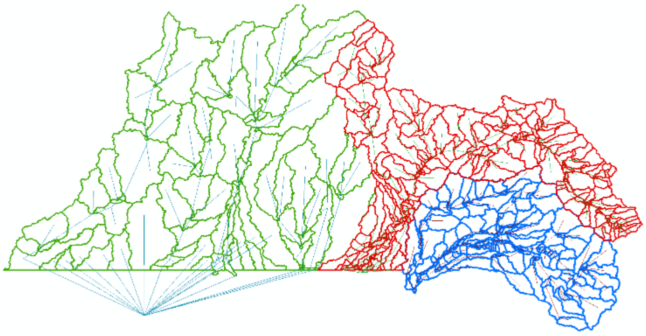
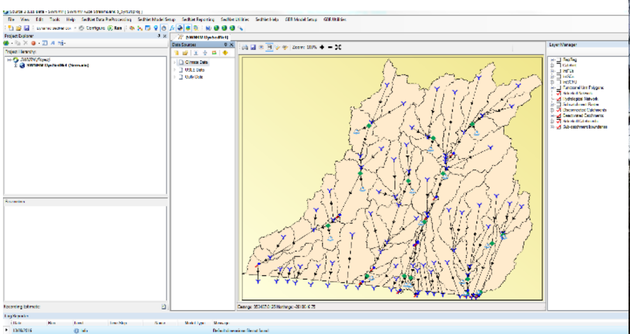
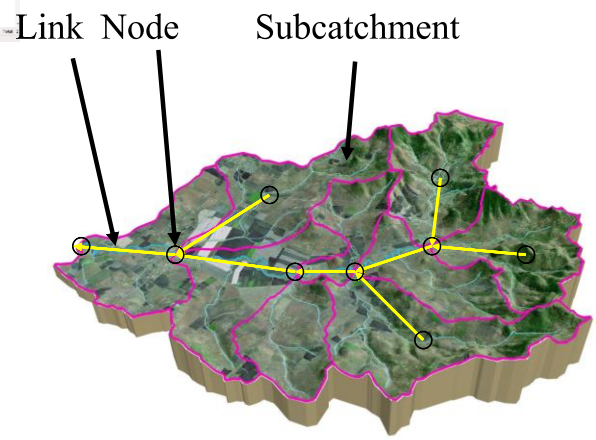
Development of a Water Quality Model for the Queensland Murray-Darling Basin using the eWater Source – Dynamic SedNet Framework







July 2018

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To reference this volume:

Davidson, W. (2018) Development of a Water Quality Model for the Queensland Murray-Darling Basin using the eWater Source – Dynamic SedNet Framework, Technical Report , Queensland Department of Natural Resources, Mines and Energy, Toowoomba, QLD

Acknowledgments

Many thanks to those who contributed including:

- Dave Waters, Robin Ellis and Shawn Darr for their assistance in collation and preparation of the data layers, and enabling me to gain a working knowledge of the Dynamic SedNet Catchment framework
- Tony King for his assistance with data collation and Jade Gould for data transformation.
- Andrew Biggs and Dave Burton for their assistance with data layer collation and presentation
- Scott McKie and Jade Gould for their support with water quality data collection

EXECUTIVE SUMMARY

Source Catchments Water Quality models were developed for the Queensland section of the Murray Darling Basin. The Queensland Murray Darling Basin (QMDB) Water Quality Models were built to assist in the development of water quality guidelines for Murray Darling Basin planning requirements. Total Suspended Sediment (TSS), Total Nitrogen (TN) and Total Phosphorus (TP) were the constituents of interest.

This work built on the experience of the Great Barrier Reef (GBR) Paddock to Reef Modelling Program and applied a similar modelling approach. Three separate models were created for the QMDB covering: South West catchments –namely the Bulloo, Paroo, Warrego and Nebine catchments (SWNRM), Condamine, Balonne and Maranoa catchments (CBM) and Moonie and Border Rivers catchments (MNBD). Models were calibrated using the Sacramento rainfall runoff model coupled to the Parameter Estimation Software Tool (PEST). Due to the limited water quality monitoring data available across the region for calibration, historical water quality (WQ) data was correlated against log transformed flow to build a relationship between TSS, TP and TN and gauge discharge by catchment. The resulting concentration values were used to calculate daily through to average annual loads. These loads were then used for model calibration.

The hydrological calibration achieved a percent bias (PBIAS) of less than 5% for 36 of the 37 gauges used for calibration for the 36 year modelling period. Modelled average annual TSS export loads for the 36 year modelling period were estimated to be 1,906 kt/yr for the SWNRM catchments, 198 kt/yr for CBM and 53 kt/yr for the MNBD catchments for the 36 year climate period (1980-2015). In terms of the overall QMDB sediment budget, gully erosion contributed 43%, streambank 37% and hillslope erosion 20% of the total sediment load exported. Limited measured data was available across the full range of flow heights for water quality calibration which meant that there is a degree of uncertainty about the measured estimates, a common problem worldwide.

The objective of the project was to develop a catchment model using the most up to date approach and data sets. This was achieved and the model has been used as one line of evidence in the development of high and low flow water quality guidelines for Water Quality Objectives for the Queensland Environmental Protection Policy. Additional water quality data collection at end of system gauges during high flow events will significantly improve model load estimates.

The model could be used and refined by regional Natural Resource Management (NRM) bodies in future years for scenario analysis such as prioritising natural resource management investment programs for improved land management practices. Using a model in a data poor area has highlighted the value of event monitoring to calibrate and validate water quality models. Development of such a model incorporating a range of erosion processes provided a basis for prioritising future research in catchments, in particular improve our understanding of sediment transport where limited measured data is available.

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1 INTRODUCTION

The Commonwealth *Water Act 2007* provides instruments for a coordinated approach to the management of water resources throughout a Basin. The *Murray Darling Basin Plan (2012)* (Basin Plan) (MDBA website, 2017) is one such instrument prepared under Part 2 of the *Water Act 2007* (Commonwealth). The Basin Plan provides the framework for a coordinated approach across the five Basin States and Territories, for the management of water resources in the Murray-Darling Basin.

Basin Plan includes a range of management objectives and outcomes to be achieved in the Murray-Darling Basin in relation to water quality, with Chapter 9 stating the requirements of the water quality and salinity management plan; and Chapter 10, Part 7 stating the need for a water resource plan (WRP) to include a water quality management plan (WQM Plan).

> *Water quality and salinity objectives, water quality targets for planning of water flows, water quality targets that apply to the preparation of the water resource plans, and water quality targets for the purposes of long-term salinity planning and management (item 10 of the table in subsection 22(1) of the Act). This Chapter also includes the key causes of water quality degradation in the Murray-Darling Basin. (*Basin Plan, Part 2, 1.05(1) Chapter 9)

As a basin State, Queensland supports the development of WQM Plans for inclusion in the WRP for each respective basin within the Queensland portion of the Murray Darling Basin.

With regard to the national framework, Queensland Department of Environment and Science also provides for the protection of water resources through the *Environmental Protection Act 1994* and the subordinate legislation *Environmental Protection (Water) Policy 2009 (EPP Water).* EPP Water provides a mechanism for Healthy Waters Management Plans (HWMPs) to be developed with the intent of improving water quality in a basin area. HWMP's include environmental values, water quality objectives and management goals for a basin area.

This project aims to develop a water quality model to support the development of HWMPs/WQM Plans, informing management actions and measures to achieve objectives as part of the respective Commonwealth accredited Water Resource Plans (WRPs). Basin and catchment scale water quality modelling is an essential tool that improves our understanding of water quality transport processes (sediment, nutrients, etc.). The model has the potential to be used by NRM groups to assist in prioritising on ground investment in improved land management practices.

This project will utilise the nationally adopted modelling framework (eWater Source) endorsed by both state and federal governments in July 2012. This project will also capitalise on learnings from the Reef Water Quality Protection Plan Water Quality Modelling (Waters et al., 2014) by applying its methodology where appropriate, to the Queensland Murray-Darling Basin (QMBD).

2 OBJECTIVES

The objective of the project are:

- Collate water quality data across the basin to derive relationship between flows and major water quality parameters (Total suspended sediment TSS, and nutrients) to calibrate the model.
- to develop a calibrated Water Quality Model incorporating functionality as used in the GBR modelling for Queensland Murray Darling Basin (QMDB) catchments
- Provide best estimates of sediment and nutrient export loads for all QMDB Basins
- Use the modelled outputs to assist in the development of water quality targets
- Consult with key stakeholder groups across the QMDB and Bulloo catchments to generate awareness of the water quality model and its potential application (Refer Table 34 for groups consulted).

3 History of Catchment Water Quality Models in the Queensland Murray Darling Basin

There have been several water quality catchment models developed within the QMDB area. These have been created to support local Natural Resource Management (NRM) groups in testing on-ground investment strategies with the support of the Department of Natural Resources, Mines and Energy (DNRME). Table 1 below provides an overview of these models. These projects created a specific model for the area within the QMBD which was the target for the project using predecessors of the eWater Source Catchments platform. This project builds on the learnings from these previous models.

TABLE 1 - HISTORY OF CATCHMENT MODELS FOR QUEENSLAND MURRAY DARLING BASIN

Year	Catchments	Model Title and Purpose
2006	Condamine, Balonne and Maranoa Catchments	Application of the EMSS water quality model for The Queensland Murray Darling Catchment – Assessing the impacts of on-ground works National Action Plan for Salinity and Water Quality – Water Quality State-level Investment Project
2008	Nebine, Warrego, Paroo and Bulloo Catchments	Water Quality Monitoring and E2 Modelling in the South West NRM Region, Queensland – Technical Report for South West NRM.
2014	Border Rivers, Condamine, Balonne, Maranoa and Moonie Catchments	Unpublished internal report DNRME – Water quality modelling in the Queensland Murray-Darling Committee NRM Region, Queensland.

3.1 Previous Approaches

These models were created to best represent the water quality processes within the catchments, using the best available data and software at the time. A summary of the models and parameters used are shown in Table 2. In the development of the current model parameters, the previous approaches were taken into account.

TABLE 2 - PREVIOUS MODEL SETUP DETAILS

Name	**SWNRM - 2008**	**QMDC - 2006**	**QMDC - 2014**
Year	2008	2006	2014
Software	E2 (earlier version of Source Catchments)	EMSS (earlier version of Source Catchments)	Source Catchments
Catchments	Nebine, Warrego, Paroo, Bulloo	Condamine, Balonne, Maranoa	Condamine, Balonne, Maranoa, Moonie, Border Rivers
Modelling Period	1967-2007	1973-2003	1960-2013
Number of run years	41	30	54
DEM cell size (m)	25 (resampled to 250m)	25 (resampled to 250m)	100
Sub Catchment Threshold (km2)	2,000	500	100
Number of Sub catchments	70	110	930
Data Source	SILO Data Drill Daily (PET and Rain)	SILO Data Drill (Rain) & Monthly PET average (BoM)	SILO Data Drill Daily (PET and Rain) 5km average
Landuses/Functional Units	Irrigation	Non-timbered grazing	Open grazing
	Nature Conservation	Timbered grazing	Forested grazing
	Forestry	Dryland cropping	Dryland cropping
	Urban	Irrigated cropping	Irrigated cropping
	Water	National Park	Horticulture
	Mining	State Forest	Conservation
	Grazing Weathered Sediments	Urban	Forestry
	Grazing Alluvia	Water	Urban
	Grazing Downs Gidgee	Rural Residential	Water
	Grazing Basalts	Mining	Other
	Grazing Fine Grained Sandstone	Intensive animal industry	
	Grazing Quartzose Sandstone	Waste Treatment	
Rainfall Runoff Model	Sacramento	SIMHYD	Sacramento
Constituent Generation Model	EMC/DWC	EMC/DWC	EMC/DWC
Storages		Cooby Creek Dam Beardmore Leslie Dam	Beardmore Chinchilla Weir
Point Source Data		STP locations + annual nutrient discharge loads	STP locations + annual nutrient discharge loads
Notes		Model stopped at Beardmore Dam in Balonne catchment due to the model inability to handle braided stream networks	Nine separate linked models to allow for shorter run times for the catchment.

3.2 Improvement recommendations

A list of recommendations from these projects are summarised in Table 3.

TABLE 3 - PREVIOUS MODEL IMPROVEMENT RECOMMENDATIONS

2006 QMDB	2008 SWNRM	2014 QMDB & Border Rivers
More EMC data - particularly high flow data	Collect samples at range of flow magnitudes e.g. event flow	Collect samples at range of flow magnitudes e.g. event flow
Investigation into hillslope, gully for improved sediment load	Investigation into hillslope, gully for improved sediment load	Investigation into hillslope, gully for improved sediment load
Capture irrigation and overland flow – improve low flow calibration	Capture in GIS the past, current and future details of on ground works.	Capture irrigation and overland flow – improve low flow calibration
Spatially apply EMC for constituents accounting for spatial variability (slope, soil type and land management practices)		Detailed hydrology calibration
Spatially variable stream routing algorithm to help account for lag in predicted flow.		Include more storages

3.2.1 Complementary Event Sampling Project

In each of the previous modelling projects, it was apparent that there was limited event data, across the range of flows, to calibrate or validate the models. An improvement in the collection of event data means a better calibration for high flows for constituents. Therefore, a separate project was established concurrently with this modelling project to use turbidity and electrical conductivity probes for continuous water quality monitoring combined with event sampling at four sites. Data collected over this period will track all flow events in-stream to assist in validation and calibration of the models into the future.

4 Description of the Region

4.1 Queensland Murray darling basin

The Queensland section of the Murray-Darling Basin covers the Condamine-Balonne, Moonie, Border Rivers, Nebine, Warrego and Paroo Catchments. This covers the areas of the Natural Resource Management (NRM) bodies of Condamine Alliance (CA), Queensland Murray Darling Committee (QMDC) and South West NRM (SWNRM). Although the Bulloo catchment does not drain into the Murray-Darling Basin, it has been included in this modelling exercise due to the Bulloo being included in the QMDB plan area for Queensland Water Resource Plans, and forms part of SWNRM management area (Figure 1).

The Border Rivers model was extended to a defined catchment boundary outlet in the upper part of NSW as opposed to stopping at the Qld border to enable loads to be extracted from the model at a catchment boundary outlet.

The total modelled area drains 336,900 km^2 of Queensland (Table 4 and Figure 1), west and south of the Great Dividing Range. The catchment has highly variable annual rainfall ranging from 1,250mm in the east to less than 500mm in the west. Annual evaporation ranges from 1600mm in the east to 2,800mm in the west.

The Condamine and Maranoa basins drain into the Balonne Basin, hence the three areas were combined into one model. This model covers 26.3% of the total area (Table 4). SWNRM model covers over 50% of the total area.

TABLE 4 - OVERVIEW OF CATCHMENTS

Model	Catchment	Natural Resource Management Body	Catchment Area (km²)	% Area of QMDB	Model Area %
Border Rivers /Moonie	Border Rivers	QMDC	45,500	13.5%	17.8%
	Moonie	QMDC	14,500	4.3%	
Condamine/ Balonne / Maranoa	Condamine – Balonne - Maranoa	QMDC / CA	88,500	26.3%	26.3%
SWNRM	Nebine	SWNRM	37,500	11.1%	55.9%
	Warrego	SWNRM	66,000	19.6%	
	Paroo	SWNRM	29,900	8.9%	
	Bulloo	SWNRM	55,000	16.3%	
TOTAL			336,900		

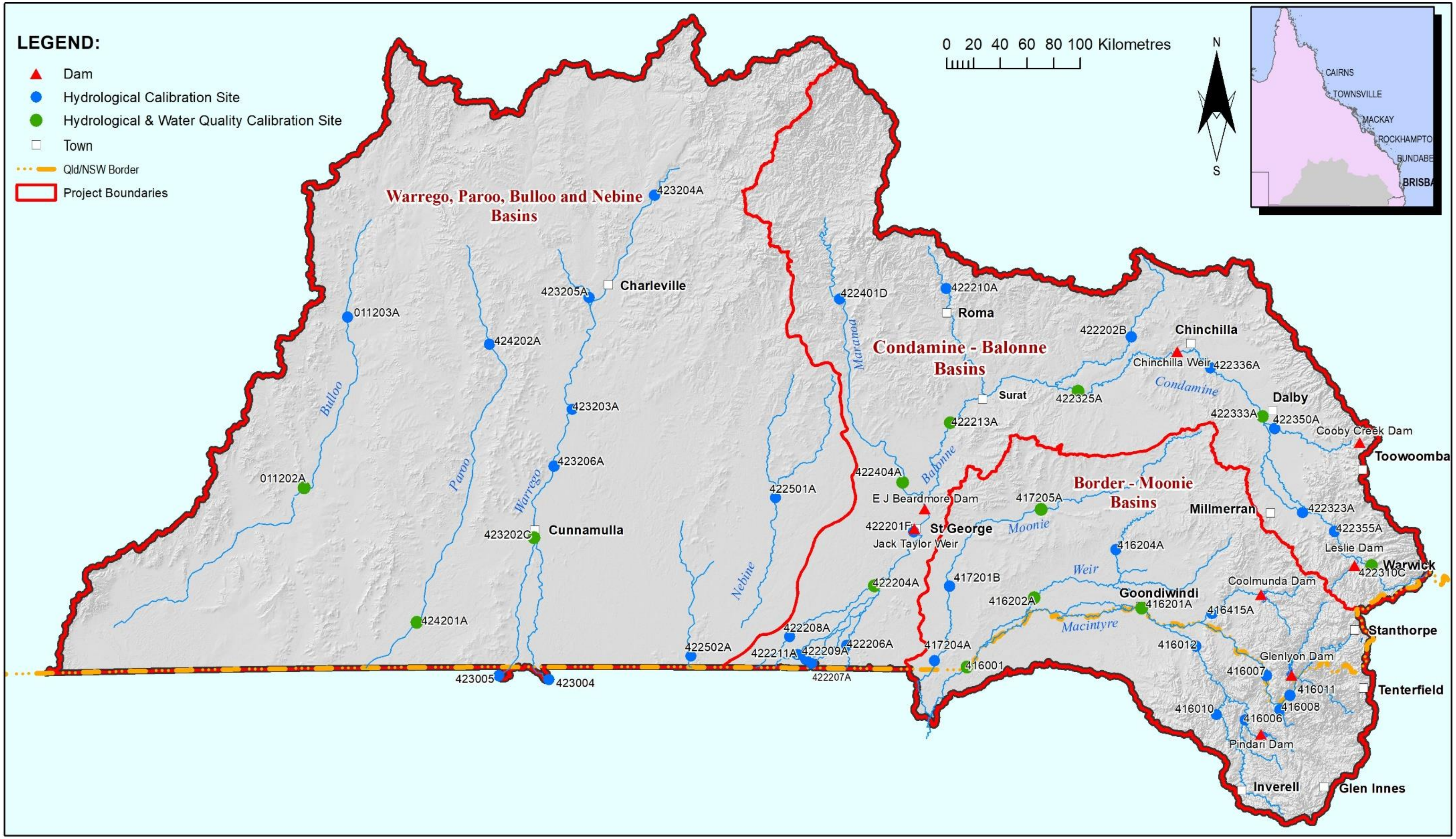


FIGURE 1 –THE QUEENSLAND MURRAY DARLING BASIN CATCHMENTS INCLUDING NRM REGIONAL BOUNDARIES

4.1.1 The Condamine-Balonne and Maranoa Catchments

The Condamine-Balonne River system (Figure 1) is a tributary system rising in the steep slopes to the west of the Great Dividing Range. In the upper reaches, the Condamine River is fed by the major tributaries Oakey Creek, that drains the Toowoomba Plateau, Myall Creek, which drains the north east Darling Downs, Charleys Creek to the North of Chinchilla and Dogwood Creek to the west of Chinchilla. The confluence with Dogwood Creek and Condamine River, midway between Condamine and Surat, becomes the Balonne River. The river meanders southwest through Surat and joins the Maranoa River upstream of St George. Downstream of St George, the river becomes a distributary system in an alluvial fan known as the lower Balonne floodplain.

4.1.2 The Moonie and Border Rivers Catchments

The Border Rivers (Figure 1) is a network of perennial streams that rise in the western slopes of the Great Dividing Range on the Granite Belt and New England Tablelands and together form the headwaters of the Darling River. The Macintyre Brook, Severn River (Queensland), Mole River and Beardy River drains the Inglewood district, Granite Belt, Tenterfield and Deep Water districts in the north. The southern section from north of Glenn Innes to Guyra is drained by the Severn River (New South Wales) and Macintyre River. The confluence of the Severn River (Queensland) and the Mole River becomes the Dumaresq River which forms part of the border between Queensland and New South Wales. The Dumaresq River enters the Macintyre River above Goondiwindi and continues to form the border between the two states. The Macintyre River flows generally west before reaching its confluence with the Weir River, west of Goondiwindi. The Weir River headwaters are located in the Dunmore State Forest south west of Cecil Plains. It is fed by a number of tributaries that drain to an area west of Millmerran and Inglewood and north of Goondiwindi. The Weir River generally flows in a south west direction and combines with the Macintyre River, north of Mungindi, where it becomes the Barwon River. During high flow events water can flow from the Weir to the Macintyre River.

The Moonie catchment (Figure 1) is bound to the east by the Border Rivers and the north and west by the Condamine Balonne. The Moonie River rises south west of Dalby and south of Tara and flows generally in a south westerly direction. A number of tributaries contribute to its flow with the largest being Teelba Creek, which joins with Bidgel Creek before joining into the Moonie River upstream of Nindigully. The Moonie River flows into the Barwon River near Mogi Mogi in New South Wales.

4.1.3 The Nebine, Warrego, Paroo and Bulloo Catchments

The Nebine, Warrego, Paroo and Bulloo catchments (Figure 1) are similar through common characteristics of limited rainfall and high evaporation, via streams that cover long distances of flat country, making these catchments an ephemeral set of streams. Nebine, Warrego and Paroo drain into the Darling River in NSW. The Bulloo is a closed system that terminates in the Bulloo Lakes in NSW. The Warrego starts from the south western regions of the Carnarvon Gorge so benefits with a slighter higher level of rainfall off this area. The Langlo and Ward Rivers meet and then intersect with the Warrego merging three streams above Charleville. This flows through to Cunnamulla where it splits into Warrego Minor and Cuttaburra Creek which travels across the border into NSW as two streams. Paroo begins from lowland headwaters and flows over the flat country through to the NSW border. The Nebine catchment is made of several streams that don’t connect until after the border.

4.2 Soils and Landscapes

The study area is distinct in soils and landscape moving east to west, however, a large amount of common features are shared throughout the broader catchments, especially on the lower flat plains. Soil type is strongly related to geology. The Condamine catchment is heavily influenced by basalts, with a variety of shallow to deep clay soils (Vertosols, Dermosols and Ferrosols) formed in the uplands and alluvia, extending from the headwaters above Warwick to Chinchilla at the lower end of the Condamine floodplain (Figure 2). The Ferrosols are found on the more weathered zones around Toowoomba.

Stoney Kandosols, Dermosols and Sodosols are found on steep terrain of granites and metamorphics in the Granite Belt and Traprock in the south-east of the study area. Unweathered Cretaceous sediments throughout the region yield extensive areas of clay soils (Vertosols and Dermosols) in both uplands and derivative alluvia. Deeply weathered components of the same geologies are covered in shallow stony Kandosols and Tenosols in steeper areas grading into deep Kandosols and Chromosols in flatter areas and in derivative alluvia.

Elements of the Cretaceous geologies and the majority of the eastern Jurassic sedimentary outcrops yield sodic texture contrast soils (Sodosols and Kurosols). Sandy soils (Tenosols, Kandosols) are formed on quartz sandstones and related alluvia in the headwaters of the Maranoa and extending throughout the South Western Catchments.

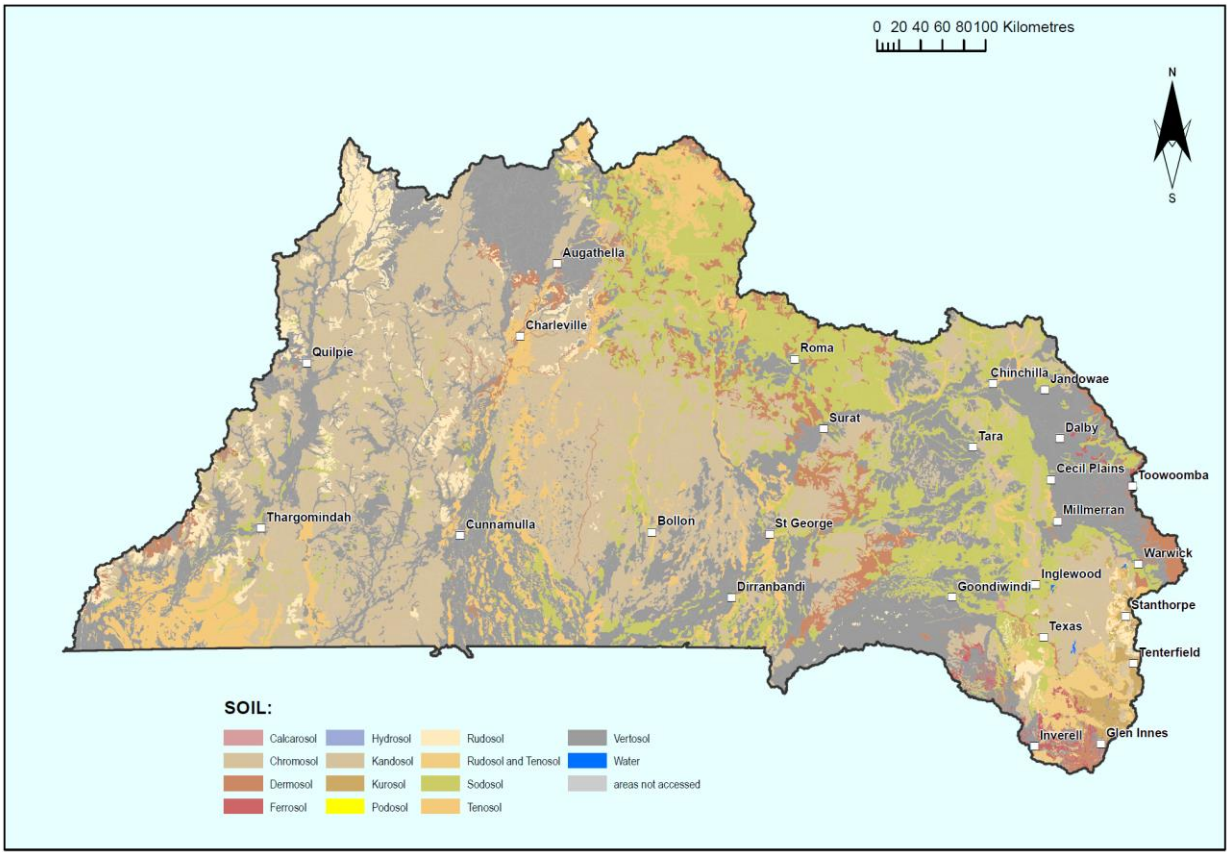


FIGURE 2 - QMDB SOILS

4.3 RAINFALL & HYDROLOGY

4.3.1 THE CONDAMINE-BALONNE AND MARANOA CATCHMENTS

The Condamine, Balonne and Maranoa catchments have a summer dominant rainfall pattern. The mean annual rainfall decreases from 1,250mm east of Warwick, near the headwaters of the Condamine River, to less than 500mm south west of St George, near the Queensland–New South Wales border (Figure 3). There is significant annual variability in rainfall, particularly in the western part of the basin. Summer rainfall is dominated by high intensity storms from October to December, which may be localised.

