332	66	6	34	317	156	94	3,450
Burnett	1,316	811	4,045	12,104	13,400	102	409	93	199	369	191	33,038
Mary	1,662	2	1,926	2,682	2,041	80	39	63	190	539	115	9,340
BM	4,717	820	7,282	19,367	16,899	296	466	201	864	1,234	675	52,818

Grazing constituent generation

Hillslope Erosion

There are two spatial inputs required to run this model, described below, along with the GIS process used to generate this data:

- KLS raster
- Surface clay and silt percentage

The KLS raster is a raster of the best resolution USLE factors multiplied, then resampled to 100 m. K is the soil erodibility factor, L is the slope length factor and S is the slope steepness factor. The S factor was calculated by methods outlined in (Brooke et al. 2008). The slope values are derived from the 1 second shuttle DEM (Farr et al. 2007) . The use of this DEM 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 thus modified for the defined floodplain areas, with a value more appropriate for floodplains (0.25%). This was value was approximated from the measurement of slope values produced from a range of high resolution DEM's, covering floodplains in the Fitzroy Catchment.

The L Factor was set to 1.

R factor values were calculated using the 'generalised rainfall intensity' method. Catchment daily rainfall used in the hydrology modelling provided the daily rainfall input.

The daily USLE is multiplied by a '% clay and silt' grid, as well as a delivery ratio. The surface clay plus silt layer was calculated through the addition of individual clay and silt values from the ASRIS data set. 'No values' were adjusted to equal the median value. Fine and coarse delivery ratios are presented in Table 31 below.

Table 31 Sediment characteristics for inclusion in the Hillslope Erosion parameteriser

Characteristic	Value
TSS HSDR value (%)	20
Coarse sediment HSDR value (%)	0
Maximum quick flow concentration (mg/L)	10,000
DWC (mg/L)	0

Gully erosion

Four raster inputs are required for the gully erosion parameteriser.

- The National Land and Water Resources Audit (NLWRA) gully density layer was used the input raster (km/km^2) for gully density in BM.
- The soil bulk density (g/cm3) and b horizon clay and silt (%) raster were both created from the ASRIS dataset.
- The year of disturbance can either be input as a raster or as a uniform value (as can the other input rasters). In the BMT model, a uniform value of 1900 was used.

Table 32 contains the BM specific gully erosion parameters. All values, except the gully cross sectional area, are set to default values. To date, much of the Australian literature 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 (Cowie, Thornton & Radford 2004; Bourne & Tuck 1993; ABS 2008). A cross-sectional area of 10 m3 has been used in the BM model.

Table 32 Gully erosion model input - spatial data and global parameters

Input parameters	Value
Daily runoff power Factor	1.4
Gully model type	DERM
TSS DR value (%)	100
Coarse sediment DR value (%)	0
Gully cross sectional area (m^2)	10
Average gully activity factor	1
Management practice factor	1
Default gully start year	1900
Gully full maturity year	2007
Density raster year	2003

Nutrients (hillslope and gully)

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 (Carroll et al. 1997). Six rasters are required as inputs to the Nutrients parameteriser, four nutrient rasters (surface and sub-surface nitrogen and phosphorus), as well as surface and sub-surface clay (%). All of the nutrient data was derived from the ASRIS dataset, 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 34 which provides data on EMC/DWC values for each of the functional units.

Sugarcane and 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 Functional Units, which in Burnett Mary 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. See the HowLeaky input parameters for the BM model are shown in tables 33 to 35.

Table 33 Cropping nutrient input parameters

Parameter	Constituent	Value
Conversion Factor	DOP	0.2
	DIP	0.8
Delivery ratio (%)	Dissolved nutrients	100
	Dissolved herbicides	100
	Particulates, sediment and particulate herbicides	20
Maximum slope (%)	sediment and particulates	8
Use Creams enrichment	Phosphorus	false
Particulate enrichment	Phosphorus	3
Particulate enrichment	Nitrogen	2
Gully DR (%)	Nitrogen and phosphorus	100

Table 34 EMC/DWC values (mg/L)

Functional Unit	DIN EMC	DIN DWC	DON EMC	DON DWC	DOP EMC	DOP DWC	DIP EMC	DIP DWC	TSS EMC	TSS DWC	PN EMC	PN DWC	PP EMC	PP DWC
Conservation	0.038	0.019	0.166	0.083	0.007	0.003	0.011	0.005	33	17	0.156	0.078	0.047	0.023
Other	0.127	0.064	0.554	0.277	0.022	0.011	0.036	0.018	110	55	0.521	0.260	0.156	0.078
Horticulture	0.318	0.159	1.385	0.693	0.055	0.028	0.090	0.045	275	138	1.302	0.651	0.390	0.195
Urban	0.254	0.127	1.108	0.554	0.044	0.022	0.072	0.036	220	110	1.041	0.521	0.312	0.156
Forestry	0.051	0.025	0.222	0.111	0.009	0.004	0.014	0.007	44	22	0.208	0.104	0.062	0.031

Table 35 shows the EMC/DWC values of tebuthiuron in grazing functional units.

Table 35 Herbicide EMC/DWC

Functional Unit	Tebuthiuron EMC (mg/l)	Tebuthiuron DWC (mg/l)
Closed grazing	0.000014	0
Open grazing	0.000014	0

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 BM 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 (Accad et al. 2001) 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.

$$\text{Streambank soil erodibility (\%)} = \text{Min}(100{,}100/\text{cut\_off} \times \text{FPW}) \tag{11}$$

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 set were added together to create the clay and silt percentage layer. 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.

Variable bank height and width functions were incorporated in the model to replace the default Dynamic SedNet fixed stream bank height and width values. Bank height and width parameters were developed from local gauging station cross section data (DNRM Hydstra database). Regression relationships were determined from 21 data points of channel width and upstream catchment area, and channel height and upstream catchment area in the BM region. Due to differences in streambank geometry between the Mary and the rest of the BM region, two pairs of relationships were developed (Figure 45). The equation was sourced from Wilkinson, Henderson & Chen (2004) where:

$$Channel\ width\ or\ height = Coefficient \times Area(km^2)^{Area\ exponent} \quad (12)$$