The majority of the catchments river systems and tributaries are ephemeral, flowing only after significant rainfall events or due to discharges from dams, weirs, sewerage treatment plants and industry. Flow in the catchment could be regarded as highly variable with the mean annual flow at St George being 1.3 million ML with a standard deviation of 616,000 ML. Often, long periods of low or no flow are experienced.

Some perennial flow does occur in the headwater of the Condamine and Border Rivers catchments. Long term records, accessed using DNRM water monitoring flow portal (2016), show that the upper reaches of the

Condamine River at Warwick flow 90% of the time, mid and lower reaches of the Condamine-Balonne flows 75% of the time with the Maranoa catchment flowing 40% of the time. Flow becomes more intermittent as average annual rainfall decreases.

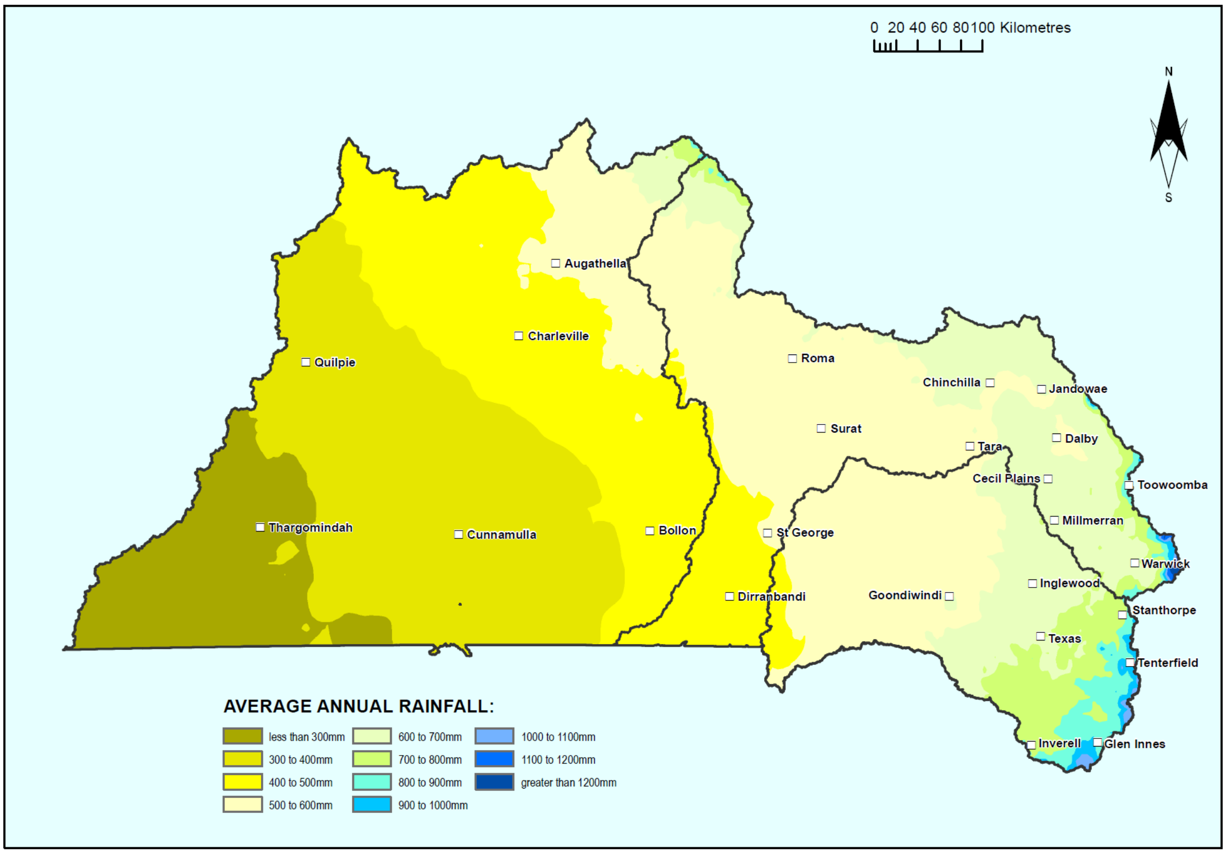


FIGURE 3 - QMDB AVERAGE ANNUAL RAINFALL DEMONSTRATING THE VARIATION THROUGHOUT THE CATCHMENTS

4.3.2 The Moonie and Border Rivers Catchments

Similar to the Condamine Balonne and Maranoa catchments, the Moonie and Border Rivers catchments have a summer dominant rainfall pattern. The largest rainfall occurs on the eastern NSW area of Border Rivers ranging from above 1,100mm per annum to less than 500mm in the west side of the Moonie (Figure 3). The variability and intensity of storms described for Condamine is also applicable in these catchments.

A number of tributaries of these catchments are ephemeral toward the western end of the catchment. Perennial flow is present in some of the eastern catchment with the presence of three dams within this catchment to utilise the water. Flows at the end of system demonstrate the difference due to the rainfall, with Border Rivers at Mungindi (Barwon River) flow 80% of the time, while in Lower Moonie it only flows 50% of the time.

4.3.3 The SWNRM Catchments

The catchments of Nebine, Warrego, Paroo and Bulloo have the lowest annual rainfall in this study, with the Warrego catchment the only catchment to receive a small area of rainfall higher than 600mm/year (Figure 3). Only the catchments Paroo, Warrego and Nebine flow into the Murray Darling Basin, as the Bulloo Catchment is an endorheic or closed catchment, draining only to the Bulloo Lakes in NSW.

These streams can be ephemeral with periods of no flow, and large flushes after rainfall. Warrego at Cunnamulla flows around 45% of the time, Paroo at Caiwarro flows 55% and Bullo at Autumnvale only 60% of the time. Large periods of flow are less than 1 m3/sec with periods of flow greater than this for all end of systems occurring 26-31% of the time. Flow becomes more intermittent as average annual rainfall decreases.

4.4 LAND USE

4.4.1 THE CONDAMINE-BALONNE AND MARANOA CATCHMENTS

The Condamine-Balonne and Maranoa catchments land use is shown in Figure 4 and Table 5. The aggregated landuse categories were based on QLUMP data (QLUMP, 2016) refer Table 19 for groupings. It is dominated by grazing (open and closed) (70% of the area) with areas of irrigated and dryland cropping concentrated along the main river in the upper Condamine and Lower Balonne.

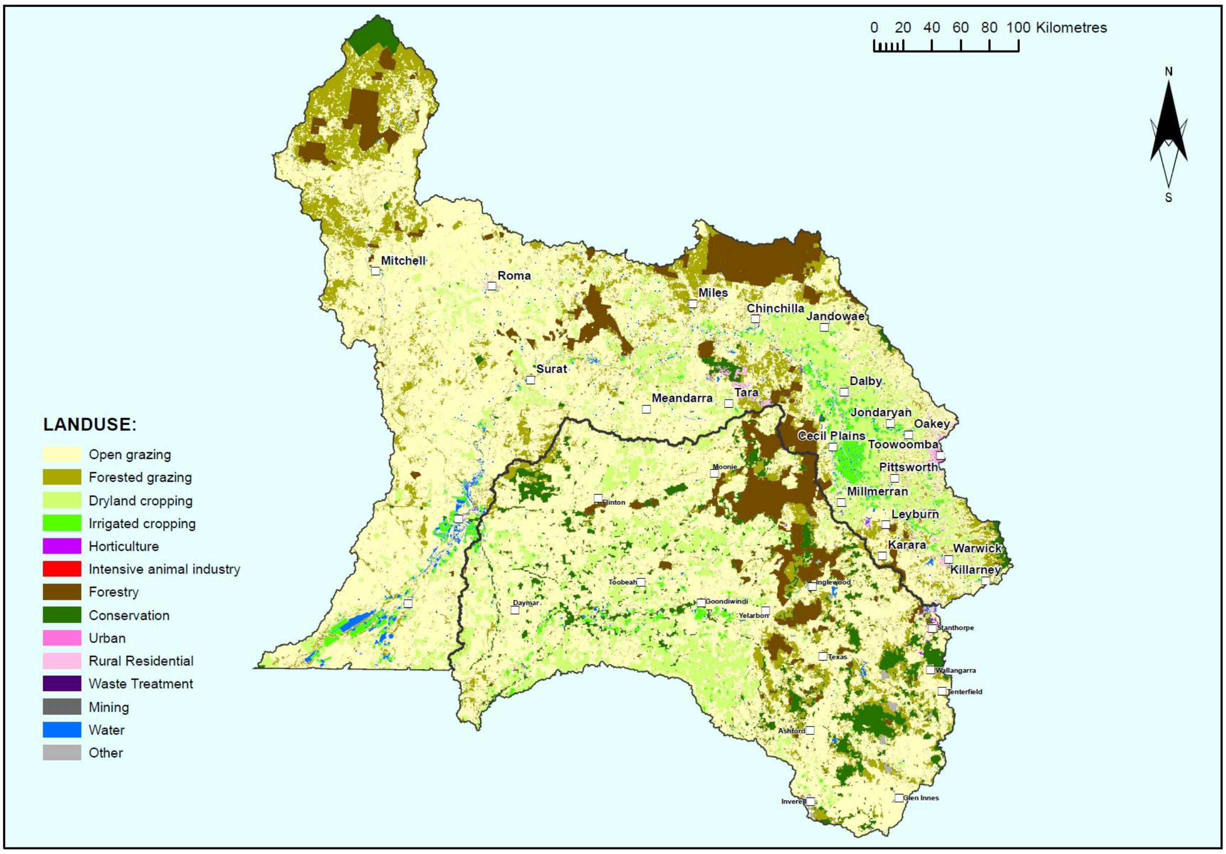


FIGURE 4 – THE LAND USE FOR THE CONDAMINE-BALONNE AND MARANOA CATCHMENTS AND THE MOONIE AND BORDER RIVERS CATCHMENTS DEMONSTRATING THE LARGE COVERAGE OF GRAZING AND CROPPING AREAS

4.4.2 THE MOONIE AND BORDER RIVERS CATCHMENTS

The Moonie and Border Rivers catchments land use is shown in Figure 4 based on QLUMP data (QLUMP, 2016) Refer Table 20 for groupings. It is dominated by grazing (open and closed) (60% of the area) with areas of forestry and conservations (20% of area) in the upper Moonie and Border Rivers (Figure 4 and Table 5).

4.4.3 THE SWNRM CATCHMENTS

The SWNRM catchments land use is shown in Figure 5 based on QLUMP data (QLUMP, 2016) Refer Table 21 for groupings. It is largely dominated by grazing occupying greater than 95% of the area. Based on experience in the previous SWNRM model, it was helpful to delineate the grazing areas further. This was done using land types and created the following Grazing – Alluvial, Grazing - Hard Country, Grazing – Sandplains, Grazing - Woodlands/Forests Grazing – Other, all for both open (cleared) and closed (timbered) areas. An overview of the process can be found in section 11.2.3 (Figure 5 and Table 5).

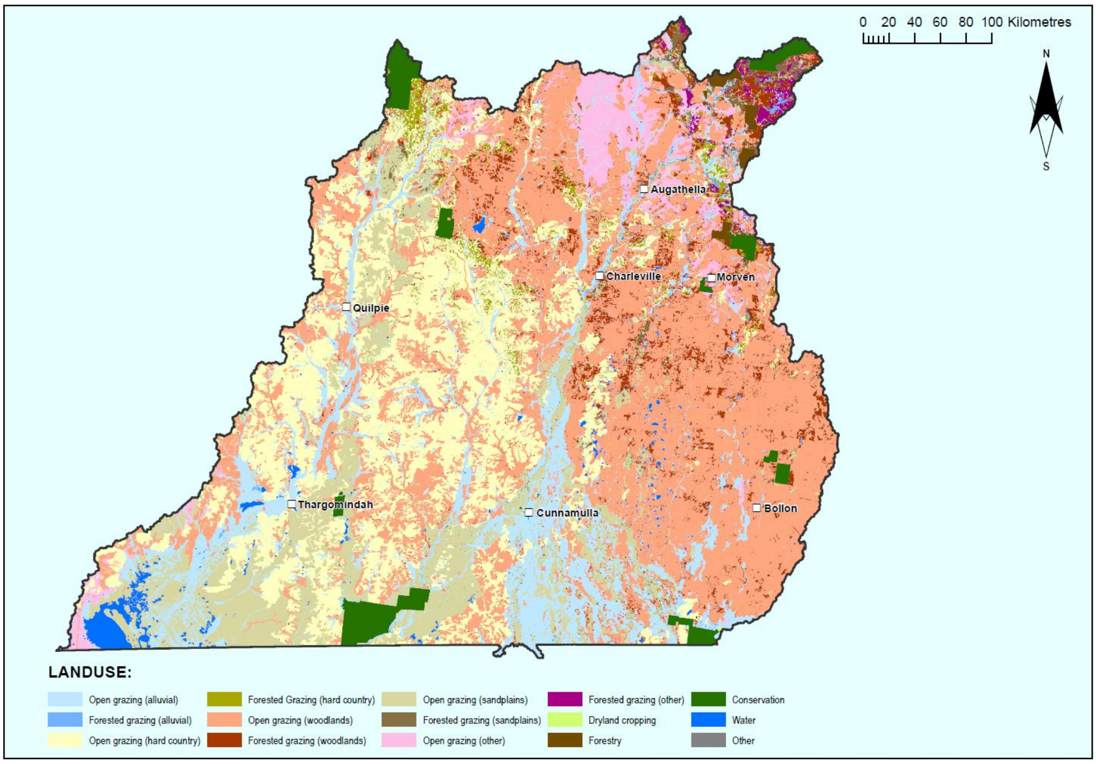


FIGURE 5 - SWNRM CATCHMENTS LAND USE

Land use across the modelled area is dominated by cattle and sheep grazing in open and forested grazing environments (>70%) (Figure 5). Significant areas of the Border Rivers and Condamine are utilised for dryland and irrigated cropping. An area of 11,901 km^2 is cropped in the Border Rivers and 10,590 km^2 in the Condamine. Dryland cropping is the predominant cropping system covering 17% of the total area with irrigated cropping representing only 2.9% of the modelled area.

TABLE 5 SUMMARY CHARACHTERISITICS OF THE REGIONS MODELLED

NRM region	Catchments	Catchment area (km^2)	Rainfall (mm/year)	Dominant land uses
Condamine Alliance and Queensland Murray Darling Committee (QMDC)	Condamine – Balonne and Maranoa	88,500	500–1250	Grazing 70%, irrigated and dryland cropping. 20%
QMDC	Moonie and Border Rivers	38,500	500-1100	Grazing 60%, irrigated and dryland cropping. 20%
South West NRM	Nebine, Warrego, Paroo and Bulloo	189,600	300-800	Grazing 95%

5 METHODS

The model was built in 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 and constituents, by integrating a range of models, data and knowledge. Sub-catchments are the basic spatial unit in Source Catchments. A sub-catchment is further delineated into 'Functional Units' (FUs) based on common hydrological response or land use (eWater Ltd 2013). Source Catchments supersedes the E2 and Water CAST modelling frameworks (eWater Ltd 2012) used by previous iterations of water quality models developed for the QMBD area (refer Table 2 - Previous Model). The major distinction between this model and previous QMDC models is that this model incorporates the dynamic SedNet plugins used in the Paddock to Reef modelling program (Waters et al., 2014). The dynamic SedNet plugin allows the user to represent hillslope, gully and streambank erosion processes as well as in stream and floodplain deposition/re-entrainment (Figure 7).

5.1 WATER QUALITY MODEL STRUCTURE

In the base eWater Source modelling framework, there are two modelling components assigned to each FU representing runoff and Constituent generation. Nodes and links represent the stream network and runoff and constituents are routed from a sub-catchment through the stream network via nodes and links (Figure 6). However, the basic eWater model structure does not represent gully and streambank erosion processes which are important contributions to erosion in the QMDB. Therefore, the approach used in the Great Barrier Reef modelling program (Waters et al., 2014) was adopted. (Refer section 9.4 for full explanation of constituent generation approach).

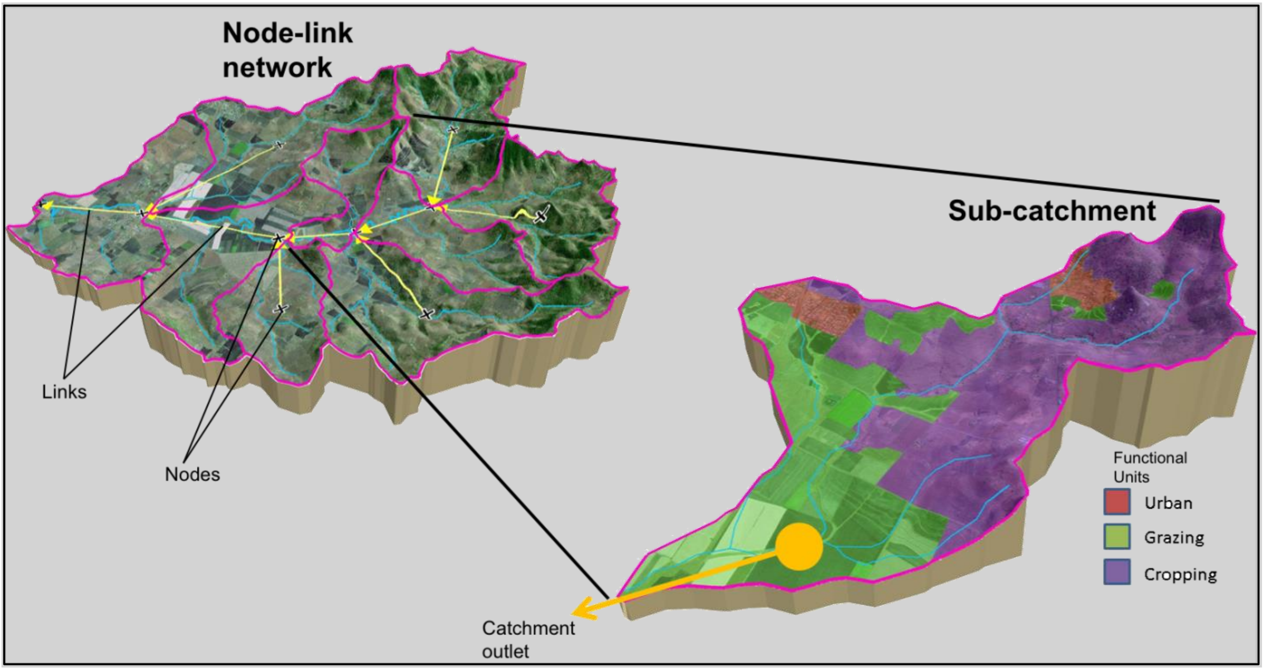


FIGURE 6 - EXAMPLE OF A FUNCTIONAL UNIT (FU) AND NODE-LINK NETWORK GENERATED IN SOURCE CATCHMENTS. THESE COMPONENTS REPRESENT THE SUB-CATCHMENT AND STREAM NETWORK

5.1.1 CONCEPTUAL APPROACH FOR CONSTITUENT GENERATION

Source Catchments framework allows specific customised models to be added as 'plug-ins' to meet a particular modelling objective. The GBR Source plug-in (Dynamic SedNet) (Ellis and Searle, 2014) was used for the QMBD Water Quality models.

While the GBR Source Catchment models incorporated paddock scale modelled outputs into the model, the QMDB Water Quality model did not use this functionality. Instead, the RUSLE model for cover dependent land uses (For example: grazing, conservation and forestry) using a modified version of the Universal Soil Loss Equation (USLE) Renard et al. 1997, and Event Mean Concentration/Dry Weather Concentration (EMC/DWC) models were used for the remaining land uses. The decision was made to use RUSLE as opposed to paddock model simulations for the QMDC model due to the time constraints, limited capacity to generate paddock model scenarios and there was no requirement to reflect management differences for this project.

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

Point source inputs of pollutants from major sewage treatment plants (STP) are included in the model. Losses from the stream as irrigation extractions were also represented at relevant nodes in the model as a daily time-series of flow and concentration. In-stream transport process such as deposition of sediment and particulate nutrients were also represented (Figure 7). A more detailed description of the modelling methodology and algorithms are available in Ellis & Searle (2014) and Wilkinson et al. (2014).

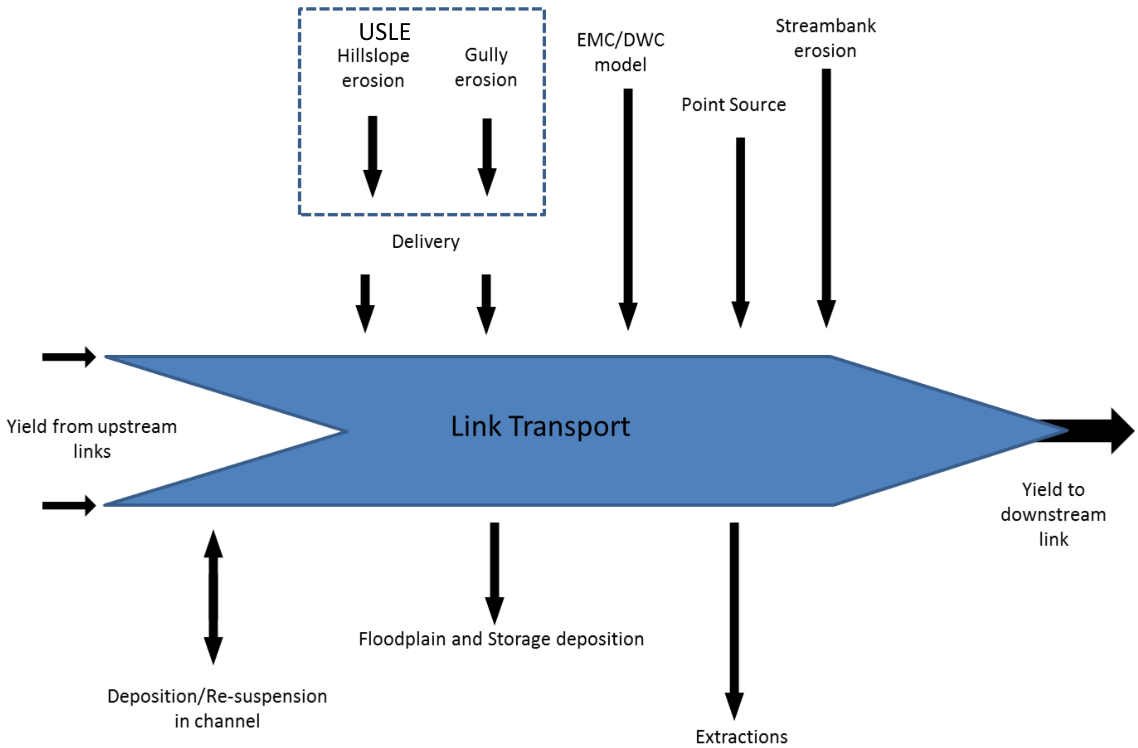


FIGURE 7 - CONCEPTUAL DIAGRAM OF DYNAMIC SEDNET SOURCE CATCHMENTS FRAMEWORK

5.1.1.1 Model Structure

Due to the large area modelled, three separate models were created, largely based on the Regional Natural Resource Management (NRM) bodies along with the natural drainage within the area. This simplified the QMBD model into the following individual model builds:

1. South West NRM (SWNRM) model

   Four western catchment form the SWNRM model which includes the Nebine, Warrego, Paroo and Bulloo catchments. These catchments are covered by the South West Natural Resource Management group (SWNRM). These four catchments drain into NSW.

2. Condamine Balonne Maranoa (CBM) Model

   The rivers of Condamine, Balonne and Maranoa form a single model. Condamine and Maranoa both drain into the Balonne River that flows across the border into NSW. Two NRM bodies cover this area, Condamine Alliance (CA) for the Condamine River (from the Condamine headwaters to the town of Condamine) and the Queensland Murray-Darling Committee (QMDC) from the town of Condamine west, covering the Maranoa and Balonne Rivers.