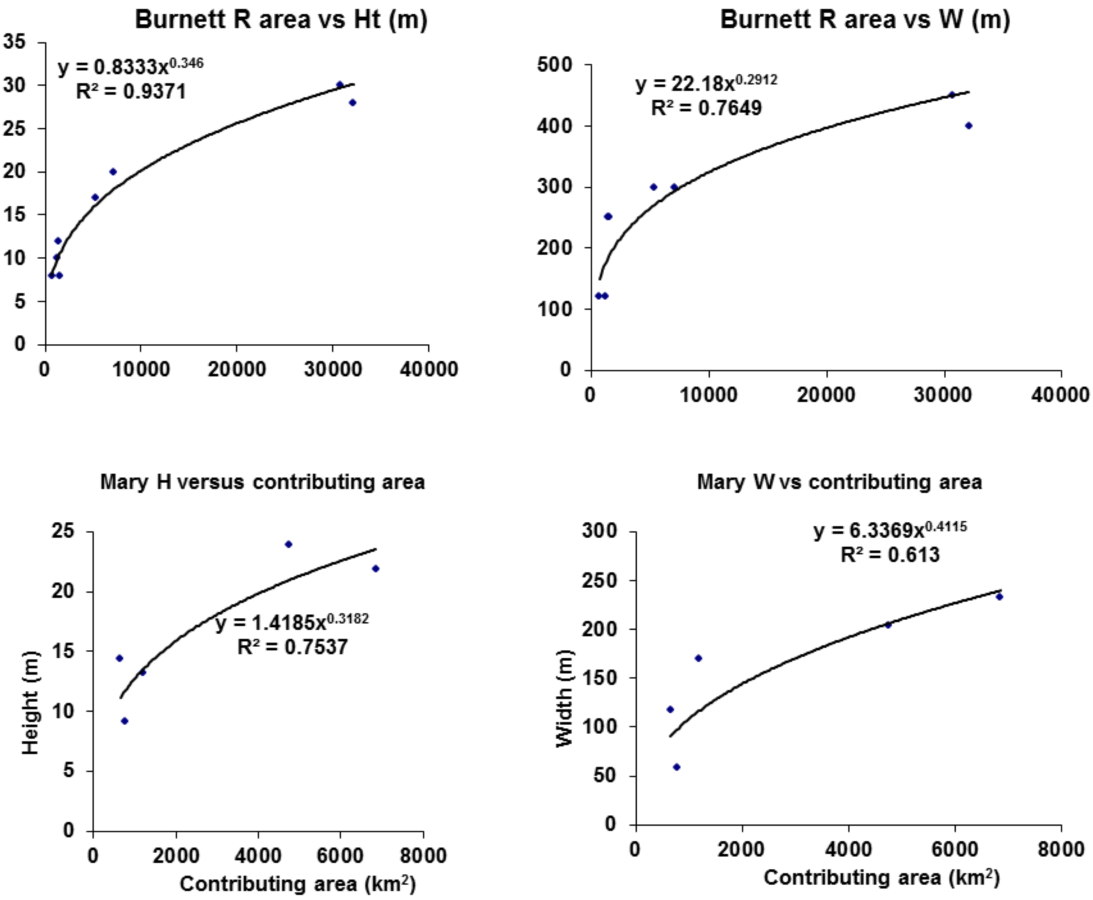

Figure 45 Bank height and width used to determine streambank erosion parameters vs catchment area (bottom: for the Mary basin and top for the rest of the basins)

A series of global input parameters are also required for the *"SedNet Stream TSS Model"* to run. These were determined on a region by region basis, using the available literature, or default values (identified in Alick (2007)). The parameter values for Burnett Mary are presented in Table 36 below.

Table 36 Dynamic SedNet Stream Parameteriser values for Burnett Mary

Parameter	Value
Ephemeral streams (upslope area)	50
Bank height	
Method	SedNet Variable - Node Based
Uniform height	n.a.
Prop. for fine sed. dep	0.2
Catchment area exponent	0.2912 for the Mary and 0.346 for others
Catchment area coefficent	1.4185 for the Mary and 0.8333 for others
Stream Attributes	
Bank full flow fecurrence interval	10 for the Mary and 6 for others
Stream buffer width	100
Max veg effectiveness	95
Sediment dry bulk density	1.5
Sediment settling velocity	1.00E-06
Sed. set. vel. for remobilisation	0.1
Bank erosion coefficent	0.00002
Mannings n coefficient	0.04
FPC threshold for streambank veg	12
Initial rop. of fine bed store	0
Daily flow power factor	1.4
Link width	
Link width type	SedNet Variable - Node Based
Unifrom width	n.a.
Min width	5
Max width	600
SedNet area exponent	0.4115 for the Mary and 0.2912 for others
SedNet area coefficent	6.3369 for the Mary and 22.18 for others
SedNet slope exponent	0
Link slope	
Stream processing type	Main Channel
Minimum link slope	0.000001
Use stream orders greater than or equal to	NA
Storage model defaults	
Reservoir length	5000
Initial trapped constituent amount	0
Bank full flow	0.005
Residence time	5

Table 37 Herbicide half lives

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

Table 38 Characteristics of storages included in the BM water quality model

Name of storage	Catchment area (km^2)	Length at FSL (m)	FSL (m)	Capacity (ML)	Completion year	Dead storage (ML)	Link in DS
Baroon Pocket Dam	67	6,600	236	61,000	1988	4,441.00	SC #485
Borumba Dam	465	16,980	132	33,300	1964	3,530.81	SC #493
Wuruma Dam	2,318	13,900	228	165,411	1968	2,431.50	SC #334
Ned Churchward Weir	32,760	33,050	0	29,500	1998	2,603.10	SC #67
Bjelke-Petersen Dam	1,670	29,780	307	125,000	1988	2,209.50	SC #121
Boondooma Dam	4,200	40,260	280	212,000	1982	136.50	SC #174
Lenthalls Dam	511	9,370	0	15,500	1984	500.50	SC #431
Fred Haigh Dam	1,310	51,610	76	586,000	1975	5,310.00	SC #46
Mary River Barrage	7,343	14,361	3	11,700	1983	5,063.90	SC #459
Cania Dam	280	15,520	331	89,000	1982	641.00	SC #382
Burnett River Dam		45,000		300,000	2005	12,923.41	SC #578

Management practice information

Table 39 shows examples of improved management practices targeted through Reef Plan.

Table 39 Examples of improved management practices targeted through Reef Plan (including Reef Rescue) investments (McCosker pers.comm. 2014). Note: the list is not comprehensive

Targets for management change	What is involved
Grazing	
Land type fencing	New fencing that delineates significantly different land types, where practical. This enables land types of varying quality (and vulnerability) to be managed differently.
Gully remediation	Often involves fencing to exclude stock from gullied area and from portion of the catchment above it. May also involve engineering works to rehabilitate degraded areas (e.g. 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 10-15cm below the surface with non-aggressive narrow tillage equipment
Controlled traffic farming	Major farming system change. Changes required to achieve CTF include altering wheelbases on all farm machinery, wider row widths, 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

Targets for management change	What is involved
	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 E – Modelling Results – Report Card 2013

Table 40 Water quality loads by catchment for all scenarios and reduction as the result of improved management practice adoption

Basin	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)
Predevelopment										
Baffle	20	30	25	3	2	127	63	12	52	0
Kolan	2	4	3	1	0	20	8	2	10	0
Burnett	3	21	8	10	3	82	19	31	32	0
Burrum	7	15	8	5	2	82	27	17	38	0
Mary	61	98	73	16	9	468	210	60	198	0
BM	93	168	117	35	17	779	327	121	331	0
Total baseline										
Baffle	50	55	44	7	4	238	105	31	101	23
Kolan	11	14	9	4	1	83	22	21	40	257
Burnett	24	37	18	14	5	258	38	123	96	271
Burrum	24	43	27	12	4	308	64	119	124	531
Mary	352	242	181	41	20	1,316	546	260	510	445
BM	462	392	278	78	35	2,202	775	554	873	1,528
Anthropogenic baseline										
Baffle	30	25	19	4	2	111	42	19	49	23
Kolan	9	10	6	3	1	63	14	19	31	257
Burnett	21	16	10	4	2	176	20	93	64	271
Burrum	17	28	19	7	2	226	37	102	86	531
Mary	291	145	108	25	12	848	336	200	312	445
BM	369	224	161	43	19	1,423	449	433	542	1,528
Reductions due to all change (Report Card 2013)										
Baffle	1	1	1	0	0	6	1	4	0	4
Kolan	1	2	2	0	0	21	3	11	7	75
Burnett	2	4	4	0	0	54	5	39	9	64
Burrum	3	8	7	1	0	54	8	32	14	156
Mary	4	7	6	1	0	78	11	49	18	121
BM	11	22	20	2	0	212	29	134	49	420
% reductions due to all change (Report Card 2013)										
Baffle	2.5	2.6	3.3	0.8	0.4	5.4	2.8	23.1	0.9	16.0
Kolan	12.5	24.3	32.2	12.1	10.1	33.0	22.1	58.1	22.4	29.3
Burnett	8.2	27.8	42.6	3.6	2.2	30.4	27.1	42.1	14.4	23.4
Burrum	16.1	27.3	36.2	9.8	7.2	23.8	21.3	30.9	16.4	29.3
Mary	1.5	4.7	5.6	2.4	1.3	9.2	3.4	24.3	5.8	27.2
BM	2.9	9.8	12.2	4.2	2.4	14.9	6.4	31.1	9.0	27.5