3. Moonie and Border Rivers (BDMN) Model
   The Border River and Moonie model are two catchments that join together below the NSW Border. As the McIntyre River, which is the major river in the Border Catchment, forms the NSW and Queensland border (thus the "Border Rivers Catchment"). This model captures the NSW area of the Border Rivers catchment and ends where the Moonie and Barwon Rivers meet. This catchment area is covered by QMDC NRM group.

The land area covered by each of these models align with the Water Plan and Water Resource Plan areas under State and Federal water planning processes respectively. This is of benefit to the development of HWMPs/WQM Plans as modelling results specific to plan areas will increase the useability of modelling results.

5.1.2 LAND USE FUNCTIONAL UNITS

Functional Units (FUs) for the modelled regions were defined from land use mapping from a number different sources due to the study area extending into New South Wales.

The original detailed land use categories were reclassified into 10 -12 aggregated land uses/FUs to represent the dominant land uses of interest. These were also informed by the previous models FUs (Table 2). For this model, some changes were identified to represent the updated land use mapping. This resulted in the land use categories being identical for the Border Rivers and Condamine models. The land use for the SWNRM region was similar with the majority (>80%) being grazing (Table 2).

Grazing areas were spilt into open (cleared) and closed (timbered) to enable differences in runoff and constituent generation for the two areas to be reflected in the model. To differentiate between open and closed grazing, closed areas were those areas with a Foliage Protective Cover (FPC) ≥20% (National Committee on Soil and Terrain 2009). Differentiation was made between these two grazing systems to enable representation of different hydrological response units during calibration. Any given land use within a sub-catchment is aggregated and represented as a single area in the model hence is not represented spatially within a sub-catchment. A complete overview of the land use categories can be found in the Appendix (11.2).

5.1.3 SUB-CATCHMENT GENERATION

The QMDB Source Catchments models contain nine catchments: SWNRM (the Bulloo, Paroo, Warrego, and Nebine), CBM (Condamine, Balonne, and Maranoa), and BDMN (Moonie and Border Rivers catchments). The catchments were delineated into smaller sub-catchments using a 100 metre, hydrologically enforced Digital Elevation Model (DEM). A stream network, generated from the DEM was used to determine the location of nodes and links. Nodes are located along the network at sub-catchment outlets and include user specified nodes such as stream gauging stations or storages. For each model, a minimum drainage threshold (Table 6) was used to identify the major stream network and contributing sub-catchments. This minimum drainage threshold was also based on input from the local NRM bodies should they wish to use this model on completion.

Some further manipulation of boundaries in GIS was done to accommodate the large flat areas between the Balonne, Moonie and Border Rivers catchments. This was done on visual inspection of imagery and local knowledge. The final sub catchments used for the QMDB models can be found in Figure 8.

TABLE 6 - SUMMARY OF SUB-CATCHMENT FOR THE QMDB MODEL REGIONS

	Number of Sub-catchments	Average Sub-catchment size
Border Rivers/Moonie	231	311 km^2
Condamine Balonne	281	286 km^2
South West NRM	91	1,958 km^2

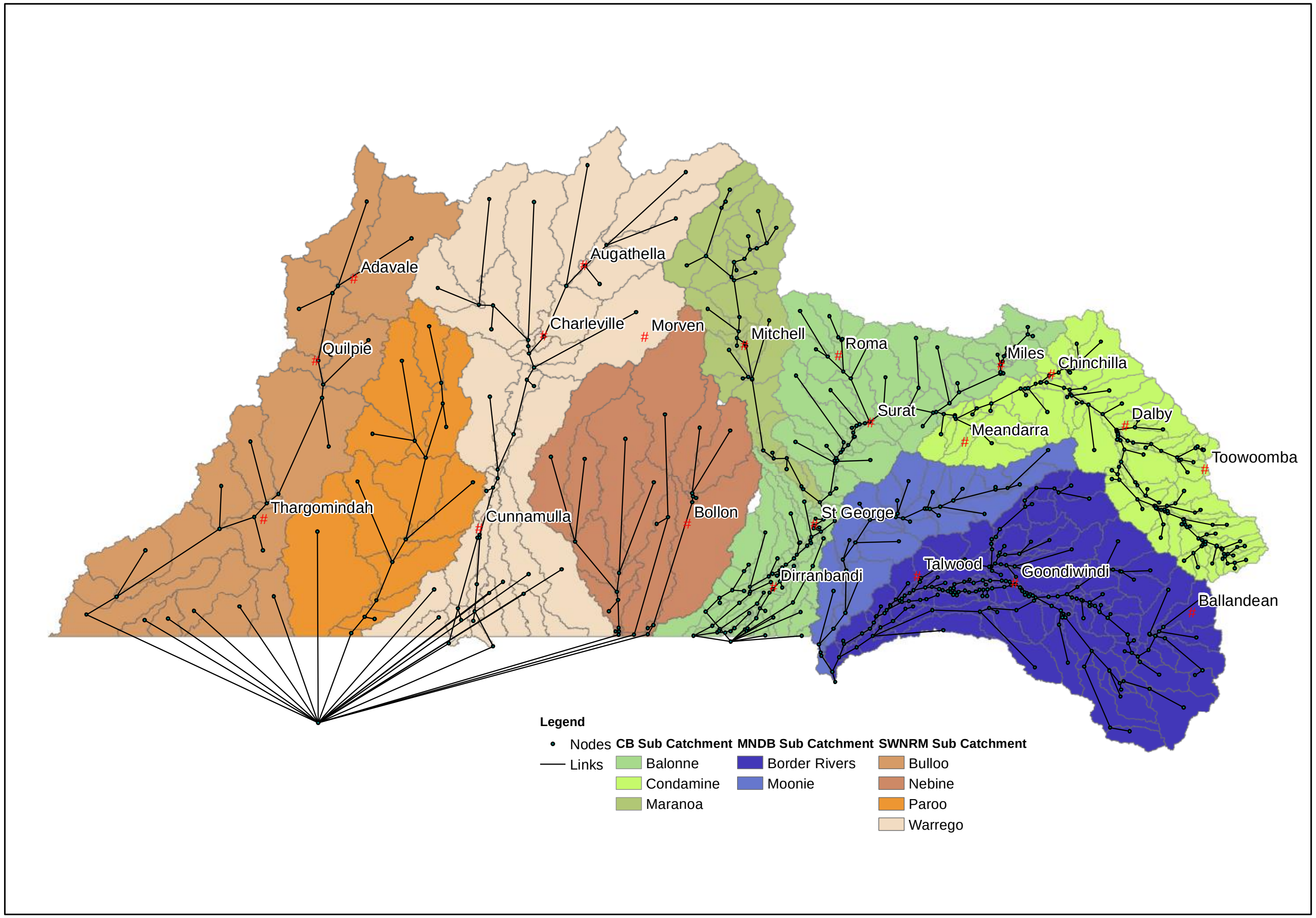


FIGURE 8 – AN OVERVIEW OF THE QMDB SUBCATCHMENT, WITH ASSOCIATED LINKS AND NODES. THE LINK AND NODES PROVIDE THE REPORTING POINTS THROUGH THE MODEL. THESE ARE ALSO GROUPED AT THE END OF THE CATCHMENT TO REPORT ON TOTAL CATCHMENT EXPORT FOR AREAS THAT HAVE MULTIPLE RIVERS THAT CROSS THE QLD/NSW BORDER

5.1.4 Climate Simulation Period

A 36 year climate simulation period was chosen (01/01/1980 – 31/12/2015). This period included a range of extreme wet and dry periods which is an important consideration for hydrology calibration.

Daily climate input files generated for each sub-catchment were used to calculate daily runoff. Rainfall and Potential Evapotranspiration (PET) inputs were derived from the Department of Science Information Technology Innovation (DSITI) Silo Data Drill database (Queensland Government 2014). The data drill accesses grids of data derived by interpolating the Bureau of Meteorology's station records. The data are supplied as a series of individual files of interpolated daily rainfall or PET on a 5 km grid. Source Catchments interrogates each daily grid and produces an 'averaged' area weighted continuous daily time series of rainfall and PET data for each sub-catchment.

5.2 Runoff generation

The Sacramento rainfall runoff model, one of six available in eWater Source, was used to generate runoff. Storage dynamics (dams/weirs) were simulated as well as irrigation extractions, channel losses and inflows such as sewage treatment plant discharges through specific node models.

5.2.1 Hydrology calibration process using PEST

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. For calibration of parameters, the command-line Source model was coupled with a model-independent parameter estimation tool called PEST (Doherty 2005). PEST was set up to use one of its parameter global optimisers, the CMAES (Covariance Matrix Adaptation Evolutionary Strategy) to estimate the optimised value of the 21 hydrological parameters. PEST's CMAES optimises model parameters using automated search algorithms that minimise the difference between modelled and measured flows, i.e. the objective function. In this calibration, we used an objective function introduced by Coron *et al.* (2012). Lerat et al. (2013) further modified this objective function to reduce the volume difference between the simulated and observed total flow volumes and the misalignment of observed and simulated peak flow timing through its three function terms. The modified objective function comprised three terms which aimed to ensure that the total flow difference was within ± 10%, that the high flow peaks were well represented and that the timing and duration of events was also well represented. A fourth term was added to improve the modelled baseflow proportion. The baseflow term minimises the difference between the simulated baseflow and an "observed" baseflow proportion derived from gauged flow data using the Lyne & Hollick (1979) approach which applies a smoothing filter to daily observed flow to split daily flow into baseflow and quickflow. Note final Sacramento parameters used are listed in Tables 16 – 18.

Once calibration was completed, model performance was assessed for the 38 QMDB gauges used in the calibration process. Performance was assessed for the calibration period 01/01/1980 – 31/12/2015. Most gauges had the complete flow records for the entire years through the calibration period. This was applied to the period of data available at each gauging station. This meant that for some sites that had long term data, the calibration period was completed for 36 years, however for some sites this period was 15 years. These sites with shorter calibration periods were in the minority. The model performance was assessed against observed flow data using the criteria in

Table 7 based on Moriasi (2007, 2015) which outlines the evaluation criteria for model performance for monthly flow.

TABLE 7 - MORIASI (2007, 2015) MODEL EVALUATION CRITERIA

Measure	Performance Criteria			
	Very Good	***Good***	***Satisfactory***	***Not Satisfactory***
R^{2*}	R^2 >0.85	0.75 < R^2 ≤0.85	0.60 < R^2 ≤0.75	R^2 ≤0.60
NSE	NSE >0.80	0.70 < NSE ≤0.80	0.50 < NSE ≤0.70	NSE ≤0.50
PBIAS (%)	PBIAS <±5	±5≤ PBIAS <±10	±10≤ PBIAS <±15	PBIAS ≥±15
RSR	RSR<0.5	0.5<RSR0.6	0.6<RSR<0.7	0.7<RSR

R^2 *- Statistical measure of how close data fits the 1 to 1 line*
NSE *– Nash Sutcliffe is similar to coefficient of determination and used to assess predictive power of a model*
PBIAS *– percent bias is a measure of difference between measured and modelled value*
RSR *– Ratio of root mean square to standard deviation*

5.2.2 REGIONALISATION OF CALIBRATION PARAMETER SETS

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

5.2.3 STREAM GAUGE DATA SELECTION FOR CALIBRATION

Flow data was extracted from DNRME Hydstra Surface Water Database to provide the 'observed' flow values for calibration. Additional flow data was received from the DSITI Water Quantity modelling team for the Border River catchment as Qld and NSW were working on an updated Integrated Quantity and Quality Model (IQQM) for Border Rivers.

Gauging Stations were identified as suitable for PEST calibration using the following criteria:

- Located on the modelled stream network;
- Had a minimum of 10 years of flow record (post 1980) with suitable corresponding quality codes in the DNRM database;
- An appropriate spatial distribution throughout the catchment; and
- In discussion with DNRME Senior Hydrographer, gauging stations were rated based on their long-term reliability of ratings with a range of events within the data set

Final gauges used in the PEST calibration process are shown in Figure 1.

5.3 CONSTITUENT GENERATION

5.3.1 WATER QUALITY CONSTITUENTS MODELLED

The water quality constituents modelled were Total Suspended Sediment (TSS) and Total Nutrients (Total Nitrogen and Total Phosphorus). Rainfall and ground cover are two dominant factors affecting hillslope runoff and erosion in the QMDB. Given grazing occupies over 70% of the QMDB, it was important that the models chosen were able to reflect the dominant erosion processes occurring in these landscapes and the spatial variability observed across such a large area. Dynamic SedNet incorporates daily rainfall, spatially and temporally variable cover to generate hillslope erosion. Gully and streambank erosion and floodplain deposition processes have also been represented.

SEDIMENT GENERATION MODELS

5.3.1.1 HILLSLOPE SEDIMENT AND NUTRIENT GENERATION

A modified version of the Universal Soil Loss Equation (USLE) was used to generate hillslope erosion in grazing lands (Renard et al. 1997, Lu et al. 2001, Renard & Ferreira 1993). This modified version is based on the Revised Universal Soil Loss Equation and is referred to as the RUSLE in this document (Lu et al. 2001, Renard & Ferreira 1993). The RUSLE model was chosen due to its proven ability to provide reasonable estimates of hillslope erosion worldwide, including the application in GBR Paddock to Reef models (McCloskey, 2015), the ability to apply the model across a large spatial extent and at the same time incorporate detailed spatial and temporal data layers including cover and rainfall components. For a detailed explanation of the application of the RUSLE model refer to Ellis and Searle (2014).

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

EQUATION 1

Hillslope particulate nutrient load (kg/ha) = RUSLE sediment load (kg/day) x clay (prop) x Surface nutrient concentration (kg/kg) x Enrichment factor x Nutrient Delivery Ration (NDR)

This estimates the total suspended nutrient load which reaches the stream. The dissolved nutrient load is the product of an EMC/DWC value and the quick and slow flow respectively. These models are described in (Ellis and Searle 2014) and replicate the original SedNet approach to dissolved and particulate nutrient generation modified to a daily basis.

Gully generation model

To derive gully erosion estimates, the critical input data layer in the gully model is gully density. This was generated through a methodology created within DNRM by which a square kilometre is divided into one hundred 100 square metre plots. These plots were examined for the presence of a gully. Where a gully was present that plot was marked as a positive for gully. The square kilometre was scored based on the number of gully plots as a percentage. Gully mapping was conducted as part of this project for 6,500 square kilometres the QMDB on a relatively even grid to sample all land types within catchments. Using cover and land types, the average gully density was extrapolated for the entire QMBD. The extrapolation provided an average gully density for that land type and cover amount, which provided a complete gully density map for the QMDB. Further information on this process can be found in Darr (2017).

5.3.2 OTHER LAND USES: EVENT MEAN CONCENTRATION, DRY WEATHER CONCENTRATION

The remaining land uses: forestry, nature conservation, urban, horticulture and the 'other' land use category had EMC/DWC models applied. In comparison to grazing and cropping, these land uses had a small relative contribution to regional loads. In the absence of specific models for these land uses, EMC/DWC models were applied where daily load is:

EQUATION 2

Daily Load (kg) = (EMC (mg/L) x quickflow runoff (ML)) + (DWC (mg/L) x slowflow runoff (ML))

Where quickflow represents the storm runoff component of daily runoff, the remainder was attributed to slowflow. EMC/DWC values were derived from monitoring data, or where monitoring data was not available, from previous studies (Waters & Packett 2007, Rohde et al. 2008, Bartley et al. 2012, and Turner et al. 2012) - Refer to Table 23 in the appendix for a summary of EMC/DWC values used.

The EMC/DWC values were based on median values used in the Waters, 2008 report for another SWNRM source model. The only change from these figures used was to increase the phosphorus median values for the BDMN model by 3 times to better represent the values that was being observed and predicted.

These median values were then spilt into ratios for Nitrogen and Phosphorus species for the hillslope model. This was based on the laboratory samples taken throughout the QMDB continuous monitoring project (section 5.4.1.4) which assigned an average proportion for DIN, DON and particulate N, FRP, DOP and Particulate P from the known laboratory sample proportions.

5.3.3 NODE BASED MODELS

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

5.3.3.1 EXTRACTION, INFLOWS AND LOSS NODE MODELS

To simulate the removal of water and the associated load of constituents from storages and or rivers, daily extraction estimates for a river reach were incorporated at relevant nodes. The irrigation extraction data was obtained from Integrated Quantity and Quality Model (IQQM) runs provided by Queensland Hydrology (DSITI) for each region. Multiple types of extractions were aggregated and allocated at the appropriate downstream nodes. Regionally specific loss models were included to account for channel losses where necessary. To account for water moving between channels at bifurcations in the rivers (e.g. the split of the Condamine River into the North and South Branch, Macintyre River in the lower Border Rivers and the lower end of the Warrego River in Southwest NRM region). Loss nodes and inflow nodes were added to the model to mimic discharge out of the main river (loss node) and this water entering a bifurcation or branch downstream (inflow node).

5.3.3.2 STORAGES

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

5.3.4 In-stream models

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

5.3.4.1 Sewage Treatment Plant (STP) Inflows

Those centres that had an STP that was 10,000 equivalent persons or higher had the average annual nutrient load discharged from the STP added into the source model at the relevant link. For the QMDB, the only STP that met this criteria was Toowoomba's Wetella sewage treatment plant. Data was accessed from the Department of Environment and Science STP database and the average annual discharge prior to and post the upgrade were used.

5.3.4.2 Streambank erosion

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

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

5.3.4.3 Floodplain deposition

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

5.4 ASSESSMENT OF CONSTITUENT LOAD PERFORMANCE

For load calibration, monitored TSS, TN and TP samples were correlated against discharge for historical water quality data from Qld and NSW datasets to provide a long-term comparison (30+ years) of catchment loads (Figure 1).

For independent validation, a short-term comparison (2015-2016) between observed and modelled concentrations was made using data collected from a project funded concurrently with this project called DEHP5 monitoring Project where water quality data was collected at four gauging stations established to support this project.

5.4.1 LOG-TRANSFORMED WATER QUALITY RELATIONSHIP ESTIMATOR (1980-2015)

Monthly and annual sediment and nutrient load estimates were derived from monitoring data to calibrate the QMDB Source Catchments model for the period January 1980 to December 2015 (36 years). Historically, within the QMDB catchments water quality data was collected sporadically and often not sampled for critical parts of the hydrograph. Efforts have been made to capture the range of values over the hydrograph through novel approaches using Water Quality sampling trailers (DNRME/SWNRM) and targeted event sampling between 2003 and 2008, dramatically increasing the event samples collected in SWNRM region with an additional 50 samples collected, which counts for 70% of the event samples for this catchment (Waters, 2008). Water quality samples were accessed from DNRME's Hydstra data set. A summary of the data is shown in Table 8.

TABLE 8 – SUMMARY OF WATER QUALITY DATA FROM DNRM'S HYDSTRA DATABASE. THE RESULTS HIGHLIGHT THE VARIABILITY IN THE NUMBER OF SAMPLES CAOLLECTED IN EACH CATCHMENT AND THE DIFFERENCES IN CONCENTRATIONS BETWEEN EVENT AND LOW FLOW CONDITIONS.

Site and Sample Details		Total Suspended Solids	Total Nitrogen	Total Phosphorus
Number of Total samples (n)	BDMN	484	213	231
	CB	1,999	954	1,439
	SWNRM	249	107	159
Number of Event samples (n)	BDMN	31	18	12
	CB	175	108	164
	SWNRM	52	40	45
Average Concentration -all samples (mg/L)	BDMN	116	1.31	0.28
	CB	308	1.60	0.84
	SWNRM	394	1.76	0.50
Average Concentration – Event Flow (mg/L)	BDMN	197	1.48	0.32
	CB	2302	4.40	3.60
	SWNRM	885	2.31	0.82
Average Concentration – Low Flow (mg/L)	BDMN	110	1.30	0.28
	CB	117	1.24	0.49
	SWNRM	265	1.43	0.38

To calibrate the Source models, ambient and event water quality data was log transformed and plotted against log transformed flow. Curves were then fitted to derive relationships between TSS, TP and TN concentrations and gauged discharge by catchment. The log transformation was undertaken to enable the data to become more symmetric and normally distributed and to make the data variance more uniform. This approach was based on an analysis of the original data and finding a positive skew and large difference in the data variance. It has become common practice to log-transform water quality data, especially chemical concentrations and stream discharge, because this simple transformation often fits the inherent assumptions when using regression analysis (Li and Migliacio, 2010). Seasonal fluctuations in concentration and short-term fluctuations related to fluctuations in flow are two factors that greatly increase variance and hinder trend detection (Richards and Baker, 2002). Removing time dependent factors allows for the relationship between flow and concentration outside of these fluctuations.

This relationship was applied to the hourly flow time series. Concentrations could then be calculated at a range of gauging stations across the region where hourly flow data was available. The resulting concentration values were used to calculate an hourly load and aggregated to provide an estimate of monthly and yearly load at validation sites throughout the catchments. Due to limited availability of measured reference data at a full range of flow heights in the data used to build the relationship, it should be noted that there is a degree of uncertainty about the measured load estimates at high flows. However, in a data poor catchment this provides the most robust approach to calibrate and validate the models. Water quality and flow data were vetted to remove erroneous data points. The overall soundness of the estimates were cross checked by calculating an average annual load by as product of the average constituent concentration (pooling all data) and the average annual flow at a site. The resultant figure gave a logic test to ensure the relationship created wasn't providing erroneous results.

5.4.1.1 Log-Transformed TSS vs DISCHARGE relationship

Separate curves were derived for the three catchments correlating TSS to discharge (see Figure 9, Figure 10 and Figure 11). The data available for a catchment informed whether a transformation using log or log +1 was undertaken and then these were assessed on the regression relationship that was achieved. For the Condamine Balonne model and by the process of testing the soundness of the result, it was revealed that in higher flows, the linear relationship was providing too much TSS based on a logic test for expected TSS loads. This logic test used an average concentration from the data applied to the flow, which provided a normal range. The linear relationship was successful at low and medium flows, however overestimated the TSS loads at large flow/events. This was rectified through using a polynomial relationship that limited TSS concentrations at high flows.

The strength of the relationship for each models data is found in Table 9, which demonstrates while the R Squared value may be low, the relationship was significant. The number of observations come from how successfully a flow value was able to be assigned to a constituent. It can be seen from Table 12 that there was a large number of observations in the Condamine Balonne Maranoa catchments in contrast to the South West and Border Rivers-Moonie catchments.