Table 41 Total baseline scenario constituent budget of the Baffle basin

Budget element	TSS (kt/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TN (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	TP (t/yr)	PSII (kg/yr)
SUPPLY	**52**	**31**	**103**	**108**	**242**	**8**	**4**	**45**	**57**	**25**
Hillslope	38	0	0	95	95	0	0	41	41	0
Gully	5	0	0	6	6	0	0	1	1	0
Streambank	9	0	0	7	7	0	0	2	2	0
Point source	0	0	0	0	0	0	0	0	0	0
Diffuse dissolved	0	31	103	0	134	8	4	0	12	25
LOSS	**2**	**0**	**1**	**3**	**5**	**0**	**0**	**2**	**2**	**2**
Extraction	2	0	1	3	5	0	0	2	2	0
Flood Plain Deposition	0	0	0	0	0	0	0	0	0	0
Stream Decay	0	0	0	0	0	0	0	0	0	2
Stream Deposition	0	0	0	0	0	0	0	0	0	0
Residual Link Storage	0	0	0	0	0	0	0	0	0	0
EXPORT	**50**	**31**	**101**	**105**	**238**	**7**	**4**	**44**	**55**	**23**
Hillslope	36	0	0	92	92	0	0	40	40	0
Gully	5	0	0	6	6	0	0	1	1	0
Streambank	9	0	0	7	7	0	0	2	2	0
Point Source	0	0	0	0	0	0	0	0	0	0
Diffuse Dissolved	0	31	101	0	132	7	4	0	12	23

Table 42 Total baseline scenario constituent budget of the Kolan basin

Budget element	TSS (kt/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TN (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	TP (t/yr)	PSII (kg/yr)
SUPPLY	**45**	**39**	**83**	**84**	**207**	**6**	**3**	**35**	**45**	**382**
Hillslope	29	0	0	71	71	0	0	32	32	0
Gully	11	0	0	9	9	0	0	2	2	0
Streambank	6	0	0	4	4	0	0	1	1	0
Point source	0	0	0	0	0	0	0	0	0	0
Diffuse dissolved	0	39	83	0	122	6	3	0	9	382
LOSS	**34**	**18**	**43**	**63**	**123**	**3**	**2**	**26**	**30**	**125**
Extraction	12	18	42	24	84	3	2	10	14	116
Floodplain deposition	1	0	0	1	1	0	0	0	0	0
Reservoir deposition	22	0	0	38	38	0	0	16	16	0
Reservoir decay	0	0	0	0	0	0	0	0	0	0
Stream decay	0	0	0	0	0	0	0	0	0	8
Stream deposition	0	0	0	0	0	0	0	0	0	0
Residual link storage	0	0	0	0	1	0	0	0	0	0
EXPORT	**11**	**21**	**40**	**30**	**91**	**4**	**1**	**12**	**17**	**257**
Hillslope	8	0	0	20	20	0	0	9	9	0
Gully	2	0	0	2	2	0	0	0	0	0
Streambank	1	0	0	1	1	0	0	0	0	0
Point source	0	0	0	0	0	0	0	0	0	0
Diffuse dissolved	0	21	40	8	69	4	1	3	8	257

Table 43 Total baseline scenario constituent budget of the Burnett basin

Budget element	TSS (kt/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TN (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	TP (t/yr)	PSII (kg/yr)
SUPPLY	**595**	**285**	**402**	**830**	**1,518**	**41**	**18**	**376**	**435**	**669**
Hillslope	284	0	0	614	614	0	0	282	282	0
Gully	160	0	0	108	108	0	0	48	48	0
Streambank	151	0	0	108	108	0	0	46	46	0
Point source	0	25	7	0	32	8	2	0	11	0
Diffuse dissolved	0	260	396	0	656	32	16	0	48	669
LOSS	**570**	**162**	**306**	**792**	**1,260**	**26**	**13**	**358**	**397**	**397**
Extraction	172	158	295	264	718	25	12	118	156	308
Floodplain deposition	7	0	0	8	8	0	0	4	4	0
Reservoir deposition	388	0	0	514	514	0	0	234	234	0
Reservoir decay	0	0	0	0	0	0	0	0	0	0
Stream decay	0	0	0	0	0	0	0	0	0	86
Stream deposition	0	0	0	0	0	0	0	0	0	0
Residual link storage	4	3	11	6	20	1	0	2	4	4
EXPORT	**24**	**123**	**96**	**38**	**258**	**14**	**5**	**18**	**37**	**271**
Hillslope	11	0	0	28	28	0	0	14	14	0
Gully	4	0	0	3	3	0	0	1	1	0
Streambank	9	0	0	7	7	0	0	3	3	0
Point source	0	25	7	0	31	8	2	0	11	0
Diffuse dissolved	0	99	90	0	188	6	3	0	9	271

Table 44 Total baseline scenario constituent budget of the Burrum basin

Budget element	TSS (kt/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TN (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	TP (t/yr)	PSII (kg/yr)
SUPPLY	**29**	**145**	**139**	**75**	**359**	**13**	**5**	**31**	**48**	**695**
Hillslope	19	0	0	65	65	0	0	29	29	0
Gully	4	0	0	5	5	0	0	1	1	0
Streambank	6	0	0	5	5	0	0	1	1	0
Point source	0	9	2	0	11	2	1	0	3	0
Diffuse dissolved	0	136	137	0	273	10	4	0	15	695
LOSS	**5**	**26**	**15**	**11**	**52**	**1**	**1**	**4**	**6**	**163**
Extraction	2	25	15	6	46	1	0	2	4	109
Floodplain deposition	0	0	0	0	0	0	0	0	0	0
Reservoir deposition	2	0	0	5	5	0	0	2	2	0
Reservoir decay	0	0	0	0	0	0	0	0	0	0
Stream decay	0	0	0	0	0	0	0	0	0	54
Stream deposition	0	0	0	0	0	0	0	0	0	0
Residual link storage	0	0	0	0	0	0	0	0	0	0
EXPORT	**24**	**119**	**124**	**64**	**308**	**12**	**4**	**27**	**43**	**531**
Hillslope	16	0	0	55	55	0	0	25	25	0
Gully	3	0	0	4	4	0	0	1	1	0
Streambank	5	0	0	5	5	0	0	1	1	0
Point source	0	9	2	0	11	2	1	0	3	0
Diffuse dissolved	0	111	122	0	233	9	4	0	13	531

Table 45 Total baseline scenario constituent budget of the Mary basin

Budget element	TSS (kt/yr)	DIN (t/yr)	DON (t/yr)	PN (t/yr)	TN (t/yr)	DIP (t/yr)	DOP (t/yr)	PP (t/yr)	TP (t/yr)	PSII (kg/yr)
SUPPLY	**455**	**318**	**573**	**791**	**1,683**	**49**	**24**	**267**	**340**	**532**
Hillslope	131	0	0	485	485	0	0	175	175	0
Gully	34	0	0	36	36	0	0	10	10	0
Streambank	289	0	0	270	270	0	0	83	83	0
Point source	0	33	9	0	42	7	2	0	9	0
Diffuse dissolved	0	285	564	0	850	42	22	0	64	532
LOSS	**103**	**60**	**63**	**72**	**194**	**8**	**3**	**25**	**37**	**90**
Extraction	17	59	61	69	189	8	3	24	36	35
Floodplain deposition	1	0	0	2	2	0	0	1	1	0
Reservoir deposition	85	0	0	0	0	0	0	0	0	0
Reservoir decay	0	0	0	0	0	0	0	0	0	0
Stream decay	0	0	0	0	0	0	0	0	0	55
Stream deposition	0	0	0	0	0	0	0	0	0	0
Residual link storage	0	1	2	0	3	0	0	0	0	0
EXPORT	**352**	**260**	**510**	**546**	**1,316**	**41**	**20**	**181**	**242**	**445**
Hillslope	93	0	0	312	312	0	0	113	113	0
Gully	25	0	0	26	26	0	0	6	6	0
Streambank	234	0	0	208	208	0	0	62	62	0
Point source	0	23	8	0	31	6	2	0	7	0
Diffuse dissolved	0	237	502	0	739	35	19	0	54	445