TABLE 9 - REGRESSION TESTS SUMMARY FOR DISCHARGE RELATIONSHIPS

	Equation	R^2	Observations	Significance F
SWNRM	$y = 0.3287x + 2.1733$	0.50	173	1.36421E-27
BDMN	$y = 0.2752x + 1.1192$	0.22	115	9.90062E-08
CBM	$y = -0.2331x^2 + 1.2043x + 1.3882$	0.37	1,862	3.403E-184

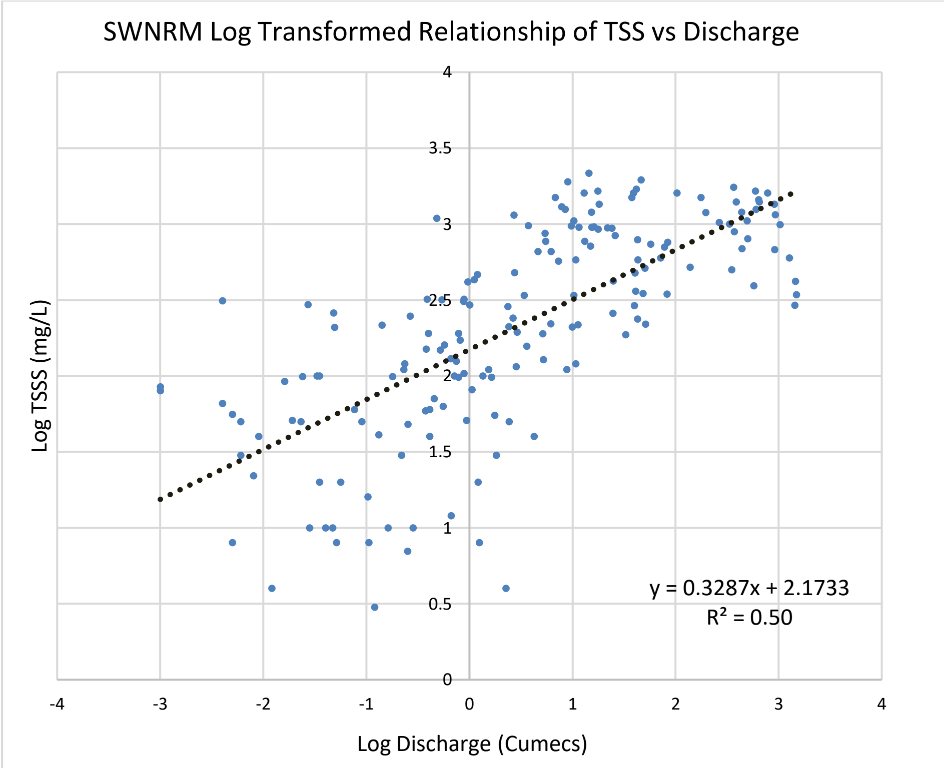


FIGURE 9 – LOG-LOG TSS DISCHARGE SWNRM RELATIONSHIP

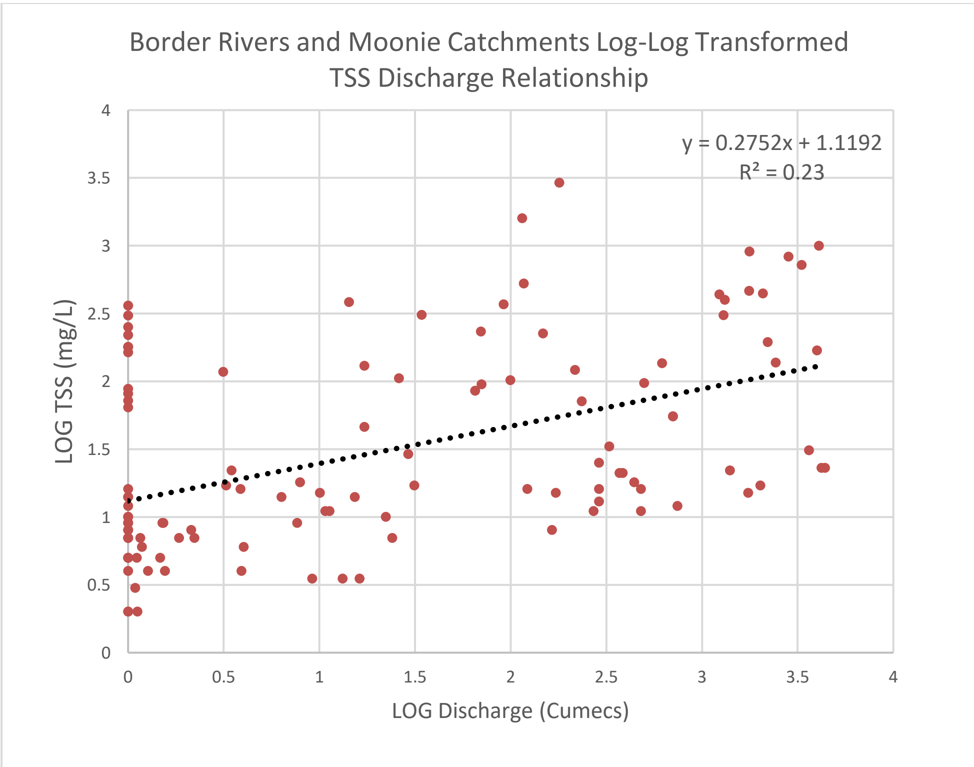


FIGURE 10 - LOG+1 - LOG+1 TSS DISCHARGE MNBD RELATIONSHIP

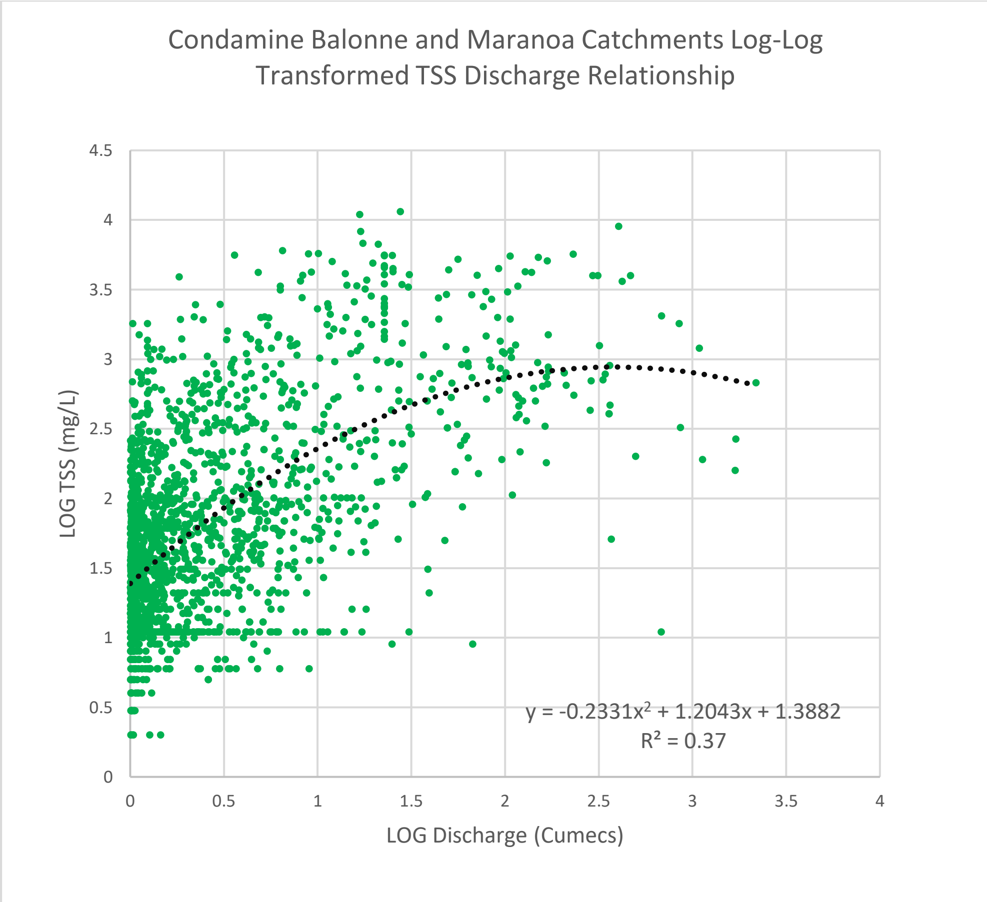


FIGURE 11 - LOG+1 - LOG+1 TSS DISCHARGE CBM RELATIONSHIP

5.4.1.2 LOG-TRANSFORMED TN AND TP VS DISCHARGE RELATIONSHIPS

To derive load estimates for nutrients, relationships were derived between discharge and TN and discharge and TP for each of the regions following the same methodology as used to derive discharge and TSS relationships.

Given the strong relationship between TSS vs TN and TSS vs TP found by Waters et al. (2008), due to the high particulate fraction in runoff for these basins, an additional correlation was derived between TSS vs TN and TSS vs TP to give another estimation of the nutrient load. This was included as only TP and Discharge had a higher number of observations than other counterparts (Table 10) and weaker relationships (R^2 and significance) with discharge (Table 10). Using two sets of measured data provides a potential range for the TN and TP values, ultimately trying to address the lack of available data by building a reliable load estimate from observed data to calibrate against. Section 11.8 contains all plots of the correlations described above.

TABLE 10 - REGRESSION TEST SUMMARY FOR TN/TP RELATIONSHIPS PROVIDING THE RELATIONSHIP EQUATION USED FOR THE CALCULATION OF AN ESTIMATE FROM 'OBSERVED' DATA FOR LOAD CALIBRATION SITES

REGION		Relationship Base	Equation	R Square	Observations	Significance F
SWNRM	TN vs	Discharge	y = 0.102x + 0.0858	0.27740	83	3.14643E-07
		TSS	y = 0.3448x - 06911	0.67058	101	1.30646E-25
	TP vs	Discharge	y = 0.1676x - 0.4993	0.45868	109	6.17562E-16
		TSS	y = 0.4981x - 1.5967	0.74451	152	2.6842E-46

BDMN	TN vs	Discharge	y = 0.0468x + 0.0198	0.05745	164	1.99E-03
		TSS	y = 0.2779x - 0.429	0.57219	206	1.79573E-39
	TP vs	Discharge	y = 0.0763x - 0.9293	0.03682	164	1.38E-02
		TSS	y = 0.6105x - 1.8926	0.75638	217	7.37324E-68
CBM	TN vs	Discharge	y = 0.1348x - 0.0163	0.15649	797	2.97358E-31
		TSS	y = 0.3288x - 0.5815	0.43638	896	1.9751E-113
	TP vs	Discharge	y = 0.2114x - 0.5674	0.18708	1175	9.40646E-55
		TSS	y = 0.4867x - 1.4994	0.51547	1068	6.4086E-170

5.4.1.3 Long-term Flow Range Concentration Estimator (1980–2015)

Sediment and nutrient loads were estimated at both the annual and monthly time steps from the relationships described above in Table 10. These estimates are referred to as the “observed” loads from this point on, and refers to an estimate derived from observed sample data used to validate the QMDB Source Catchments model for the period January 1980 to December 2015 (36 years).

A subset of calibration sites used for the Hydrological Calibration (5.2.3) were used for the TSS, TN and TP calibration process. These sites were selected because they were located at the end of major basins (for example Condamine, Balonne Warrego) (Figure 1) to capture broad representative areas of catchment land use and features that were assumed to have a similar response to the TSS, TN and TP generation. In addition there was little extra monitoring data available at other sites to justify calibrating at a finer scale in any basin.

Calculation of monthly loads enabled a consistent statistical model evaluation for sediment and nutrients using Moriasi et al. (2007, 2015). Four quantitative statistics were used (Table 11). The statistics were calculated and model performance rated.

TABLE 11 - GENERAL PERFORMANCE RATINGS FOR RECOMMENDED STATISTICS AT MONTHLY TIME-STEP (FROM MORIASI ET AL. 2007, 2015)

Performance rating	RSR	NSE		R^2		PBIAS	
	Sediment	Sediment	N, P	Sediment, P	N	Sediment	N, P
Very good	0.00–0.50	>0.8	>0.65	>0.8	>0.7	<±10	<±15
Good	0.50–0.60	0.7-0.8	0.5-0.65	0.65-0.85	0.6-0.7	±10–±15	±15–<±20
Satisfactory	0.60–0.70	0.45-0.7	0.35-0.5	0.4-0.65	0.3-0.6	±15–±20	±20–±30
Not Satisfactory	>0.70	<=0.45	<=0.35	<=0.4	<=0.3	>±20	>±30

An important element of the calibration was to adjust broad spatial parameters of regions that generated the load for TSS. This included streambank erosion parameters (height of bank, width, and overbank flow reoccurrence interval), hillslope fine sediment delivery ratio and for gully erosion, the average gully cross section and the delivery ratio of these gullies. Gully width and streambank height were derived from aerial photography at approximately 50 sites across the region. This number of sites were sampled as it was deemed to provide a reasonable spatial coverage for the limited time and resources available to complete the project.

5.4.1.4 Independent Data Comparison using Grab Sample data

In addition to the long-term load comparisons, a short-term comparison (2015-2016) of modelled and observed constituent concentrations was made using grab sample data collected from the previously mentioned monitoring project running concurrently (DEHP5). The project uses a combination of grab samples and continuous monitoring probes at four gauging stations throughout the QMDB catchments to test whether a continuous monitoring system could reliably provide TSS and EC values with the long term aim to derive correlations between turbidity and TSS/TP/TN and EC and total dissolved solids for continuous load estimates. This project is being run over three years (2016-2018) and involves regular site visits to calibrate these probes. During these visits and during runoff events grab samples are taken to correlate to the probe readings.

6 Results

6.1 Hydrology calibration result

The Moriasi et al (2007, 2015) results for the summary of all calibration gauges for the models are found in Table 12 with full detailed results in Table 22. Condamine Balonne Model returned the best result using the criteria set out in Table 11, scoring “Very Good” for 100% of measures for all of its catchments. This was followed by SWRNM which had 85% of all measures being “Very good” and Border Rivers with 78% of all measures being “Very good”.

Overall, PBIAS was “Very Good” for 97% or 36 of the 37 calibration gauges for the volume of modelled versus the observed over the modelled period. 81% of gauges scored a “Very Good” for R2 monthly flow. The monthly NSE was “Very Good” for 78% of the gauges and RSR had “Very Good” for 89% of the gauges calibrated.

Scatter plots showing predicted and observed monthly stream flow are presented in Figure 12 - Figure **15**. These plots demonstrate the relationship of observed and predicted flow, and the correlation of the predicted monthly flows to the monthly observed flows.

Figure 16 shows a typical cross verification of daily observed runoff (blue line) and predicted runoff (red line). These are from a range of events and gauging stations. The hydrographs demonstrate the good alignment between predicted and observed flow.

TABLE 12 - SUMMARY OF MONTHLY HYDROLOGY CALIBRATION AGAINST MORIASI (2007, 2015) PERFORMACE EVALUATION CRITERIA

Model Scenario	Catchment	Number of calibration sites	Proportion Calibration Sites of Performance Evaluation Criteria that meet Moriasi (2015,2007) "Very High" Requirements				
			PBIAS	R^2	NSE Monthly	RSR	Total
SWNRM	Bulloo	2	100%	100%	100%	100%	100%
	Paroo	1	100%	0% #	0% #	0% #	25%
	Warrego	5	100%	80% ^	80% ^	80% ^	85%
	Nebine	2	100%	100%	100%	100%	100%
	Total	10	100%	80%	80%	80%	85%
Condamine Balonne	Condamine	7	100%	100%	100%	100%	100%
	Maranoa	2	100%	100%	100%	100%	100%
	Balonne	4	100%	100%	100%	100%	100%
	Total	13	100%	100%	100%	100%	100%
Border Rivers	Moonie	3	100%	33% *	0%*	66% *	50%
	Border Rivers	9	88% @	66% @	66% @	88% @	80%
	Weir	2	100%	100%	100%	100%	100%
	Total	14	93%	60%	53%	53%	78%
Overall	Total	37	97%	81%	78%	89%	86%

the remaining Paroo calibration site results: R2 scored "Good", NSE and RSR scored "Satisfactory" for Moriasi Performance Criteria
^ The remaining Warrego calibration site results: R2 and RSR scored "Good", NSE scored "Satisfactory" for Moriasi Performance Criteria
* The remaining Moonie calibration site results: R2 scored "Good", NSE scored 66% "Good" and 33% "Satisfactory" and RSR scored "Satisfactory" for Moriasi Performance Criteria
@ The remaining Border River calibration site results: R2 scored 22% "Good" and 11% "Satisfactory", NSE scored 22% "Good" and 11% "Satisfactory", PBIAS scored "Satisfactory" and RSR scored "Satisfactory" for Moriasi Performance Criteria

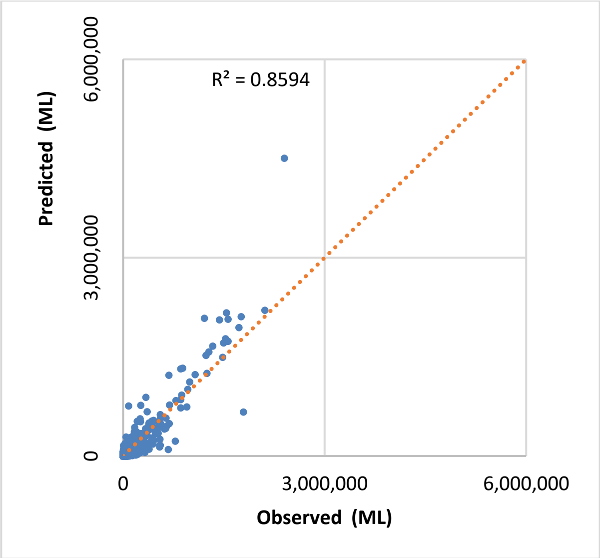


FIGURE 12 – WARREGO, PAROO, NEBINE AND BULLOO MONTHLY CALIBRATION RESULTS

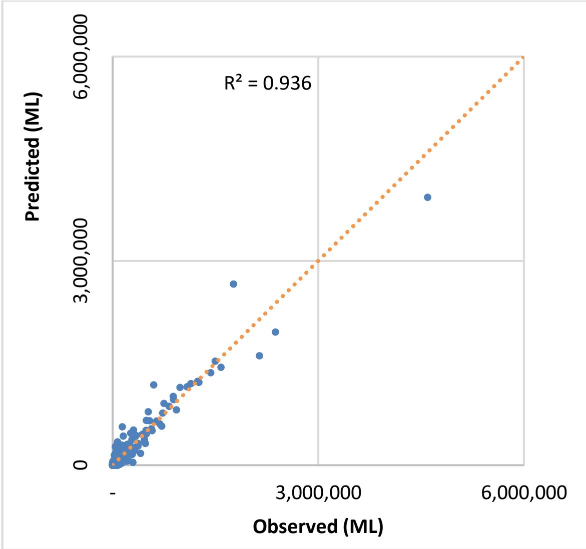


Figure 14 – CONDAMINE MONTHLY CALIBRATION RESULTS

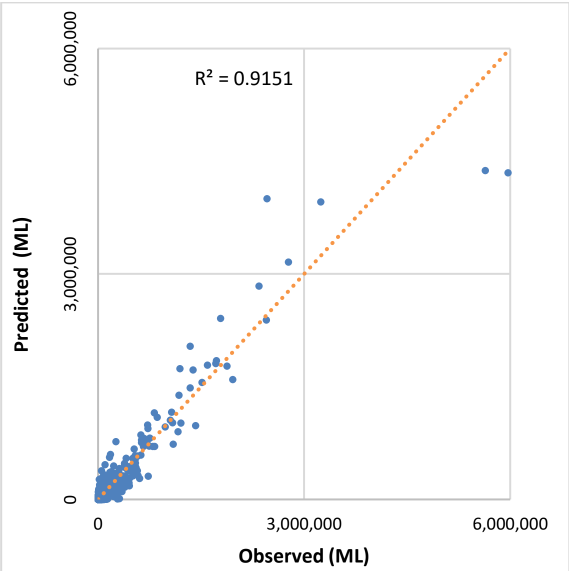


FIGURE 13 – MARANOA AND BALONNE MONTHLY CALIBRATION RESULTS

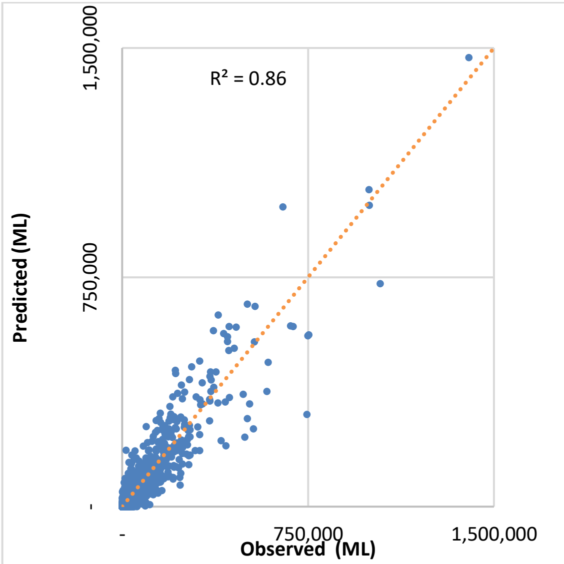


FIGURE 15 – Moonie and Border Rivers MONTHLY CALIBRATION RESULTS

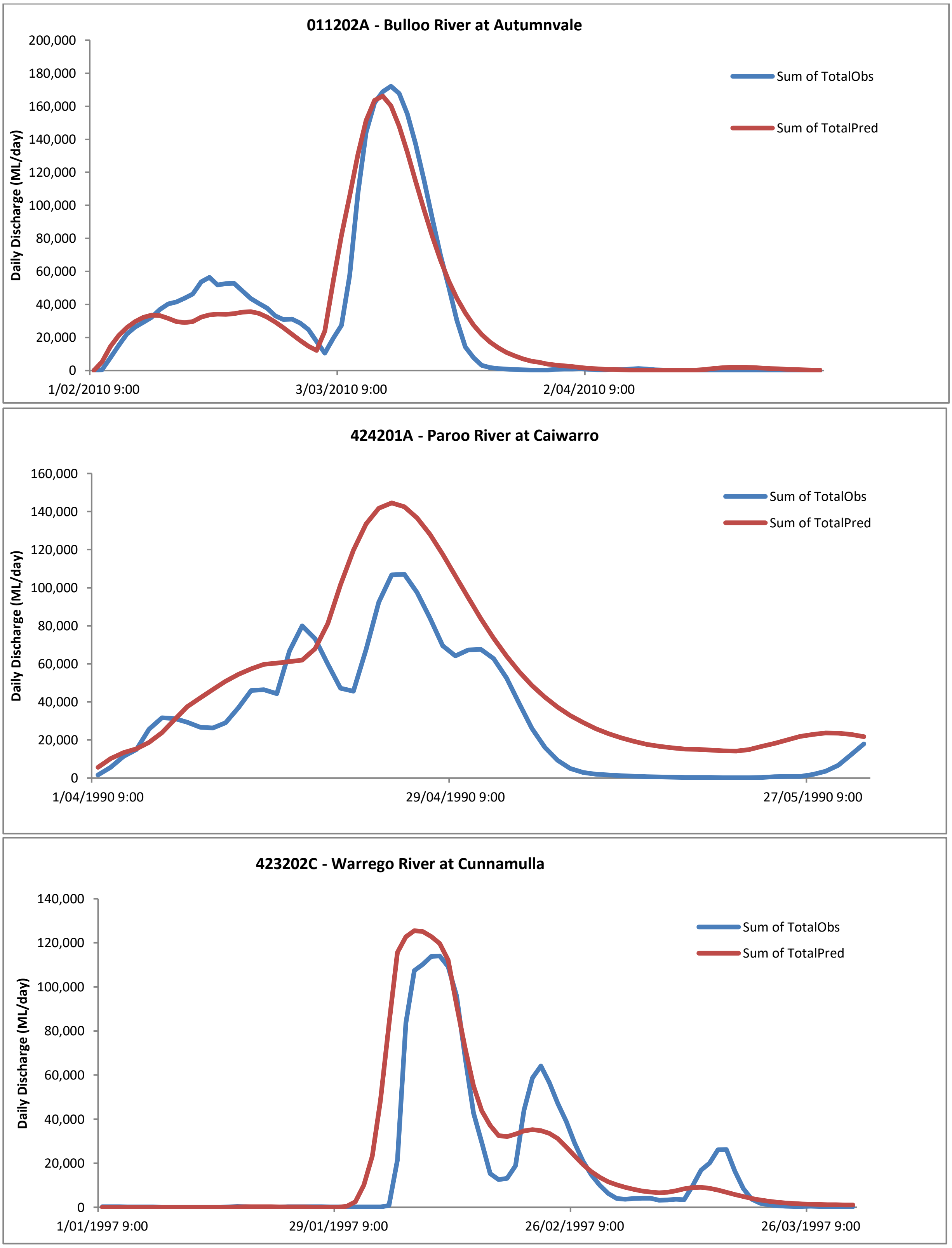


FIGURE 16 - TYPICAL CROSS VERIFICATION OF HYDROGRAPH PEAK ALIGNMENT

6.2 Load Calibration and Validation

Load calibration was undertaken through an iterative process of parameterisation of the streambank, gully and hillslope erosion components of the Source models.

Average annual and annual loads were first calculated as per equations derived in section 5.4.1. The modelled loads were then compared to the loads estimated from the observed data. Hillslope delivery ratios or gully cross sectional areas or in stream deposition rates were then adjusted up or down, the model then rerun and the process continued until modelled loads were within a sensible range for the Moriasi statistics to better align with the observed load estimates until the modelled and observed loads were deemed to be suitable from average annual and annual perspective.

The Moriasi results for TSS, TN and TP at the calibration gauges are summarised in Table 13 for the yearly comparison, with the monthly summary of sites shown in Table 27 calibration results. The yearly calibration performs equal to, or better than, the monthly calibration results in all cases.

Overall, 10% of the sites achieved a TSS calibration score of Very Good and ~65% of performance measures scored above Satisfactory for Total Suspended Solids for Moriasi results. For Total Nitrogen, 56% scored Very Good and ~43% of performance measures scored above Satisfactory for Moriasi results. For Total Phosphorus, 42% of the statistics rated as Very Good and ~57% of performance measures scored above Satisfactory for Moriasi results. Scatter plots showing predicted and observed yearly loads are presented for TSS, TN and TP in Figure 17- 34. Full Moriasi results for both monthly and yearly analysis are provided in Tables 28-29 for TSS, Tables 30-31 for TN and Tables 32-33 for TP.

TABLE 13 – MORIASI ANNUAL LOAD CALIBRATION SUMMARY

		RSR				**PBIAS**				**R^2**				**NSE Yearly**				**Total**			
Model	**Modelled parameter**	*Very Good*	*Good*	*Satisfactory*	*Indicative*	*Very Good*	*Good*	*Satisfactory*	*Indicative*	*Very Good*	*Good*	*Satisfactory*	*Indicative*	*Very Good*	*Good*	*Satisfactory*	*Indicative*	*Very Good*	*Good*	*Satisfactory*	*Indicative*
TSS	*SWNRM*	33%	33%	33%	-	-	33%	67%	-	33%	33%	33%	-	33%	33%	33%	-	25%	33%	42%	-
	CB	-	50%	17%	33%	17%	-	17%	67%	-	50%	50%	-	-	17%	50%	33%	4%	29%	33%	33%
	MNBD	-	25%	-	75%	25%	-	-	75%	-	50%	25%	25%	-	-	25%	75%	6%	19%	13%	63%
	Total	8%	38%	15%	38%	15%	8%	23%	54%	8%	46%	38%	8%	8%	15%	38%	38%	10%	27%	29%	35%
TN	*SWNRM*	67%	33%	-	-	33%	33%	33%	-	67%	33%	-	-	67%	33%	-	-	58%	33%	8%	-
	CB	33%	-	50%	17%	50%	-	17%	33%	67%	17%	17%	-	33%	50%	-	17%	46%	17%	21%	17%
	MNBD	50%	50%	-	-	25%	-	25%	50%	100%	-	-	-	100%	-	-	-	69%	13%	6%	13%
	Total	46%	23%	23%	8%	38%	8%	23%	31%	77%	15%	8%	-	62%	31%	-	8%	56%	19%	13%	12%
TP	*SWNRM*	67%	-	33%	-	33%	-	67%	-	67%	33%	-	-	67%	33%	-	-	58%	17%	25%	-
	CB	17%	17%	33%	33%	17%	17%	17%	50%	67%	-	33%	-	33%	50%	-	17%	33%	21%	21%	25%
	MNBD	25%	-	25%	50%	50%	-	-	50%	75%	25%	-	-	25%	50%	25%	-	44%	19%	13%	25%
	Total	31%	8%	31%	31%	31%	8%	23%	38%	69%	15%	15%	-	38%	46%	8%	8%	42%	19%	19%	19%

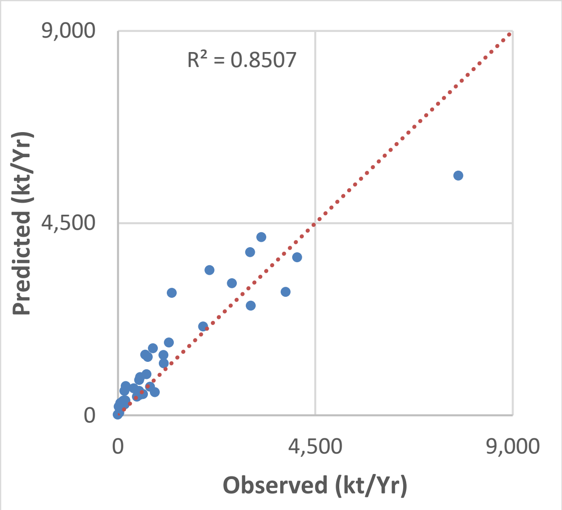


FIGURE 17 - SWNRM YEARLY PREDICTED VS OBSERVED TSS LOAD

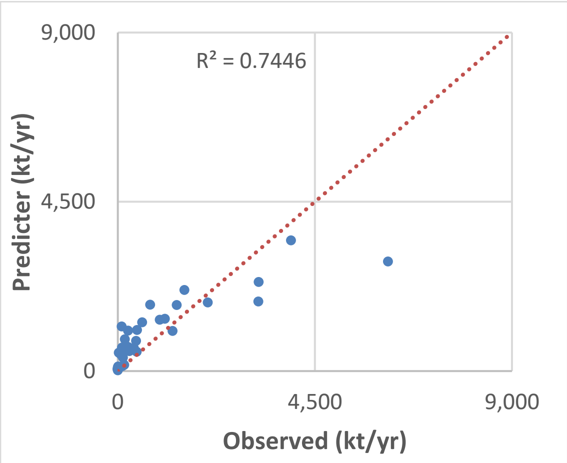


FIGURE 18 - CONDAMINE YEARLY PREDICTED VS OBSERVED TSS LOAD

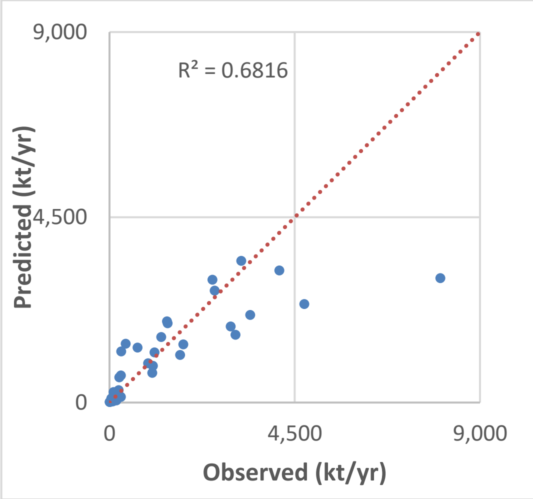


FIGURE 19 - MARANOA BALONNE YEARLY PREDICTED VS OBSERVED TSS LOAD

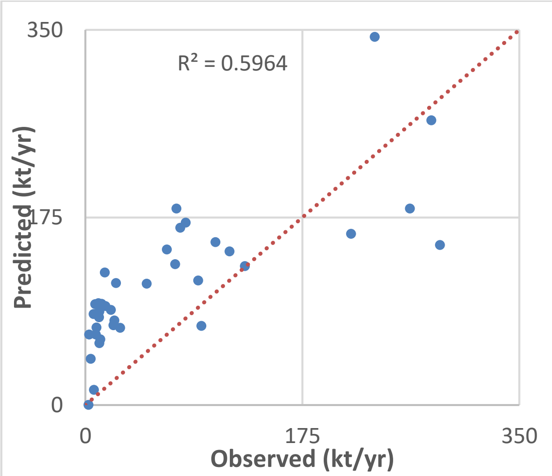


FIGURE 20 –BORDER RIVERS & MOONIE YEARLY PREDICTED VS OBSERVED TSS LOAD

Note: *"Observed" loads were derived from correlations between flow and water quality samples for TSS/TN/TP*

For SWNRM, MB and Condamine the scatter plots shown in Figure 17 - Figure 20 show a good fit between predicted and observed TSS loads with R^2 all above 0.60. Similarly for TN (Figure 21-24), R^2 are greater than or equal to above 0.87. In general the highest 6-10 events are under predicted by the model and small events are over predicted to compensate for this.

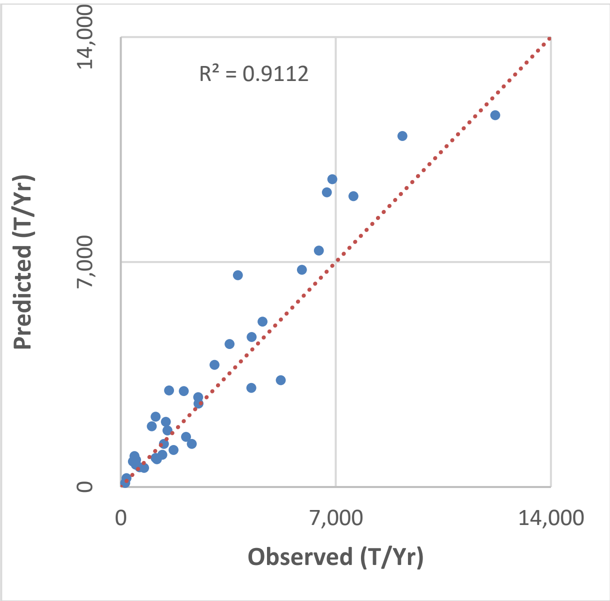


FIGURE 21 - SWNRM YEARLY PREDICTED VS OBSERVED TN LOAD

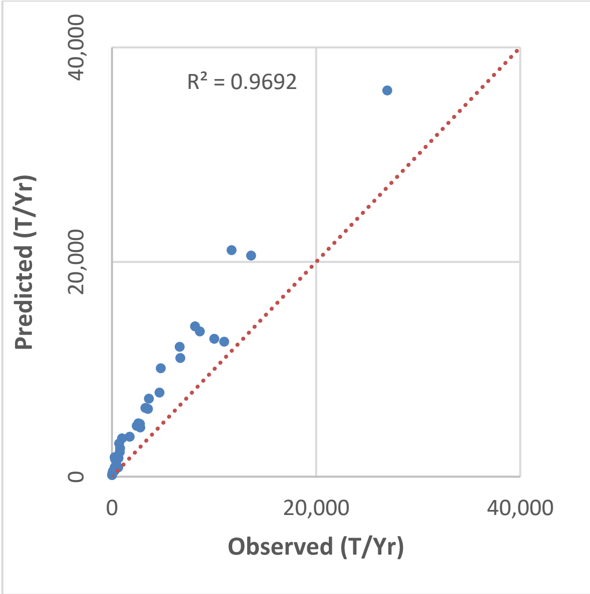


FIGURE 23 - MARANOA BALONNE YEARLY PREDICTED VS OBSERVED TN LOAD

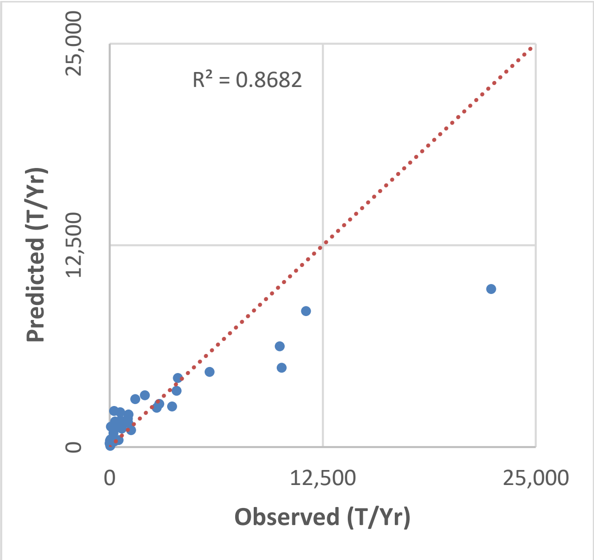


FIGURE 22 - CONDAMINE YEARLY PREDICTED VS OBSERVED TN LOAD

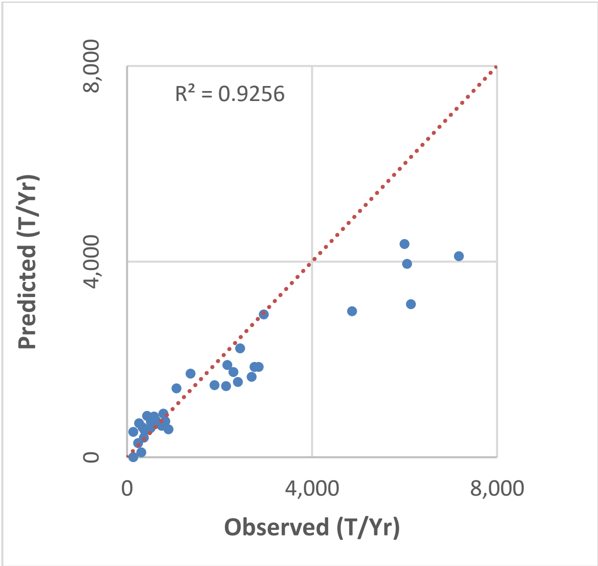


FIGURE 24 – MOONIE AND BORDER RIVERS YEARLY PREDICTED VS OBSERVED TN LOAD

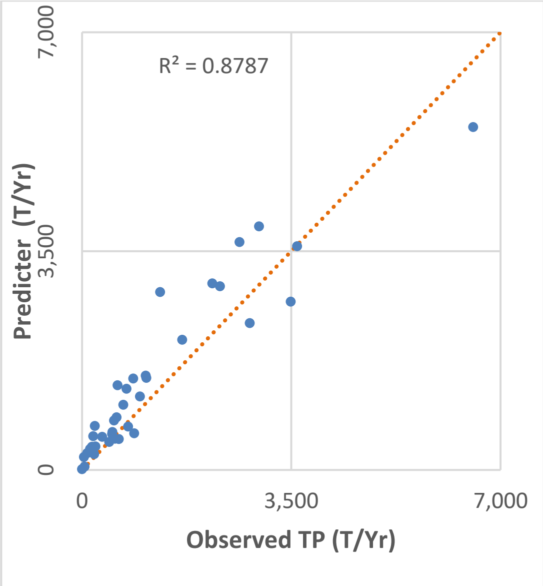


FIGURE 25 - SWNRM YEARLY PREDICTED VS OBSERVED TP LOAD

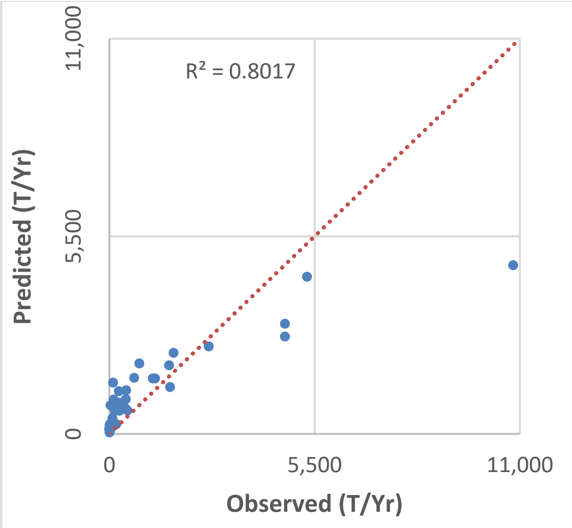


FIGURE 26 - CONDAMINE YEARLY PREDICTED VS OBSERVED TP LOAD

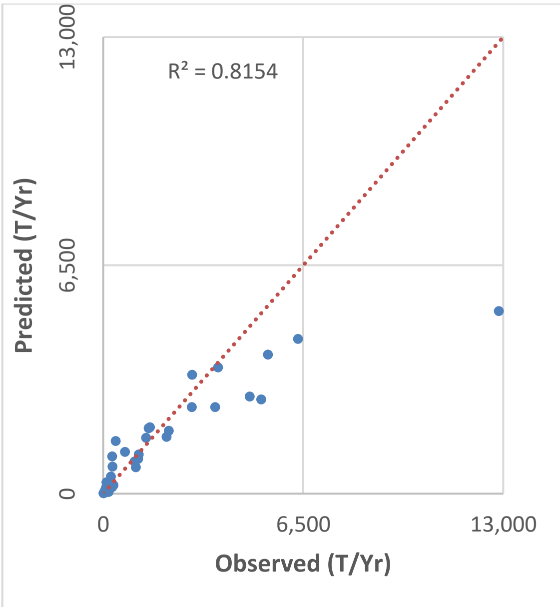


FIGURE 27 - MARANOA BALONNE YEARLY PREDICTED VS OBSERVED TP LOAD

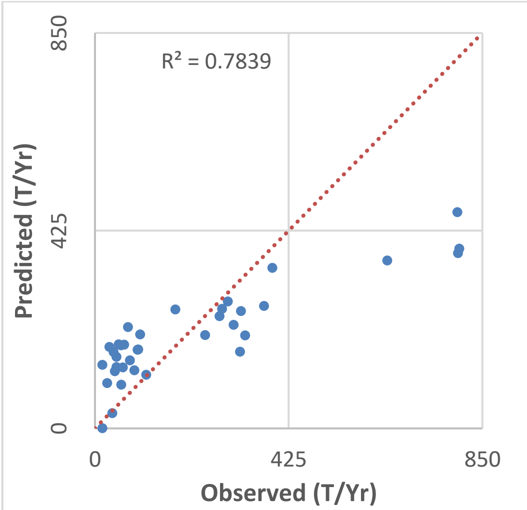


FIGURE 28 - MOONIE AND BORDER RIVERS YEARLY PREDICTED VS OBSERVED TP LOAD

The scatter plots for predicted vs observed yearly TP (Figure 25, Figure 26, Figure 27 and Figure 28) show a good fit with the R^2 values all above 0.78, however these fits were not aligned well to the one to one relationship except for SWNRM. All larger loads were under predicted, however for Maranoa Balonne, Condamine and Moonie-Border Rivers this under prediction also began at the mid to large loads, over predicting the smaller loads also in the Condamine and Moonie-Border Rivers. Given loads are a function of flow, a number of the significant large runoff events were under predicted and this was translated through into loads. The exception being TN which suggests that the input data used to generate Total Nitrogen loads may be an over estimation of the actual generation rates.

6.2.1 Average Annual and Total Load Comparison

Results for the average annual loads for TSS, TN and TP were calculated for predicted and observed (Figure 29, Figure 30 and Figure 31) respectively. Annual loads for all constituents are also provided in Tables 24-26.

6.2.1.1 Total Suspend Solids Results

Figure 29 shows the average annual predicted and observed TSS loads for each calibration gauging station for the three modelled areas. This figure demonstrates the range of total loads between the three regions, highlighting that Border Rivers/Moonie has a much a lower average annual sediment load (approx. 10% of the SWNRM and CBM models). Important to note is the small contributions for Moonie River at Flinton (417205A) and the Weir River at Talwood (416202A). The load is on average, over predicted by 45% for the Border Moonie (BDMN) Catchments models. For the CBM, the load increases as you move downstream from the uplands at Warwick (423210C) down the Condamine to Cotswold (422325A) and then Weribone (422213A) on the Balonne River. The lower loads generated from the Maranoa basin at the gauge (422404A) are evident. The Maranoa and Weribone gauges both drain into Beardmore Dam. The Culgoa gauge (422204A), is downstream of Beardmore Dam which accounts for the drop in load at Culgoa gauge. In the Condamine basin, the model over predicts the observed loads by an average of 23% with a maximum of 45% at the top gauge (423210C) down to 8% at the furthest downstream gauge in the Condamine (422325A) . For SWNRM, the model over predicts the load with the results from all three gauges within 20% of the observed load.

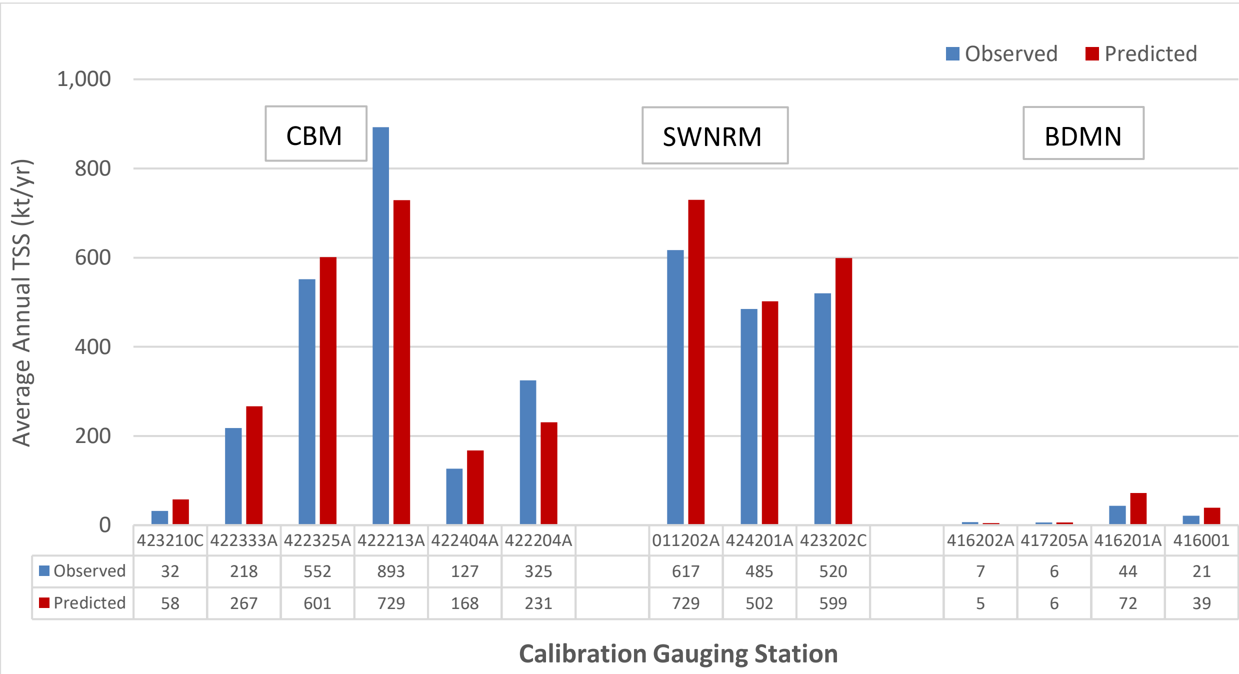
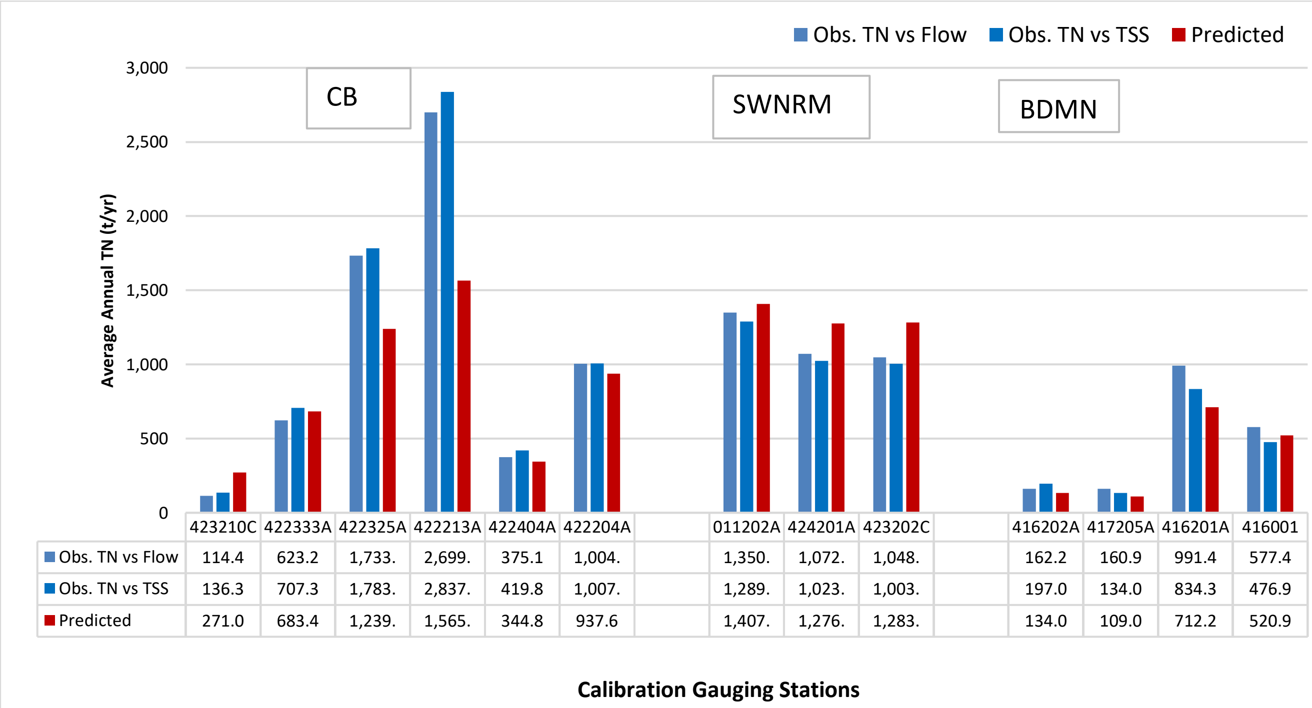


FIGURE 29 – AVERAGE ANNUAL PREDICTED VS OBSERVED TSS LOADS FOR CALIBRATION GAUGES

6.2.1.2 Total Nitrogen Results

Figure 30 summarises the average annual predicted versus observed TN loads for each calibration site. There are two observed estimates of TN, one being correlated against flow and the other against TSS concentration.

For the Condamine Balonne region, modelled TN loads were within 10% of observed for the middle section of the Condamine (422333A – Loudon Bridge) sites, and lower Balonne (422204A) and Maranoa (422404A) sites, while the model is 35% under predicting in the mid-section gauges at the end of the Condamine(422313A) and the top of the Balonne Rivers (422404A). SWNRM modelled loads were within 20% of the observed loads. For the BDMN, the model under predicted (within 30%) the TN load for three of the four load calibration gauges.

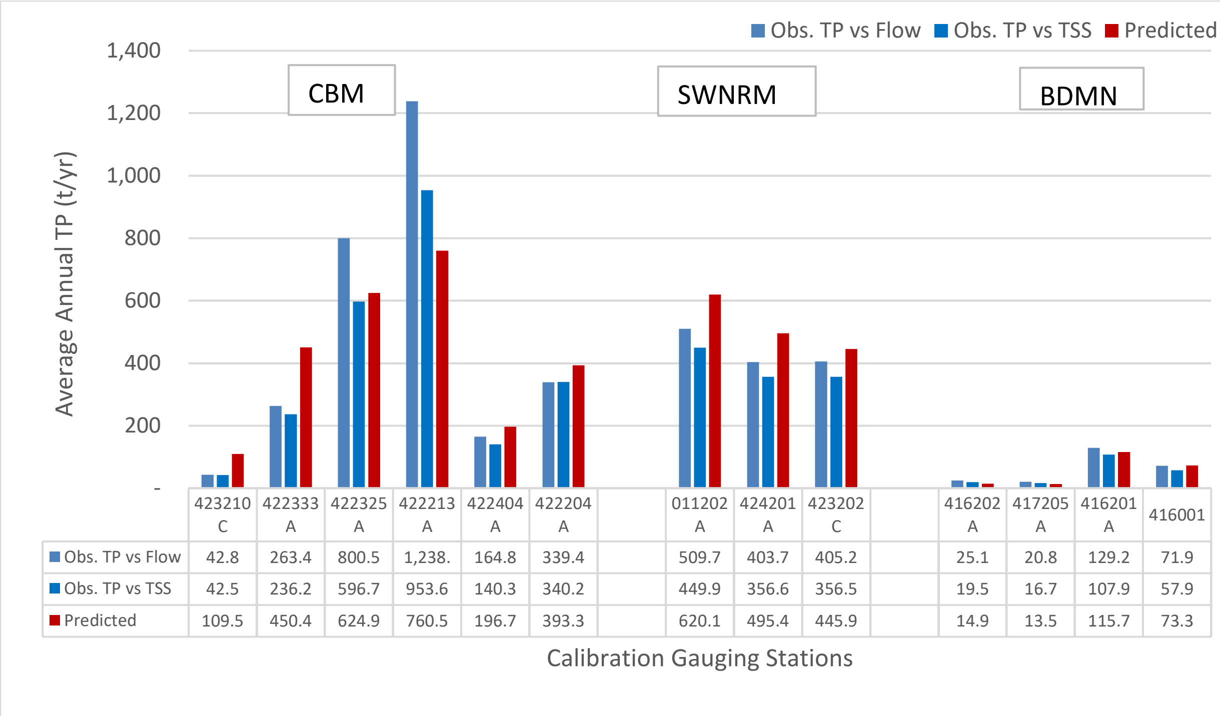


	423210C	422333A	422325A	422213A	422404A	422204A		011202A	424201A	423202C		416202A	417205A	416201A	416001
Obs. TN vs Flow	114.4	623.2	1,733.	2,699.	375.1	1,004.		1,350.	1,072.	1,048.		162.2	160.9	991.4	577.4
Obs. TN vs TSS	136.3	707.3	1,783.	2,837.	419.8	1,007.		1,289.	1,023.	1,003.		197.0	134.0	834.3	476.9
Predicted	271.0	683.4	1,239.	1,565.	344.8	937.6		1,407.	1,276.	1,283.		134.0	109.0	712.2	520.9

FIGURE 30 - AVERAGE ANNUAL PREDICTED VS OBSERVED TN LOAD AT EACH CALIBRATION GAUGE

6.2.1.3 Total Phosphorus Results

Figure 31 shows the average annual observed and predicted TP load at the calibration gauges. The pattern is very similar to TN which is not unexpected given the observed loads are correlated to the same data as TN and both are well correlated to TSS. TP was over predicted for all sites (up to 23%) in SWNRM region. For BDMN, the predicted loads range from 41% over prediction to minimum of 2% under prediction. For CBM, TP loads were over predicted. Loads at the top of the Condamine (423210C-Warwick and 422333A – Loudon) and the Lower Balonne (422204A – Culgoa) and Maranoa (422404A – Cashmere) sites. The lower Condamine (422325A – Cotswold) occurs at the lower end the observed range, and Upper Balonne (422213A – Weribone) under predicts. Overall the difference for CBM was around 50%.