Table 46 TSS export (kt/yr) by land use from the total baseline scenario

	Conservation	Dryland cropping	Forestry	Irrigated cropping	Grazing forested	Grazing open	Horticulture	Other	Sugarcane	Urban	Streambank	Total
Baffle	2.0	0.1	0.8	0.5	29.5	6.6	0.1	0.1	0.2	1.4	8.8	50.0
Kolan	0.2	0.1	0.1	0.5	4.9	1.6	0.2	0.0	2.1	0.6	1.1	11.2
Burnett	0.1	0.4	0.1	0.6	5.5	3.8	0.2	0.2	3.5	1.2	8.7	24.3
Burrum	1.6	0.5	1.5	0.7	3.7	1.8	0.4	0.3	5.8	3.1	4.9	24.3
Mary	6.1	0.1	9.7	2.4	44.6	29.8	1.1	0.9	5.5	17.6	234.2	352.0
BM total	**10.1**	**1.2**	**12.2**	**4.6**	**88.1**	**43.6**	**2.0**	**1.5**	**17.0**	**23.8**	**257.7**	**461.9**

Table 47 TN and TP export (t/yr) by land use from the total baseline scenario

	Conservation	Dryland cropping	Forestry	Irrigated cropping	Grazing forested	Grazing open	Horticulture	Other	Sugarcane	Urban	Streambank	Point source	Total
TN													
Baffle	22.1	0.4	9.4	1.2	116.8	51.5	3.2	0.8	10.6	15.1	6.6	0.0	237.6
Kolan	2.3	0.2	0.8	1.4	12.6	8.9	4.8	0.2	44.8	6.4	0.7	0.0	83.1
Burnett	2.3	3.5	2.6	2.9	27.7	36.1	4.0	2.2	124.9	13.2	7.1	31.5	258.1
Burrum	17.9	1.1	17.7	1.5	24.8	19.2	9.7	3.6	162.8	33.8	4.6	10.9	307.6
Mary	72.7	0.5	111.9	9.1	180.5	225.3	29.0	10.2	227.1	210.5	207.9	30.9	1,315.6
BM total	**117.3**	**5.7**	**142.4**	**16.1**	**362.4**	**341.0**	**50.7**	**17.0**	**570.2**	**279.0**	**226.9**	**73.3**	**2,202.1**
TP													
Baffle	3.9	0.1	1.7	0.6	32.6	9.3	1.2	0.1	0.7	2.7	2.3	0.0	55.3
Kolan	0.4	0.1	0.1	0.9	3.0	1.5	1.8	0.0	5.2	1.1	0.2	0.0	14.3
Burnett	0.3	0.9	0.3	1.2	4.2	4.5	1.6	0.4	7.7	2.3	3.0	10.7	37.2
Burrum	3.2	0.7	3.0	0.8	3.2	2.6	3.7	0.6	15.2	6.0	0.6	3.1	42.7
Mary	11.7	0.2	18.9	3.5	43.4	37.2	11.1	1.7	11.3	33.9	62.0	7.4	242.3
BM total	**19.5**	**2.0**	**24.0**	**7.0**	**86.5**	**55.2**	**19.4**	**2.9**	**40.1**	**46.0**	**68.1**	**21.3**	**391.8**

Appendix F – Report Cards 2010–2013 notes and results

Appendix F includes loads and percentage reductions for Report Cards 2010-2013.

Main changes in total baseline models between Repot Cards 2010 to Report Card 2011:

- DON/DIP/DOP – adjusted predicted dissolved nutrient losses based on APSIM runoff which is affected by management changes. In Report Card 2010 no management effect was incorporated hence no reductions in DON/DIP/DOP loads due to improved management.
- Updated a curve number function in model to bring HowLeaky functions in line with published approaches. Will result in a reduction in runoff for Howleaky runs and by 10-15%. Reduction in runoff will then in turn affect sediments and other constituent loads.
- The indirect effects of grazing management on gully and streambank erosion applied in Report Card 2011 assuming that a shift from C&D class practices to A and B resulted in reduced gully and streambank erosion rates (refer grazing synthesis report)
- Modifications to models have resulted in large changes in baseline DIP and DOP between Report Cards 2010–2011
- For Report Card 2011 for sugarcane, slightly different baseline management proportions were used compared to the Report Card 2012 and Report Card 2013 baseline management proportions. This slight shifting in baseline management proportions was necessary to accommodate reported management changes. For each Report Card, the modellers receive additional information on changes to practice adoption areas by regional bodies. The assumption has to be that if the investment funded a change from C to B management, the 'from' category existed in our baseline year. In reality, it may be that this investment was a follow up to an earlier improvement on the same piece of land; however, this information was not provided to the modellers. Therefore, for each report card the baseline distribution was reallocated to ensure that reported changes could be represented.