	423210C	422333A	422325A	422213A	422404A	422204A		011202A	424201A	423202C		416202A	417205A	416201A	416001
Obs. TP vs Flow	42.8	263.4	800.5	1,238.	164.8	339.4		509.7	403.7	405.2		25.1	20.8	129.2	71.9
Obs. TP vs TSS	42.5	236.2	596.7	953.6	140.3	340.2		449.9	356.6	356.5		19.5	16.7	107.9	57.9
Predicted	109.5	450.4	624.9	760.5	196.7	393.3		620.1	495.4	445.9		14.9	13.5	115.7	73.3

FIGURE 31 - AVERAGE ANNUAL PREDICTED VS OBSERVED TP LOAD AT EACH CALIBRATION GAUGE

6.2.2 Catchment Loads Results

Table 14 shows the constituents exported as a total load and on a per hectare basis. For CBM, Balonne has the largest export of TN, TP and TSS and both Condamine and Maranoa loads are significantly less. This can be explained by the fact that the Condamine, and Maranoa drain into the Balonne catchment above Beardmore dam (Figure 1), thus the load exported from the outlet of the Maranoa catchment includes runoff and loads from the Condamine and Maranoa system.

For the BDMN model, the Border Rivers catchment has a higher export for TSS, TP and TN than the Moonie catchments. For the SWNRM model the catchment exports loads from the lowest for TSS, TP and TN, to the highest respectively are Nebine, Warrego, Paroo and Bulloo. It is interesting to note that for BDMN the TN exported load is around 10 times of that TP, whereas for CBM and SWNRM the ratio of TN export is only around three times greater than the TP export.

TABLE 14 - EXPORT CONSTITUENTS LOADS BY CATCHMENT

Model	Catchment	TSS (kt/yr)	TN (t/yr)	TP (t/yr)
CBM	Balonne	189	1805	1634
	Condamine	560	1177	590
	Maranoa	149	309	174
BDMN	Border Rivers	49	1001	127
	Moonie	5	143	17
SWNRM	Bulloo	874	1755	832
	Nebine	58	111	47
	Paroo	326	913	342
	Warrego	310	727	254
	Total	**2,520**	**7,941**	**4,017**

6.2.3 Sediment Budget for TSS

The model is able to track sediment and nutrient sources and sinks to create a sediment budget. Table 15 summarises the components of the sediment budget as a proportion of the total load exported for each major basin in the QMDB. Hillslope erosion has the greatest percentage contribution of sediment in the Border Rivers catchment and the lowest in the Balonne catchment. For gully contribution, the highest is Moonie and lowest is the Condamine, and for Streambank, the highest relative contribution is from the Condamine and lowest from Moonie catchments.

TABLE 15 – TSS SEDIMENT BUDGET AS A PROPORTION (%) OF TOTAL EXPORT

	QMDB	Condamine	Balonne	Maranoa	Border River	Moonie	Bulloo	Nebine	Paroo	Warrego
Channel Remobilisation	1	1	1	2	1	2	0	0	1	1
Gully	42	19	53	60	20	73	32	45	44	27
Hillslope	18	14	7	13	39	23	10	14	26	17
Streambank	37	66	32	24	37	2	57	41	29	46
Undefined	2	0	7	0	3	0	0	0	0	9

6.2.4 Land use Loads

Figure 32, Figure 33, Figure 34 show the breakdown of the contribution to total export by landuse.

The contribution from grazing is the largest contribution to export for TSS for BDMN and SWNRM catchments (~40-80% respectively) while cropping is the greatest percentage of TSS load exported for the Condamine Balonne and Maranoa catchments (~20%). The per unit area contribution by landuse is also provided in Table 34.

The contribution from grazing is the largest for TN and TP SWNRM catchments (>80%) while cropping is the greatest percentage of TN and TP loads exported for the Condamine Balonne and Maranoa catchments and Moonie Border River catchments (>20% in both).

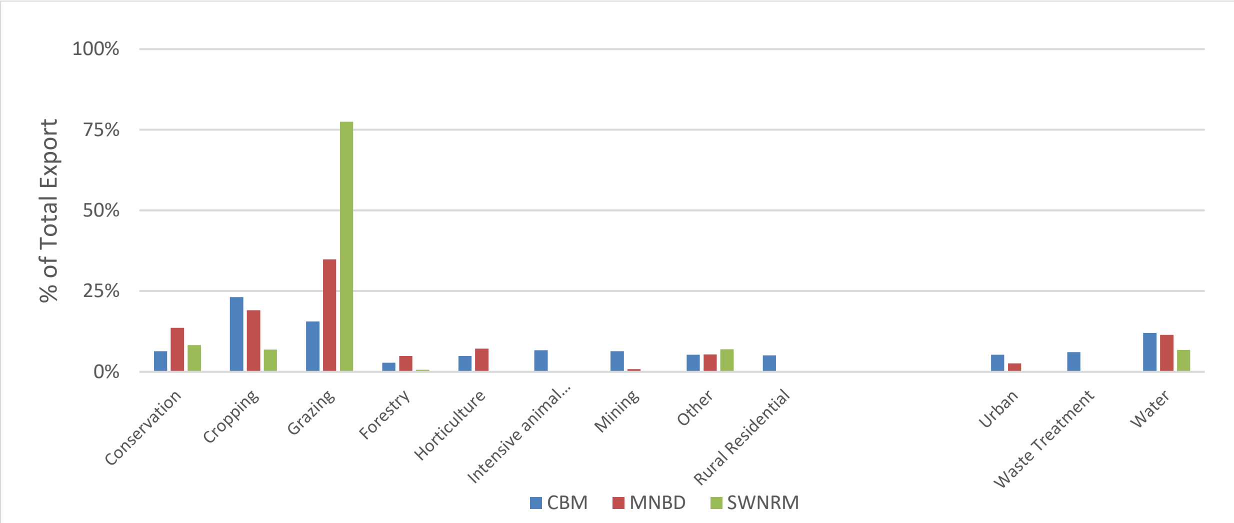


FIGURE 32 – TSS CONTRIBUTION TO EXPORT BY LANDUSE

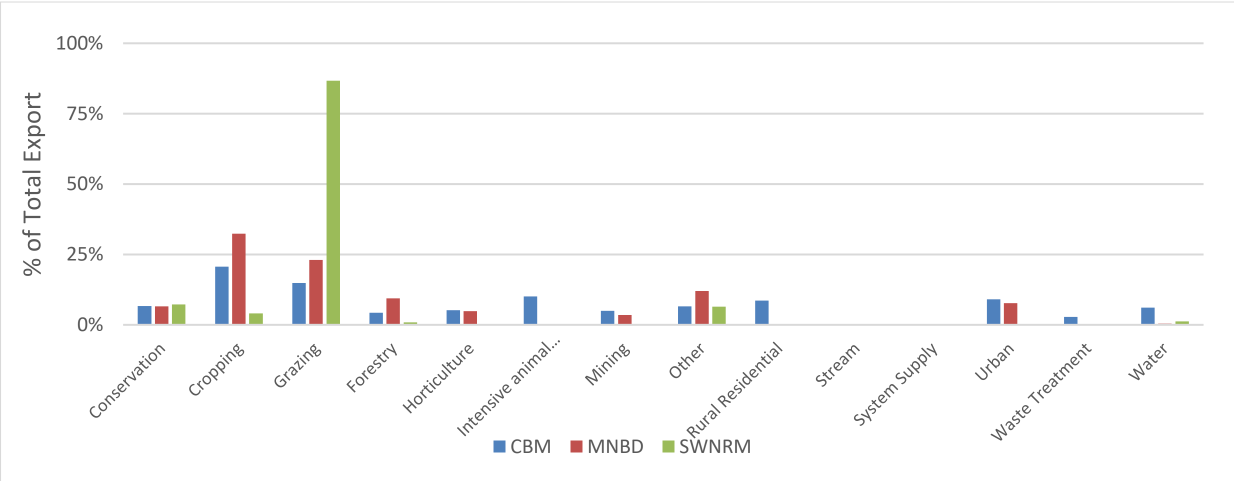


FIGURE 33 – TN CONTRIBUTION TO EXPORT BY LANDUSE

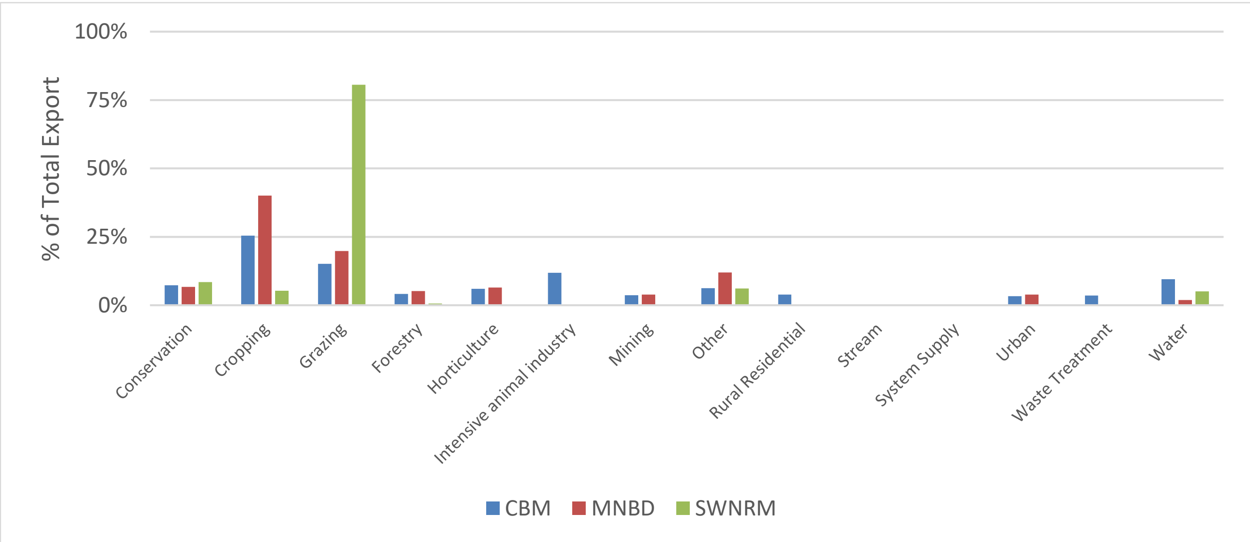


FIGURE 34 – TP CONTRIBUTION TO EXPORT BY LANDUSE

6.2.5 INDEPENDENT VALIDATION

Figure 36 and Figure 35 show the modelled and independent grab sample concentrations plotted for 2015-2016 at Mungindi (416001). These preliminary results are very encouraging and suggests that the predicted TSS concentrations for the 2016 event are showing good agreement with the modelled TSS concentrations particularly at higher TSS concentrations greater than 200 mg/l.

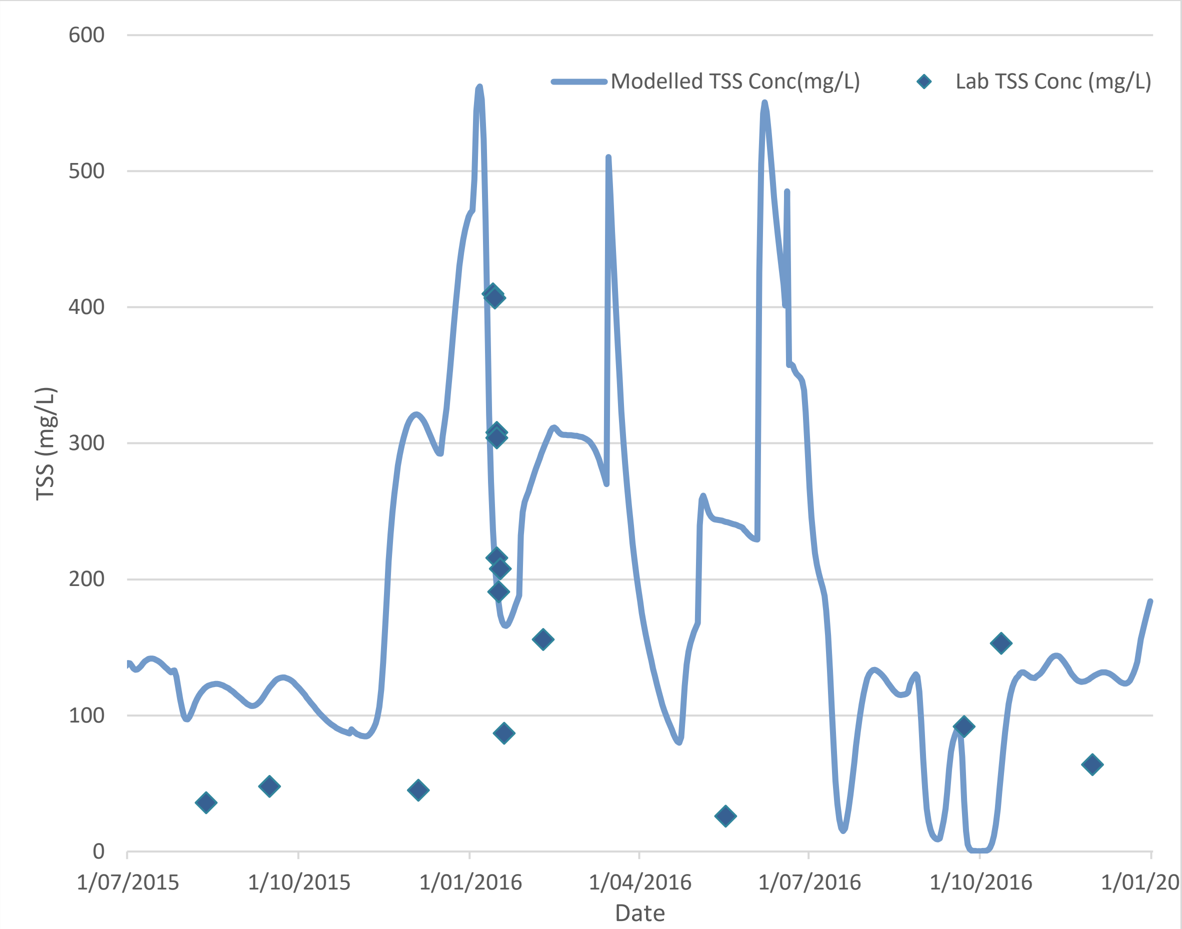


FIGURE 35 – COMPARISON OF LABORATORY SAMPLES AGAINST MODELLED TSS CONCENTRATION AT MUNGINDI FOR THE PERIOD JULY 2015 TO JANUARY 2017

Grab samples of TP and TN are generally half the modelled concentrations (Figure 36). Both TN and TP again follow the similar trend over an event and the model follows the drop (01/01/16) on the falling stage of the hydrograph during the event. The modelled and observed concentrations are variable although tend to suggest that during event flows the model is over predicting concentrations. However the results are encouraging given the model is within an order of magnitude of the measured concentrations. Further work is now required to investigate why the model is over predicting. The result could be due to overestimation of the hillslope generation loads or potentially the input layer for TN and TP in the gully and streambank models may have been derived from limited field data. Future work needs to investigate the results further.

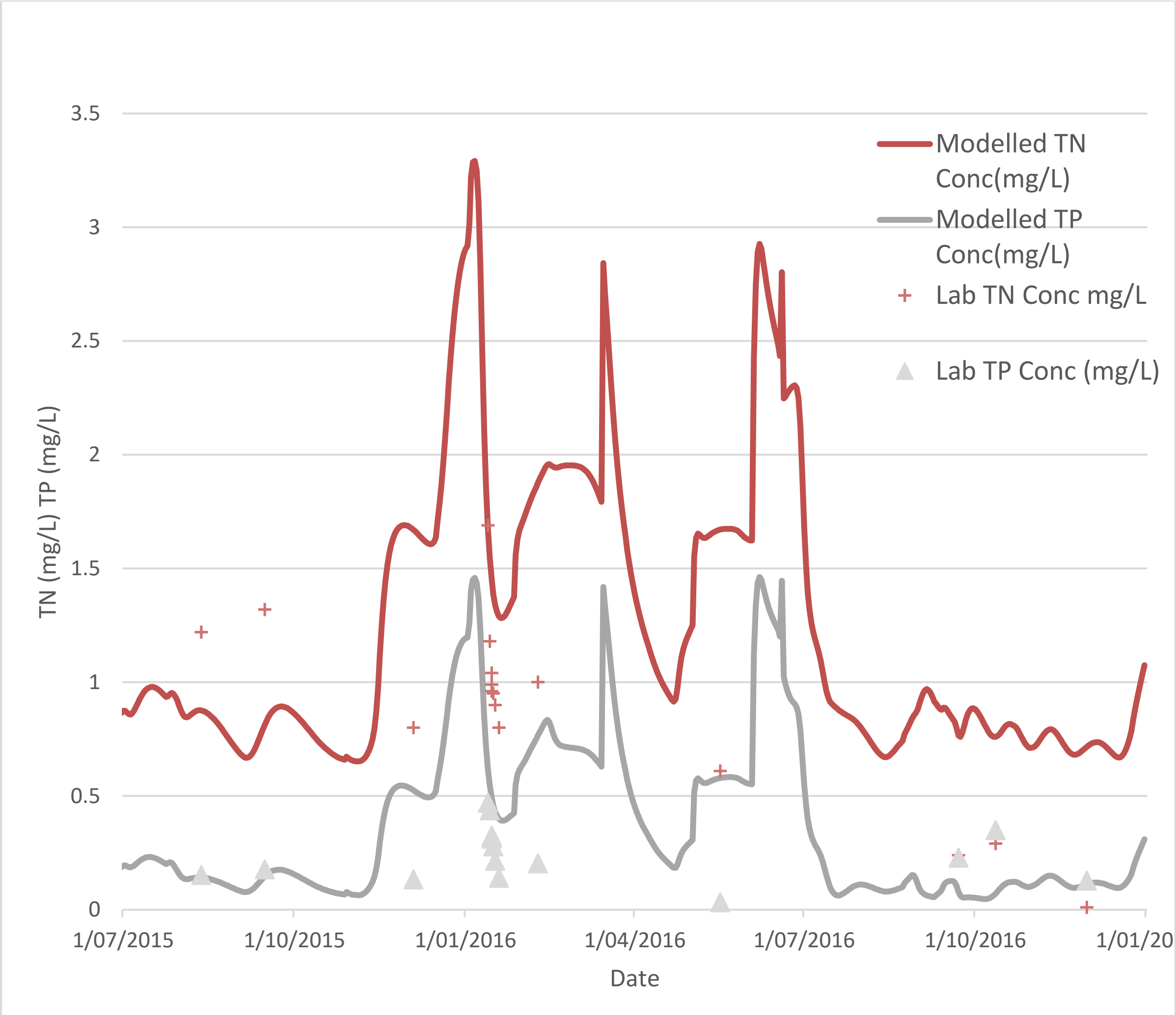


FIGURE 36 – INDEPENDENT TN AND TP LABORATORY SAMPLES AGAINST MODELLED TN AND TP CONCENTRACTION AT MUNGINDI

7 DISCUSSION

7.1 HYDROLOGY

The hydrology calibration produced a high quality calibration when assessed against Moriasi (2007, 2015) performance criteria with 36 of the 37 gauges calibrated within ±5% of observed flow. The hydrology calibration was a significant improvement on the models previously created by Waters (2008). In the EMSS QMBD model, predicted flows were ±33% using SIMHYD and only 7 of the 14 gauges calibrated met both the required performance measures (Waters, 2006). The monthly NSE values were generally rated as very good with average monthly NSE values averaging 0.87, 0.81 and 0.84 for CB, SWNRM and BDMN respectively.

Where poorer calibrations were achieved it was generally due to the large distances between gauges. For example, in the SWNRM in Warrego where the Ward River joins the Warrego below Charleville there were calibration issues. This was also present in the CBM at the Weribone gauging station where there is a 300km stretch of river between calibration sites with multiple tributaries joining. Even though the calibration process utilised the latest techniques to best fit the hydrograph timing this section was problematic. In the Border Rivers, the issues were more associated with headwater gauges, especially capturing the flows off the areas of granite country. One potential source of uncertainty is due to the highly variable rainfall along the elevated ridges of the Border Rivers where there may be a lack of rainfall gauges to adequately capture the variability.

The final issue was at Mungindi gauging station in the Border Rivers where the Macintyre River joins the Weir River and through the braided section of river after Goondiwindi. This may be attributed to the highly variable flow path of runoff depending on the discharge with multiple break out areas at difference flow stages.

Representing pollutant movement through the braided stream networks such as the low lying areas of the Warrego, Balonne, Border Rivers and the Condamine catchments, created some challenges in the current Source configuration. Losses from one section of the river had to be reflected as an inflow in adjacent drainage lines where it was known that a break out occurred into an adjacent stream above a certain discharge. This approach was necessary at a number of locations to maintain a mass balance. In future modelling, a new plug in could assist or an alternative approach such as aggregation of these areas into a single catchment may result in an easier model build and less complexity in constituent load calculation.

7.2 MODELLED CONSTITUENT LOADS AND VALIDATION

7.2.1 CONSTITUENT LOAD CALIBRATION AND VALIDATION

Having limited water quality data to calibrate a model for such a large area was challenging although not an uncommon problem in the water quality area. Calibration of the model therefore required a relationship to be derived between the available sample data and flow which was then used to build a long-term average annual load estimate.

The loads derived from historical measured data provided a useful reference dataset to calibrate against. However, a low number of samples for high flow events introduces possible errors in the relationship. Collecting further samples over the range of the hydrograph may result in greater confidence in the measured load estimates. Overall, the Log-Log relationships provided a satisfactory method to calculate an “observed” set of constituent loads. This was used to enable the comparison of the predicted loads and provided a satisfactory calibration in areas where there is limited reference data to calibrate loads against. This however does not preclude a complete set of reference water quality data to calibrate against when one is available.

Comparing modelled concentrations to the independent samples (Figure 35 and Figure 35), was very encouraging and suggests that the model is doing a reasonable job of load prediction as a first approximation.

When deriving the TSS concentration and flow relationship there were almost double the number of samples available compared to the number of TN and TP samples to derive the correlations(CBM TSS had ~1800 samples, TP had ~1000 samples) (also refer Table 9 and Table 10). The greater number of samples available to derive the TSS vs flow correlation gave greater confidence in the estimate for TSS compared to TN and TP estimates.

The results identified larger discrepancies between predicted and observed loads for event years. Predicted results were in line with the observed loads for average rainfall years. In the absence of TSS and nutrient data at very high flows ideas on how to “cap” the load were tested including setting an upper limit on the TSS concentration. The rationale being that sediment concentrations can often reach a maximum as flow increases which can be attributed to sediment exhaustion from the catchment. To reflect this, a polynomial relationship was used which allowed the concentration of the TSS to flatten off at higher flows (Figure 11).

In previous work in SWNRM catchments (Waters, 2008) it was noted that TSS was well correlated to both TN and TP. This relationship was investigated further for datasets outside of SWNRM and the method was repeated for all regions (Figure 30 and Figure 31 respectively) to provide an alternative estimate of loads at gauges. The loads derived from TSS/TN and flow/TN were similar. For TSS/TP however the result was markedly different to the flowTP in the CBM with FlowTP being ~20% higher than the TSS/TP relationship. This result occurred in the section of river at Chinchilla gauge (Figure 1). In this area there is extensive cropping suggesting that fertiliser inputs may have influenced the correlation between flow and constituents potentially. Further down the Balonne system where grazing dominates the load estimates using TSS and flow and TSS vs TN and TSS vs TP were much more closely aligned.

The modelled hillslope/gully/streambank erosion proportions seem credible when compared to modelled contributions in the Fitzroy Basin (McCloskey, 2017). The Fitzroy was used for comparison due to its relative similar range of land uses, climate and size as the QMDB catchment. The Fitzroy’s sediment loads were 29% from hillslope, 52% from gully and 19% from streambank erosion, with the QMBD relative contributions being 18% from hillslope, 42% from gully, 39% from streambank.

One observation from the modelled load estimates is the contrasting loads exported for each of the basins. The difference between generation rates of sediment between relatively similar areas of CBM (3.5 kg/ha) and BDMN (0.3 kg/ha) with both having similar climatic conditions and land uses may be explained by the differences in runoff between the two regions and secondly, the low TSS concentrations of samples collected in the BDMN. The runoff from the upland areas of the Border Rivers make up around 40% of the BDMN catchment, while the majority of the CBM is flat with close connectivity to the river from cropping lands. The flow from BDMN (600,000 ML/yr) exhibits lower sediment concentrations than the CBM due to its more natural environment of forestry and nature conservation in the uplands areas. Runoff from the CBM (1,400,000 ML/y) includes greater areas of agricultural and grazing activity. Further event water quality data collected in each of these specific landuses and targeting event runoff will enhance the ability of building relationships to validate model predictions.

In relation to the overall load calibration results (Table 13) the results suggest that TN and TP estimates generated better Moriasi statistics than TSS. This could be partly due to the fact that the Moriasi (2015) assessment criteria require TSS estimates to be closer to the observed load than nutrients when determining the performance rating.

7.2.2 Contribution by land use and source

The contribution of sediment and nutrients by land use are similar to the findings for previous models (Waters, 2006 and 2008). Similar results were found for the Fitzroy catchment (McCloskey, 2017) with comparative load contributions generally following landuse, grazing followed by cropping. Fitzroy is used for comparison to the QMDB due to its relatively similar range of land uses, rainfall and area.

Interestingly in the calibration of the loads along the Condamine catchment into the Balonne, the calibration for TP and TN align well in the upper part of the Condamine catchment at Warwick and Loudon Bridge gauging stations, but dramatically underestimate the load further downstream at Cotswold and Weribone calibration sites. Further investigation should be undertaken to identify why the model is underestimating in this area, or event samples to bolster the TN and TP vs discharge relationship used to create the observed flow. This may require further data collection for the lower end of the Balonne system, including gauging stations observing flow in this 300km stretch of river.

7.2.3 Comparison with Great Barrier Reef Paddock to Reef modelling

Comparing the GBR WQ models (McCloskey, 2017) to the QMDB modelled output allows some context be given to the model outputs. Table 36 shows the comparison of Constituent export loads to average annual flow and area of the catchments. For example when comparing the Fitzroy to Warrego, Paroo and Bulloo TSS export per unit area are similar whilst loads exported from the Balonne are approximately a quarter of the load per unit area of the Fitzroy basin. The other notable factor is that QMDB flows are less than a quarter of the annual flows of the GBR basins.

7.2.4 Independent Data Validation Over an Event

The model predictions are encouraging when comparing sediment and nutrient concentrations from the model to an independent set of water quality samples collected at one gauging station in the Border Rivers at Mungindi (Figure 35 and Figure 36). The modelled concentrations were within 100% of the measured concentrations which is extremely encouraging considering the hillslope/gully and streambank models were all originally developed as an average annual erosion model and were never intended to be used at a daily timestep. The TSS modelled concentrations aligned well with the grab samples for higher flows and underestimated the results at low flows. Given the majority of the sediment is transported in higher flows this allows for a good approximation by the model for TSS loads.

In addition, given TSS is aligning well at high flows and TN &TP correlate well to TSS (Table 10), suggests that the modelling approach used to estimate TN and TP may require further investigation. The model results are very encouraging and further investigation is warranted into the input data behind the particulate nutrient generation models at high flows. It has been previously reported by McCloskey et al. (2017) that the subsurface nutrient data sets used as an input data set to the model may be too low.

8 CONCLUSIONS

The project was successful in collating the range of water quality data sets collected across the basins and deriving flow and concentration relationships. The data was then used to derive the most up to date estimates of catchment loads. A catchment water quality model was successfully built.

The model has been used to estimate constituent loads for the QMDB drawing on the latest modelling methods. This model provides improved estimates of sediment and nutrient loads compared to the previous model estimates in particular due to the advances made in hydrology calibration approach and the representation of the dominant erosion process namely hillslope, gully and streambank erosion. The method described in this report provides an alternative approach of deriving load estimates to calibrate a water quality model in areas where there is limited water quality data.

The modelling exercise has also provided an additional benefit to assist in the development of water quality guidelines by the Queensland Government in parts of the basin where data is not available.

This method provides a way forward to model sediment loads in data poor catchments. With further refinement and additional event data collection, the model can be used to inform where on ground works should be implemented and to priorities future research.

9 FUTURE RECOMMENDATIONS

Future effort to improve the model should focus on regionalisation of the constituent generation parameters. For example delivery ratios could be derived regionally based on local soil attributes. Similarly for gully and stream bank geometry. With limited desktop analysis regionalised parameters could be derived to improve spatial representation of sediment and nutrient generation processes.

The flow to TSS/TN/TP relationships can be significantly improved by assessing existing data collected at gauging stations and targeting specific flow ranges where data is currently limited at each of the calibration sites. This will do two things to improve the relationship. Firstly, allow for a better understanding of the loads generated in high flows versus low flows as well as improve the understanding of how concentrations vary on rising and falling limbs of the hydrograph at a site. Secondly, targeting landuse specific areas such as upland grazing and intensive cropping areas along the lower Condamine River will greatly enhance the spatial calibration of loads for specific industries.

10 References

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

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

(DNRM) Department of Natural Resources and Mines (2003), (includes Bulloo, Warrego, Paroo) River System Hydrology Report- Volume 1. Internal Report

Doherty, J (2009), *PEST: Model-Independent Parameter Estimation, User Manual: 5th Edition*, Watermark Numerical Computing, Brisbane.

DPI (1978). Western Arid Region Land Use Study – Part IV. Queensland Department of Primary Industries. Technical Bulletin No. 23

Ellis, R, Doherty, J & Searle, R (2009), "Applying parameter estimation and prediction uncertainty analysis to WaterCAST water quality models", *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences*, eds. R.S. Anderssen, R.D. Braddock & L.T.H. Newham, Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics, Cairns, July.

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

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

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

Li, Y., Migliacio, K., (2010) Water Quality Concepts, Sampling and Analyses. CRC Press (ISBN 9781420092677)

Lyne, V. & Hollick, M. 1979, "Stochastic time variable rainfall-runoff modelling", Proceedings of the Hydrology and Water Resources Symposium, Perth, 10-12 September, Institution of Engineers National Conference Publication, No. 79/10, pp. 89-92

McCloskey, G.L., Waters. D., Baheerathan, R., Darr, S., Dougall, C., Ellis, R., Fentie, B., Hateley, L. (2017). Modelling pollutant load changes due to improved management practices in the Great Barrier Reef catchments: updated methodology and results – Technical Report for Reef Report Cards 2015, Queensland Department of Natural Resources and Mines, Brisbane, Queensland.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., Veith, T. L. (2007) Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. Transactions of the ASABE, Vol. 50(3) 885-900.

Moriasi, D. N., Gitau, M. W., Pai, N., Daggupati, P., (2015) Hydrologic and Water Quality Models: Performance Measures and Evaluation Criteria, *Natural Resources & Environmental Systems Community of ASABE*, Vol. 58(6): 1763-1785

MDBA, (2017) What's in the Basin Plan? https://www.mdba.gov.au/basin-plan/whats-basin-plan accessed 31/10/2017

Qld Government (2017) *Soils data*, https://www.qld.gov.au/environment/land/soil/soil-data accessed 2/10/2017

Qld Department of Natural Resources and Mines (2016) *Queensland Government Water Monitoring Information Portal*, https://water-monitoring.information.qld.gov.au/ accessed 2/1/2016

QLUMP – Queensland Department of Natural Resources and Mines website (accessed 22nd January, 2016) Queensland Land Use Mapping Program Background, Department of Natural Resources and Mine https://www.qld.gov.au/environment/land/vegetation/mapping/qlump-background/#

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

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

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

Silo - Queensland Department of Natural Resources. (2004). The SILO Data Drill. Department of NRM. Available from http://www.nrm.qld.gov.au/silo/datadrill/datadrill_frameset.html

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

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

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

Waters, D. (2006). Application of the EMSS water quality model for the Queensland Murray Darling catchment -Assessing the impacts of on-ground works. Technical Report of the Water Quality State-level Investment Project. Brisbane: Queensland Government - National Action Plan for Salinity and Water Quality.

Waters, D. (2008) Water Quality monitoring and E2 modelling in the South West NRM region, Queensland – Technical Report for South West NRM

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

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

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

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

11 APPENDICES

11.1 PARAMETERS ADOPTED IN SACRAMENTO MODEL

TABLE 16 - SACRAMENTO PARAMETERS FOR MOONIE AND BORDER RIVERS

	Border Rivers & Moonie													
Parameter	**417205A**	**417204A**	**417201B**	**416415A**	**416204a**	**416202a**	**416201a**	**416012**	**416011***	**416010***	**416008***	**416007***	**416006***	**416001***
Uztwm	1.30E+02	1.78E+02	1.44E+02	1.29E+02	9.43E+01	6.81E+01	8.81E+01	1.78E+02	1.33E+02	1.36E+02	1.00E+02	4.64E+01	1.62E+02	7.68E+01
Uzfwm	9.86E+01	1.13E+02	4.54E+01	2.80E+01	8.19E+01	1.47E+02	4.42E+01	2.35E+01	3.27E+01	1.74E+01	2.23E+01	6.25E+01	2.99E+01	5.99E+01
Uzk	1.01E-01	1.21E-01	2.26E-01	2.99E-01	8.84E-01	1.79E-01	7.78E-01	3.18E-01	2.79E-01	5.19E-01	1.95E-01	2.96E-01	5.68E-01	2.22E-01
Zperc	1.29E+00	7.71E+01	1.52E+02	5.20E+01	3.15E+02	1.33E+01	3.98E+02	2.93E+01	1.90E+01	1.02E+00	1.41E+00	1.50E+01	1.07E+00	2.47E+01
Rexp	1.77E+00	4.31E+00	2.01E+00	2.49E+00	2.42E+00	2.28E+00	4.69E+00	1.88E+00	1.98E+00	4.07E+00	1.70E+00	2.84E+00	5.23E+00	2.34E+00
Pctim	2.55E-04	1.68E-04	4.38E-04	9.27E-03	2.33E-05	6.36E-04	3.85E-05	9.28E-04	1.19E-02	6.41E-03	1.15E-02	1.19E-03	2.05E-02	3.40E-04
Sarva	8.19E-03	8.94E-04	3.24E-02	7.18E-05	2.30E-04	2.06E-02	1.43E-04	4.49E-04	8.88E-05	5.41E-03	3.40E-04	2.56E-03	2.01E-04	5.22E-07
Ssout	5.53E-03	6.44E-04	1.23E-02	4.28E-05	4.65E-06	2.28E-05	3.69E-03	1.71E-03	9.66E-04	4.18E-05	7.11E-02	1.00E-02	1.72E-06	1.67E-04
Adimp	1.61E-02	2.02E-03	5.98E-03	2.36E-03	8.63E-03	2.82E-04	3.74E-02	7.55E-04	1.36E-03	8.62E-06	5.67E-02	8.14E-04	9.80E-06	1.13E-04
Pfree	2.08E-01	3.74E-02	9.08E-02	6.48E-02	4.75E-01	1.27E-01	3.20E-02	6.43E-02	1.48E-01	9.41E-02	3.80E-01	2.76E-01	2.19E-02	6.54E-02
Lztwm	1.00E+01	1.00E+01	4.22E+01	1.00E+01	1.01E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01
Lzfsm	2.60E+01	5.30E+01	1.92E+02	2.93E+01	4.67E+00	1.75E+01	1.14E+01	1.96E+01	4.11E+01	1.41E+02	6.45E+01	1.27E+01	1.78E+02	7.71E+00
Lzfpm	1.00E+02	4.78E+00	1.10E+01	1.37E+01	9.75E+00	9.20E+00	3.88E+00	1.97E+01	4.98E+01	1.54E+02	9.77E+01	2.11E+01	1.29E+02	3.05E+00
Lzsk	1.25E-01	1.19E-03	1.92E-03	1.00E-03	3.39E-02	6.78E-03	5.48E-01	1.20E-02	5.40E-03	3.19E-02	5.36E-02	1.69E-01	3.72E-02	4.37E-01
Lzpk	1.89E-03	8.69E-02	2.45E-02	3.91E-02	1.86E-01	5.89E-01	1.07E-02	1.72E-02	1.86E-02	3.03E-03	2.30E-03	7.67E-02	1.62E-02	6.40E-02
Rserv	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01
Side	2.87E-04	2.61E-03	1.08E-03	1.54E-04	1.94E-03	1.77E-04	1.20E-03	1.58E-04	2.08E-03	1.36E-04	1.15E-06	1.82E-03	4.11E-03	7.58E-04
lagUHmodifier	1.58E-05	4.22E-06	6.54E-06	1.10E-04	3.29E+00	5.55E-07	2.97E+00	6.17E-04	6.35E-04	2.53E-05	8.87E-09	2.52E-05	1.04E-03	5.27E-02
RoutingPower	6.80E-01	1.00E+00	8.82E-01	8.13E-01	6.08E-01	8.89E-01	6.13E-01	7.97E-01	7.65E-01	9.05E-01	7.63E-01	6.48E-01	6.62E-01	7.98E-01
regionalConstant	1.21E-07	8.95E+04	6.87E+02	9.06E-13	4.94E-02	4.63E+01	4.52E+05	1.98E+04	4.64E-11	1.86E+03	2.88E+05	3.84E+02	1.27E+03	9.12E+00

TABLE 17 - SACRAMENTO PARAMETERS FOR SWNRM

Parameter	SWNRM									
	011202A	011203A	422501A	422502A	423202C	423203A	423204A	423205A	423206A	424201A
Uztwm	4.98E+01	7.66E+01	1.14E+02	1.04E+02	1.56E+02	1.80E+02	1.32E+02	1.07E+02	1.47E+02	7.07E+01
Uzfwm	1.53E+02	5.06E+01	2.93E+01	5.73E+01	1.11E+01	1.51E+02	8.87E+01	6.70E+01	6.39E+01	1.48E+02
Uzk	1.01E-01	1.60E-01	3.39E-01	2.26E-01	3.67E-01	4.48E-01	2.79E-01	1.14E-01	1.45E-01	1.25E-01
Zperc	1.00E+00	1.77E+01	2.05E+02	2.58E+01	9.69E+01	7.11E+01	1.21E+02	4.85E+00	2.49E+02	4.74E+00
Rexp	1.62E+00	2.38E+00	1.64E+00	1.85E+00	1.87E+00	1.06E+00	3.44E+00	2.45E+00	1.40E+00	1.00E+00
Pctim	2.33E-03	9.67E-02	2.35E-04	1.16E-03	2.81E-03	1.72E-02	1.29E-03	1.39E-02	9.45E-04	2.96E-02
Sarva	5.48E-02	1.09E-01	6.67E-02	2.08E-03	3.34E-02	3.32E-05	8.26E-04	3.76E-02	4.94E-02	9.19E-02
Ssout	4.36E-05	9.96E-02	1.67E-04	1.17E-04	1.48E-03	9.99E-02	2.11E-02	5.24E-02	1.81E-02	4.34E-04
Adimp	2.00E-03	3.29E-04	4.36E-03	1.76E-03	7.13E-05	3.65E-03	7.60E-04	1.94E-02	1.78E-03	1.33E-03
Pfree	2.78E-01	3.93E-02	3.20E-02	1.56E-02	2.92E-01	8.28E-02	5.88E-02	4.92E-01	3.23E-01	1.21E-01
Lztwm	9.31E+01	1.00E+01	1.21E+01	1.14E+02	1.00E+01	1.01E+01	5.50E+02	1.00E+01	2.54E+02	1.06E+01
Lzfsm	1.68E+01	1.27E+01	5.96E+01	2.91E+01	2.28E+00	1.89E+00	6.80E+01	2.00E+02	1.12E+01	1.16E+00
Lzfpm	1.31E+02	1.15E+02	2.99E+02	5.48E+01	4.90E+00	1.13E+02	3.59E+01	7.26E+01	2.24E+00	1.70E+02
Lzsk	2.94E-02	1.86E-01	1.01E-03	1.21E-02	1.38E-01	6.07E-03	1.17E-02	1.01E-03	3.84E-02	9.22E-02
Lzpk	7.45E-02	3.21E-03	1.22E-03	1.31E-01	1.28E-01	8.96E-03	1.83E-02	4.93E-02	8.02E-02	1.85E-02
Rserv	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01
Side	9.43E-02	4.37E-04	1.22E-02	6.00E-02	8.13E-04	9.97E-02	1.84E-02	2.53E-04	5.93E-05	1.53E-03
lagUHmodifier	1.56E-04	2.49E+00	1.64E-06	1.70E-05	1.01E-06	1.62E+00	1.86E-04	5.40E-04	4.96E-07	2.61E-03
RoutingPower	1.00E+00	8.69E-01	8.43E-01	1.00E+00	9.33E-01	9.00E-01	9.57E-01	8.68E-01	6.43E-01	9.97E-01
regionalConstant	9.95E+03	1.06E+02	9.11E+01	3.31E+01	6.74E+05	3.09E+05	3.77E+01	1.72E+02	8.34E-12	1.06E+03

TABLE 18 - SACRAMENTO PARAMETERS FOR CONDAMINE BALONNE MARANOA

	Condamine Balonne Maranoa													
Parameter	**422404a**	**422401d**	**422310c**	**422355a**	**422350a**	**422336a**	**422333a**	**422325a**	**422323a**	**422310c**	**422213a**	**422202b**	**422201f**	**422204a**
Uztwm	8.55E+01	1.28E+02	1.49E+02	1.35E+02	9.75E+01	1.08E+02	8.98E+01	1.10E+02	8.62E+01	1.49E+02	1.68E+02	1.10E+02	1.36E+02	1.51E+02
Uzfwm	6.39E+01	8.08E+01	5.01E+01	2.62E+01	1.51E+02	8.37E+01	1.51E+02	1.11E+02	1.25E+02	5.01E+01	1.36E+02	1.17E+02	1.71E+01	5.88E+01
Uzk	3.51E-01	6.53E-01	2.72E-01	2.76E-01	2.78E-01	4.52E-01	4.68E-01	2.29E-01	2.84E-01	2.72E-01	1.03E-01	3.38E-01	2.52E-01	2.38E-01
Zperc	4.34E+02	3.88E+02	1.79E+00	7.96E+01	1.66E+02	6.87E+01	2.81E+01	1.03E+00	2.91E+01	1.79E+00	3.55E+01	4.21E+01	7.22E+01	4.21E+01
Rexp	1.02E+00	1.19E+00	1.19E+00	2.45E+00	2.31E+00	3.11E+00	1.53E+00	1.19E+00	1.01E+00	1.19E+00	2.47E+00	4.03E+00	2.41E+00	5.46E+00
Pctim	9.95E-04	4.07E-05	9.20E-03	7.54E-03	6.01E-03	2.18E-04	1.14E-03	2.44E-04	4.53E-07	9.20E-03	1.63E-05	5.87E-03	2.41E-03	4.95E-05
Sarva	9.56E-02	1.57E-02	2.87E-04	3.74E-04	2.80E-04	1.40E-02	2.19E-03	2.94E-03	1.31E-02	2.87E-04	1.76E-03	8.85E-03	3.85E-04	3.41E-02
Ssout	1.69E-03	1.19E-05	6.39E-02	3.10E-03	4.94E-06	4.61E-05	6.98E-03	1.45E-03	3.89E-04	6.39E-02	5.68E-03	9.99E-02	5.39E-04	8.58E-05
Adimp	1.02E-03	4.40E-02	3.50E-04	3.07E-03	6.15E-02	3.23E-05	7.51E-04	2.68E-03	2.31E-02	3.50E-04	2.11E-04	6.20E-03	7.89E-04	5.74E-03
Pfree	2.08E-02	1.06E-01	1.25E-01	1.41E-01	3.85E-02	9.18E-02	3.93E-02	5.22E-02	1.70E-02	1.25E-01	1.11E-01	4.84E-01	7.03E-02	1.24E-02
Lztwm	1.54E+01	1.04E+02	1.00E+01	1.00E+01	9.49E+01	1.00E+01	1.06E+01	1.00E+01	1.12E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01
Lzfsm	3.47E+02	3.64E+00	3.43E+02	1.47E+01	3.02E+02	1.27E+01	6.84E+00	2.71E+01	3.30E+02	3.43E+02	2.26E+01	2.21E+02	6.98E+00	1.96E+01
Lzfpm	6.36E+00	3.79E+01	2.45E+02	1.13E+01	2.93E+02	7.36E+00	6.49E+00	2.14E+01	1.80E+00	2.45E+02	3.53E+00	2.35E+02	1.13E+01	1.78E+00
Lzsk	1.03E-03	1.17E-01	2.06E-03	3.25E-02	1.00E-03	4.49E-02	4.56E-02	2.69E-03	1.89E-03	2.06E-03	4.39E-02	1.00E-03	5.23E-03	1.85E-01
Lzpk	1.44E-02	8.05E-03	3.05E-02	4.44E-03	1.15E-03	1.38E-01	5.69E-01	3.83E-01	4.90E-01	3.05E-02	1.05E-02	5.69E-03	1.02E-01	9.97E-03
Rserv	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01
Side	5.74E-03	7.97E-02	1.39E-03	4.00E-04	5.35E-05	1.14E-03	1.06E-03	8.63E-06	1.65E-02	1.39E-03	8.94E-04	1.60E-02	1.26E-04	2.21E-03
lagUHmodifier	5.09E-02	3.61E-06	7.17E-07	1.95E-06	8.37E-10	1.42E+00	5.25E-06	5.73E-10	4.36E-09	7.17E-07	6.26E-06	3.10E-10	1.86E-03	5.62E-07
RoutingPower	8.76E-01	6.77E-01	6.64E-01	8.30E-01	8.19E-01	7.10E-01	6.96E-01	9.99E-01	6.92E-01	6.64E-01	6.41E-01	8.41E-01	8.45E-01	7.28E-01
regionalConstant	1.63E+04	3.71E+03	7.64E+00	3.41E-13	5.80E-11	5.60E+00	3.21E+04	1.87E+00	1.26E+03	7.64E+00	1.47E-11	5.01E+00	6.59E+03	9.63E+00

11.2 OVERVIEW OF FUNCTIONAL UNIT CREATION

11.2.1 Condamine Balonne

Land use layer used: Qld Land use Mapping (SIR layer – Current) (Areas covered are based on 2012/2013 imagery - see Figure 37)

Foliage Projected Cover - 2013

Rationale:

A diverse range of land use within the catchments allows for the use of the QLUM to group a range of Functional Units. The exception being grazing, which was split into two further groups based on the Foliage Projected Cover (FPC) – open grazing (less than 20% FPC) and forested grazing (>=20% FPC).

Categories:

As set out in Table 19.

TABLE 19 - FUNCTIONAL UNIT CATEGORIES FOR CONDAMINE BALONNE MODEL

Functional Unit	Additional Layer Rules	Actual selection criteria using Qld Land Use Mapping Program (QLUMP) layer
Open grazing	FPC <20%	SECONDARY = "Grazing native vegetation" OR SECONDARY = "Grazing modified pastures"
Forested grazing	FPC>=20%	SECONDARY = "Grazing native vegetation" OR SECONDARY = "Grazing modified pastures"
Dryland cropping		SECONDARY = 'Cropping' OR "SECONDARY" = 'Cropping - Cotton' OR "SECONDARY" = 'Land in transition'
Irrigated cropping		SECONDARY = 'Irrigated modified pastures' OR "SECONDARY" = 'Irrigated cropping' OR "SECONDARY" = 'Irrigated cropping - Cotton'
Horticulture		SECONDARY = 'Perennial horticulture' OR "SECONDARY" = 'Seasonal horticulture' OR "SECONDARY" = 'Irrigated perennial horticulture' OR "SECONDARY" = 'Irrigated seasonal horticulture' OR "SECONDARY" = 'Intensive horticulture'
Conservation		PRIMARY_ = 'Conservation and natural environments'
Forestry		SECONDARY = 'Plantation forestry' OR "SECONDARY" = 'Production forestry'
Urban		TERTIARY = 'Urban residential' OR "TERTIARY" = 'Residential'
Water		PRIMARY_ = 'Water'
Mining		SECONDARY = 'Mining' OR "TERTIARY" = 'Gas treatment, storage and transmission'
Other		After assigning all other categories, select anything not assigned

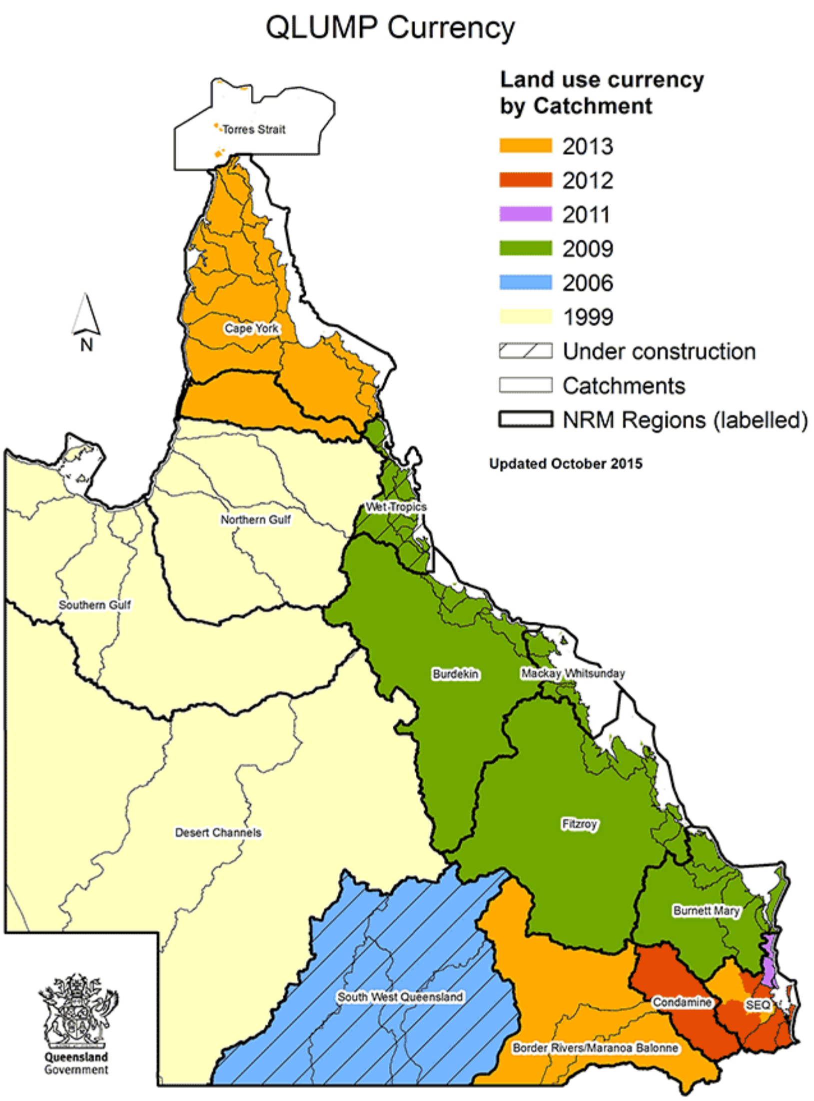


FIGURE 37 - QLUMP CURRENCY BASED ON IMAGERY USED (DNRM QLUMP, 2016)

11.2.2 Moonie and Border Rivers

Land use layer used: 2006 Australian land use classification

Rationale:

As these two catchments both have sections of the area within NSW, which is not covered by Queensland Land use mapping, the Australian Land Use Mapping (ALUM) was used to create a complete coverage for this model. The Qld Land Use Mapping (QLUM) uses the standard set up by the ALUM, but extends it through mapping done by local operators at a finer scale.