Table 48 Report Card 2011* predevelopment, baseline and management change results. Note, these are different to Report Cards 2012 and 2013 loads which are the loads that should be cited when referencing this work

	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)
Predevelopment load	93	168	117	35	17	779	327	121	331	0
Total baseline load	462	391	278	78	35	2,203	775	558	870	1,552
Anthropogenic baseline load	369	223	161	43	19	1,425	449	437	539	1,552
Report Card 2011 load	455	380	268	77	35	2,077	759	471	848	1,285
Reductions (Report Card 2011*)	7	11	10	1	0	126	16	88	22	267
% reduction (Report Card 2011)	1.9	5.1	6.2	2.5	1.5	8.9	3.6	20.1	4.1	17.2

* It should be noted that for Report Card 2011 reductions to be compared to Report Cards 2012 and 2013 loads and reductions, it was necessary to re-run this management scenario and the corresponding baseline scenario with the same parameters and the same version of Dynamic SedNet as for Report Cards 2012 and 2013. As the result, the reductions for Report Card 2011 presented here are different from those reported previously.

- Report Card 2011: Lewis model used, but storages had zero length resulting in little deposition (close to zero TE).
- Report Cards 2012 and 2013: For consistency, Lewis model will be used for particulate nutrients as TSS, but the same reservoir length as in TSS is used instead of zero. This will result in similar TE values for all TSS, PN and PP as shown below
- Inflow used in as input to the storage trapping model Report Cards 2012 and 2013 instead of outflow used in Report Card 2011 and Report Card 2010
- Actual storage capacity used in Report Cards 2012 and 2013 instead of the max storage volume in the storage rating curve. This change is significant particularly in the Burnett Mary where there are relatively more storages and the max storage volumes in the rating curves appear to be significantly greater than the actual storage capacities.
- Changes to the nutrients parameter table:

- N_particulate enrichment ratio values were 1.2 and 2 now altered to 2 globally
- N_particulate hillslope delivery ratio were 20 and 40 now altered to 20 globally
- P_particulate enrichment ratio was 2 now altered to 3 globally
- P_particulate hillslope delivery ratio values were 20 and 40 now altered to 20 globally
- A different set of baseline c-factor layers have modified to generate management scenario c-factors. The baselines for the revised Report Card 2011, Report Cards 2012 and 2013 are all based on these baseline c-factors.

- The total baseline load figures changed between Report Card 2012 and Report Cards 2012 and 2013. The reasons for this are:
- For Report Card 2011 for APSIM, slightly different baseline management proportions were used.

Table 49 Report Card 2012 predevelopment, total baseline and management change results

	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)**
Predevelopment load	93	168	117	35	17	779	327	121	331	0
Total baseline load	462	392	278	78	35	2,202	775	554	873	1,528
Anthropogenic baseline load	369	224	161	43	19	1,423	449	433	542	1,528
Report Card 2012 load	453	374	263	77	35	2,021	752	433	836	1,176
Reductions (Report Card 2012)	9	17	16	1	0	181	23	121	36	352
% reduction (Report Card 2012)	2.4	7.8	9.7	3.2	1.9	12.7	5.2	28.1	6.7	23.0

Table 50 Report Card 2013 predevelopment, total baseline and management change results

	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)
Predevelopment load	93	168	117	35	17	779	327	121	331	0
Total baseline load	462	392	278	78	35	2,202	775	554	873	1,528
Anthropogenic baseline load	369	224	161	43	19	1,423	449	433	542	1,528
Report Card 2013 load	451	370	259	76	35	1,990	747	420	824	1,108
Reductions (Report Card 2013)	11	22	20	2	0	212	29	134	49	420
% reduction (Report Card 2013)	2.9	9.8	12.2	4.2	2.4	14.9	6.4	31.1	9.0	27.5