Categories:

Used the same functional units as set for the Condamine Balonne Model applied to the ALUM as per Table 20.

TABLE 20 - CRITERIA FOR FUNCTIONAL UNITS FOR MOONIE AND BORDER RIVER MODELS

Functional Unites	Additional Layer Rules	Actual selection criteria
Open grazing	FPC <20%	Process - grab layer from Federal source, Extract by rectangle using the extent of the buffered 5km MNBD catchment. Perform Raster To Polygon (without simplified polygons) Using the Grazing selection to identify grazing areas. Remove the areas over lapped with the QLD FPC layer and base the LU grazing on the FPC and for the rest use the inbuilt grazing differences. Identify the grazing areas that overlap with the FPC >= 20%. Remove this grazing area form the original map and replace with the data that has been through the identify process on it.
Forested grazing	FPC>=20%	
Dryland cropping		LU_DESC2 ='Cropping'
Irrigated cropping		LU_DESC2 = 'Irrigated cropping'
Horticulture		LU_DESC2 = 'Irrigated perennial horticulture' OR "LU_DESC2" ='Irrigated seasonal horticulture' OR "LU_DESC2"= 'Seasonal horticulture' OR "LU_DESC2"= 'Perennial horticulture'
Conservation		LU_DESC = 'CONSERVATION AND NATURAL ENVIRONMENTS'
Forestry		LU_DESC2 = 'Plantation forestry' OR "LU_DESC2" = 'Production forestry'
Urban		LU_DESC3 = 'Urban residential'
Water		LU_DESC = 'WATER'
Mining		LU_DESC2 = 'Mining'
Other		After assigning all other categories, select anything not assigned including intensive animal industry, waste treatment and rural residential

11.2.3 South West NRM Catchments

Land use layer used:

Qld Land use Mapping (SIR layer – Current) (Areas covered are based on 2006 imagery - see Figure 37)

Australian Land use mapping (small areas overlap with NSW)

Grazing Land Management Layer version 2 (SIR layer)

Rationale:

Grazing covers over 85% of the catchments of Bulloo, Paroo, Warrego and Nebine, using the Qld Land use Mapping. Land use was a surrogate of the landscape response to environmental factors grouping both natural and man-made processes. As within the 2008 E2 Model process (Waters, 2008) a broader definition of the Grazing areas within the South West Catchments was adopted. This was after consultation with SWNRM to understand how the landscape was broken up. A decision was made to adopt the broad Grazing Land Management Land Type Groups which were used in the State Rural Leasehold Land process in understanding the condition of land types. These categories were created to fill the grazing areas based on the largest types

For the non-grazing areas a similar grouping were made with QLUMP.

Categories:

Use the same categories as set out in **Table 21**.

Table 21 – Functional Units Categories used for the SWNRM Model

Functional Unit	Additional Layer Rules	Actual selection criteria
Grazing - Alluvial	Select Areas that overlap with Grazing from the Landuse layer created above (QLUMP Version), clip to areas of Frontage/Alluvial	SECONDARY = 'Grazing native vegetation'
Grazing - Hard Country	Select Areas that overlap with Grazing from the Landuse layer created above (QLUMP Version), clip to areas of Jump-ups/Hard country	SECONDARY = 'Grazing native vegetation'
Grazing - Sandplains	Select Areas that overlap with Grazing from the Landuse layer created above (QLUMP Version), clip to areas of Sandplains/Inland dune fields	SECONDARY = 'Grazing native vegetation'
Grazing - Woodlands/Forests	Select Areas that overlap with Grazing from the Landuse layer created above (QLUMP Version), clip to areas of Woodlands/Forests	SECONDARY = 'Grazing native vegetation'
Grazing - Other	Select Areas that overlap with Grazing from the Landuse layer created above (QLUMP Version), clip to areas of Other	SECONDARY = 'Grazing native vegetation'
Conservation	As method above - in QLUMP	Primary = "Conservation and natural environments"
Dryland Cropping	Combine Irrigated and Dryland Cropping due to small areas covered	SECONDARY = 'Cropping' OR "SECONDARY" = 'Irrigated cropping' OR "SECONDARY" = 'Irrigated cropping - Cotton'
Forestry	As method above - in QLUMP	Secondary = "Production forestry" OR Secondary = "Plantation forestry"
Water	As method above - in QLUMP	Primary = "Water"
Mining		SECONDARY = 'Mining'
Other	Anything Not Assigned yet.	

11.3 Overview of Subcatchment creation

The sub catchment generation was undertaken for the project in three phases.

Phase 1: Discussion with end users

Meeting were arranged with the three NRM bodies to ascertain the likely uses of the model and also the required planning level to assist the planning work within the region. This discussion helped identify the appropriate size for the sub catchment size.

Phase 2: Source Catchment DEM catchments generation

Using the AUS STRM 1 SEC DEM –Hydrological enforced version 1 the area surrounding catchments were extracted along with a 25km buffer. This was used for the basis of the creation of sub catchments within the program Source Catchments. Sub catchment layers were generated using individual clipped DEM for the individual catchment due to the size of the data that needed to be processed (>1Gb) using the Geographic Scenario wizard process. This was an iterative process on a variety of sub catchment sizes to ensure all of the Gauging Stations and Storages were identified as nodes. Draft sub catchments were exported at a variety of sub catchment sizes.

Phase 3: Final Sub catchment generation

Utilizing the understanding gained through a variety of sub catchment sizes, the final set of sub catchment were generated through combining draft sub catchment of different sizes to ensure all required nodes are correctly represent in the sub catchment model. The table below outlines some of these modifications

Model	Size (sq. km) of sub catchment base layer	Size Modifications	Notes
Bulloo, Paroo, Warrego, Nebine (SWNRM)	2000	individual sub catchments 750 and 1000 to capture nodes in the Paroo and Warrego	Small area of Warrego continues over border to allow for calibration, however the remaining sub catchments were clipped to the Border.
Condamine Balonne (CB)	400	Individual sub catchments of 50 and 100 included to capture Condamine uplands and along lower Balonne	Flat areas on lower Balonne meant the overlap with the Nebine and Moonie created issues, which were corrected through smaller catchment generation and correct of the flow direction in some cases. In the Condamine headwaters larger catchments were exchanged with the smaller sub catchments.
Moonie, Border Rivers	400	Single sub catchment replaced with 50 km2 sub catchments	Only one subcatchment needed be removed in the flat areas between the lower border rivers where two gauging stations weren’t picked up.

The final associated sub catchment nodes and links models were modified to allow for correct flow direction on reloading back into Source.

11.4 Calibration Results

TABLE 22 - FULL CALIBRATION RESULTS FOR ALL GAUGES USED IN THE HYDROLOGICAL CALIBRATION PROCESS

Catchment	Gauging Station	RSR		PBIAS		R2		NSE Monthly		NSE Daily		Total Flow Volume	Base flow	
		Value	Rating (Moriasi 2007)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	(pred/obs)	Observed	Modelled
Bulloo	011203a	0.370	Very good	-0.04	Very good	0.894	Very good	0.863	Very good	0.687	Satisfactory	1.001	11%	9%
	011202a	0.341	Very good	0.01	Very good	0.914	Very good	0.883	Very good	0.766	Good	1.001	16%	16%
Paroo	424201a	0.611	Satisfactory	0.01	Very good	0.788	Good	0.627	Satisfactory	0.589	Satisfactory	1.000	11%	10%
Warrego	423204a	0.268	Very good	0.02	Very good	0.935	Very good	0.928	Very good	0.732	Good	1.000	10%	10%
	423205a	0.410	Very good	0.03	Very good	0.895	Very good	0.832	Very good	0.574	Satisfactory	1.000	11%	16%
	423203a	0.581	Good	0.20	Very good	0.817	Good	0.663	Satisfactory	0.630	Satisfactory	1.000	16%	30%
	423206a	0.218	Very good	-3.24	Very good	0.962	Very good	0.953	Very good	0.837	Very good	1.032	18%	13%
	423202c	0.295	Very good	-4.01	Very good	0.943	Very good	0.913	Very good	0.772	Good	1.040	17%	16%
Nebine	422501a	0.369	Very good	-0.09	Very good	0.867	Very good	0.864	Very good	0.254	Unsatisfactory	1.001	11%	13%
	422502a	0.429	Very good	-0.01	Very good	0.889	Very good	0.816	Very good	0.507	Satisfactory	1.000	11%	45%
Condamine	422310c	0.285	Very good	-0.005	Very good	0.930	Very good	0.919	Very good	0.663	Satisfactory	1.000	28%	22%
	422355a	0.217	Very good	0.678	Very good	0.953	Very good	0.953	Very good	0.885	Very good	0.985	21%	22%
	422323a	0.244	Very good	0.017	Very good	0.952	Very good	0.941	Very good	0.799	Good	0.999	22%	17%
	422350a	0.359	Very good	0.050	Very good	0.882	Very good	0.871	Very good	0.769	Good	0.999	15%	12%

Catchment	Gauging Station	RSR		PBIAS		R2		NSE Monthly		NSE Daily		Total Flow Volume	Base flow	
		Value	Rating (Moriasi 2007)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	(pred/obs)	Observed	Modelled
	422333a	0.281	Very good	0.142	Very good	0.930	Very good	0.921	Very good	0.839	Very good	0.997	17%	13%
	422336a	0.232	Very good	0.502	Very good	0.949	Very good	0.946	Very good	0.819	Very good	0.995	15%	14%
	422325a	0.261	Very good	0.280	Very good	0.932	Very good	0.932	Very good	0.852	Very good	0.997	17%	25%
Maranoa	422401d	0.216	Very good	0.104	Very good	0.959	Very good	0.953	Very good	0.817	Very good	0.999	10%	2%
	422404a	0.299	Very good	0.015	Very good	0.947	Very good	0.911	Very good	0.754	Good	1.000	11%	22%
Balonne	422202b	0.314	Very good	-0.045	Very good	0.919	Very good	0.902	Very good	0.809	Very good	1.000	9%	9%
	422213a	0.344	Very good	-1.190	Very good	0.889	Very good	0.882	Very good	0.466	Unsatisfactory	1.012	22%	22%
	422201f	0.259	Very good	1.491	Very good	0.934	Very good	0.933	Very good	0.791	Good	0.985	21%	21%
	422204a	0.330	Very good	-4.030	Very good	0.908	Very good	0.891	Very good	0.762	Good	1.040	24%	24%
Moonie	417205a	0.611	Satisfactory	-0.046	Very good	0.754	Good	0.626	Satisfactory	0.409	Unsatisfactory	1.000	12%	13%
	417201b	0.458	Very good	0.269	Very good	0.863	Very good	0.790	Good	0.667	Satisfactory	0.997	14%	14%
	417204a	0.470	Very good	-0.092	Very good	0.824	Good	0.779	Good	0.564	Satisfactory	1.001	15%	14%
Border Rivers	416011*	0.327	Very good	0.077	Very good	0.898	Very good	0.893	Very good	0.850	Very good	0.999	37%	40%
	416008*	0.415	Very good	0.036	Very good	0.846	Good	0.828	Very good	0.492	Unsatisfactory	1.000	19%	25%
* is in NSW	416006*	0.612	Satisfactory	-0.109	Very good	0.732	Satisfactory	0.625	Satisfactory	0.571	Satisfactory	1.000	22%	22%
	416010*	0.414	Very good	3.424	Very good	0.856	Very good	0.828	Very good	0.633	Satisfactory	0.966	22%	20%
	416007*	0.338	Very good	-0.013	Very good	0.887	Very good	0.886	Very good	0.820	Very good	1.000	38%	41%

Catchment	Gauging Station	RSR		PBIAS		R2		NSE Monthly		NSE Daily		Total Flow Volume	Base flow	
		Value	Rating (Moriasi 2007)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	(pred/obs)	Observed	Modelled
	416012*	0.457	Very good	-2.061	Very good	0.883	Very good	0.791	Good	0.662	Satisfactory	1.021	27%	44%
	416415a	0.208	Very good	0.068	Very good	0.963	Very good	0.957	Very good	0.738	Good	1.000	17%	43%
	416201a	0.329	Very good	0.665	Very good	0.898	Very good	0.892	Very good	0.757	Good	0.993	36%	37%
	416001*	0.466	Very good	11.741	Satisfactory	0.800	Good	0.783	Good	0.564	Satisfactory	0.883	45%	37%
Weir	416204a	0.363	Very good	2.549	Very good	0.869	Very good	0.869	Very good	0.796	Good	0.975	19%	28%
	416202a	0.381	Very good	0.008	Very good	0.868	Very good	0.855	Very good	0.787	Good	0.937	11%	20%

11.5 EMC/DWC VALUES USED

TABLE 23 - MEAN EVENT CONCENTRATION USED FOR THE MODEL BY FUNCTIONAL UNIT

CBM

Functional Unites	Model Group	DIN EMC	DON EMC	DOP EMC	FRP EMC
Open grazing	USLE	-	-	-	-
Forested grazing	USLE	-	-	-	-
Dryland cropping	EMC	0.24	0.57	0.07	0.24
Irrigated cropping	EMC	0.10	0.23	0.03	0.10
Horticulture	EMC	0.10	0.23	0.03	0.10
Conservation	USLE	-	-	-	-
Forestry	USLE	-	-	-	-
Urban	EMC	0.22	0.52	0.01	0.02
Water	EMC	0.03	0.08	0.02	0.05
Mining	EMC	0.10	0.23	0.01	0.03
Other	EMC	0.15	0.35	0.03	0.11

BDMN

Functional Unites	Model Group	DIN EMC	DON EMC	DOP EMC	FRP EMC
Open grazing	USLE	-	-	-	-
Forested grazing	USLE	-	-	-	-
Dryland cropping	EMC	0.33	0.80	0.04	0.16
Irrigated cropping	EMC	0.13	0.32	0.02	0.06
Horticulture	EMC	0.13	0.32	0.02	0.06
Conservation	USLE	-	-	-	-
Forestry	USLE	-	-	-	-
Urban	EMC	0.42	1.03	0.02	0.06
Water	EMC	-	-	-	-
Mining	EMC	0.19	0.46	0.02	0.08
Other	EMC	0.22	0.53	0.02	0.08

SWNRM

Functional Unit	Model Group	DIN EMC	DON EMC	DOP EMC	FRP EMC
Grazing - Alluvial	USLE	-	-	-	-
Grazing - Hard Country	USLE	-	-	-	-
Grazing - Sandplains	USLE	-	-	-	-
Grazing - Woodlands/Forests	USLE	-	-	-	-
Grazing - Other	USLE	-	-	-	-
Conservation	USLE	-	-	-	-
Dryland Cropping	EMC	0.40	0.95	0.02	0.05
Forestry	USLE	-	-	-	-
Water	EMC	-	-	-	-
Other	EMC	0.35	0.83	0.01	0.04

* EMC (Mean Event Concentration) represents the hillslope generation. The delivery ratio and gully model is applied separately.

11.6 ANNUAL LOADS AND FLOW

TABLE 24 – SOUTHWEST NRM MODELLED ANNUAL LOADS AND FLOW

Bulloo **51,875** **Km²**

Year	TN (t)	TP (t)	TSS (kt)	Flow (ML)
1980	88	34	38	37,004
1981	1,682	848	935	944,967
1982	172	74	79	67,502
1983	4,170	2,253	2,448	1,792,818
1984	1,675	867	897	1,016,925
1985	2,555	1,237	1,317	1,532,526
1986	243	104	109	136,065
1987	921	436	474	467,411
1988	1,297	650	690	963,440
1989	4,855	1,816	1,935	2,725,345
1990	5,125	1,711	1,784	3,032,601
1991	2,607	1,454	1,587	1,151,658
1992	649	341	345	228,230
1993	378	169	180	169,991
1994	1,253	656	736	490,181
1995	2,265	1,230	1,185	1,248,368
1996	472	201	215	213,092
1997	1,228	601	620	481,059
1998	2,764	1,428	1,480	1,739,193
1999	1,561	812	855	572,774
2000	4,763	2,561	2,670	1,913,083
2001	308	142	143	145,641

Nebine **38,180** **Km²**

Year	TN (t)	TP (t)	TSS (kt)	Flow (ML)
1980	2.2	0.7	0.8	696
1981	38.7	15.7	20.1	6,796
1982	81.3	33.4	43.3	12,474
1983	554.3	213.6	292.4	181,540
1984	245.3	104.3	139.4	54,689
1985	36.3	14.4	18.6	7,356
1986	3.3	1.1	1.1	984
1987	3.5	1.2	1.2	1,085
1988	19.2	8.5	10.8	4,289
1989	134.6	71.7	103.3	29,420
1990	591.0	264.0	308.4	204,474
1991	50.3	26.5	34.3	8,189
1992	1.2	0.4	0.4	505
1993	2.1	0.7	0.7	697
1994	19.1	7.1	9.1	4,077
1995	51.0	25.2	34.2	9,319
1996	4.8	1.6	1.7	1,451
1997	365.2	168.9	236.8	69,273
1998	81.3	41.7	61.1	16,901
1999	75.4	31.5	43.7	15,891
2000	192.9	86.8	124.2	41,936
2001	4.0	1.4	1.5	1,132

2002	331	156	160	130,222
2003	141	51	55	68,312
2004	2,150	1,142	1,193	824,542
2005	563	270	298	240,024
2006	250	100	109	115,075
2007	1,251	660	649	591,515
2008	1,308	650	690	526,667
2009	558	259	271	216,166
2010	8,237	3,248	3,230	4,299,755
2011	2,830	1,518	1,632	1,205,277
2012	3,450	1,807	1,961	1,944,875
2013	222	90	95	118,799
2014	619	293	304	259,747
2015	226	95	98	92,807
Total	63,169	29,966	31,465	31,703,658
Average	**1,755**	**832**	**874**	**880,657**

2002	60.2	21.2	22.5	3,028
2003	1.3	0.4	0.4	451
2004	128.8	57.3	77.8	21,610
2005	3.1	1.1	1.2	908
2006	2.9	1.0	1.1	857
2007	2.8	0.9	0.9	876
2008	38.9	17.0	22.6	7,218
2009	19.7	10.9	15.8	2,531
2010	602.3	223.9	214.9	254,766
2011	62.1	24.5	34.5	17,553
2012	524.9	206.6	218.2	203,487
2013	3.5	1.0	1.2	1,425
2014	2.7	0.9	0.9	839
2015	3.0	1.0	1.2	912
Total	4,013	1,688	2,100	1,189,635
Average	**111**	**47**	**58**	**33,045**

Paroo **32,255** **Km²**

Year	TN (t)	TP (t)	TSS (kt)	Flow (ML)
1980	62	30	27	16,874
1981	587	249	241	305,032
1982	32	17	14	10,161
1983	2,511	943	970	1,613,219
1984	756	342	316	316,632
1985	885	384	385	709,618
1986	101	51	43	49,668
1987	398	183	166	158,012
1988	1,092	463	452	774,949
1989	2,440	919	994	1,519,653
1990	4,207	895	905	3,440,734
1991	984	415	397	650,672
1992	345	167	151	90,489
1993	204	99	89	82,469
1994	272	137	119	74,189
1995	1,316	580	517	917,622
1996	260	134	103	71,622
1997	378	176	152	129,619
1998	1,518	627	595	1,158,443
1999	327	168	129	158,874
2000	2,331	932	960	1,614,498
2001	98	50	39	34,782
2002	364	182	148	74,448
2003	136	72	55	29,919
2004	934	435	399	314,005
2005	253	105	100	92,965

Warrego. **65,682** **Km²**

Year	TN (t)	TP (t)	TSS (kt)	Flow (ML)
1980	58	10	10	17,646
1981	710	241	296	182,100
1982	295	94	101	40,590
1983	2,390	939	1,215	890,832
1984	734	248	289	133,938
1985	103	35	37	18,960
1986	224	76	78	25,065
1987	218	77	78	24,911
1988	105	37	38	18,575
1989	1,119	428	541	695,558
1990	3,926	995	1,169	4,191,166
1991	315	118	128	60,424
1992	175	62	62	20,236
1993	251	84	87	33,679
1994	731	250	292	143,789
1995	328	138	163	177,273
1996	598	213	256	110,632
1997	2,000	739	916	784,667
1998	296	106	123	217,763
1999	308	99	111	52,101
2000	1,018	384	490	363,803
2001	121	39	44	25,879
2002	225	74	84	37,710
2003	598	212	267	115,477
2004	798	263	308	124,991
2005	268	88	106	64,985

2006	173	90	70	40,800
2007	795	387	331	221,210
2008	802	364	333	281,655
2009	481	227	195	133,847
2010	4,289	1,064	1,004	3,019,065
2011	987	434	399	531,787
2012	2,001	701	719	1,286,727
2013	128	65	50	46,907
2014	236	123	95	64,948
2015	169	91	69	32,480
Total	32,853	12,299	11,730	20,068,594
Average	**913**	**342**	**326**	**557,461**

2006	114	40	45	19,753
2007	518	175	207	86,583
2008	1,403	541	671	612,126
2009	128	42	47	23,208
2010	3,084	1,166	1,490	2,226,195
2011	1,191	432	559	341,674
2012	1,551	597	751	854,019
2013	39	13	15	9,879
2014	118	39	44	23,627
2015	115	38	42	14,911
Total	26,173	9,133	11,160	12,784,723
Average	**727**	**254**	**310**	**355,131**

Table 25 – BORDER RIVERS MODELLED ANNUAL LOADS AND FLOW

Moonie **15,905** **Km²**

Year	TN (t)	TP (t)	TSS (kt)	Flow (ML)
1980	0.1	0.1	0.0	25
1981	5.5	1.5	0.9	3,754
1982	51.6	14.2	10.6	39,763
1983	1032.0	101.0	17.6	1,273,261
1984	440.7	60.1	18.8	508,593
1985	18.6	8.2	3.8	11,624
1986	3.8	1.6	0.8	3,378
1987	2.0	1.0	0.4	1,321
1988	305.0	29.9	5.8	375,054
1989	72.7	16.5	10.4	63,303
1990	253.0	26.9	7.5	302,893
1991	14.9	6.4	3.0	10,946
1992	4.7	1.9	1.0	4,261
1993	2.7	1.4	0.6	1,711
1994	59.6	16.5	9.6	41,235
1995	75.2	10.9	4.7	80,032
1996	342.8	30.1	4.7	433,439
1997	178.7	20.0	5.7	209,707
1998	350.0	32.0	5.9	435,294
1999	70.4	10.4	5.7	81,057
2000	46.9	9.7	7.5	44,397
2001	5.5	1.8	1.0	4,470
2002	0.7	0.2	0.1	953
2003	2.2	0.4	0.4	2,155

Border **50,742** **Km²**

Year	TN (t)	TP (t)	TSS (kt)	Flow (ML)
1980	42	16	9	24,147
1981	873	176	103	914,795
1982	1,072	126	44	1,315,651
1983	3,330	375	132	4,128,354
1984	2,283	286	111	2,816,753
1985	549	141	68	503,029
1986	96	33	14	63,608
1987	188	58	28	134,065
1988	2,556	308	103	3,093,447
1989	978	125	72	1,213,021
1990	1,275	163	87	1,577,227
1991	792	108	36	917,253
1992	316	74	39	296,351
1993	64	20	9	46,421
1994	468	102	43	472,198
1995	999	133	37	1,187,361
1996	2,800	262	72	3,438,419
1997	890	122	46	1,070,430
1998	2,647	250	62	3,271,041
1999	621	72	23	756,126
2000	1,183	131	33	1,400,725
2001	1,130	129	60	1,358,691
2002	144	26	14	162,467
2003	315	84	41	257,937

2004	145.4	20.3	7.2	159,838
2005	30.9	5.7	4.6	30,117
2006	0.1	0.1	0.0	55
2007	7.5	1.3	0.5	7,542
2008	40.4	6.3	3.5	41,059
2009	6.9	1.5	1.0	5,698
2010	542.8	52.4	10.8	663,533
2011	430.6	44.1	12.0	531,129
2012	302.6	27.4	4.9	373,802
2013	283.5	29.3	8.1	359,657
2014	24.4	7.2	4.3	18,022
2015	2.0	0.8	0.4	1,814
Total	5156.4	598.7	183.6	6,124,893
Average	**143.2**	**16.6**	**5.1**	**170,136**

2004	1,689	199	52	2,079,964
2005	639	76	21	812,269
2006	150	40	20	127,943
2007	197	51	27	173,868
2008	287	63	32	303,151
2009	413	64	30	476,502
2010	1,890	197	94	2,289,991
2011	2,114	200	48	2,641,577
2012	777	88	31	1,001,766
2013	1,209	121	31	1,536,502
2014	476	53	16	611,820
2015	596	115	63	606,366
Total	36,050	4,589	1,750	43,081,233
Average	**1,001**	**127**	**49**	**1,196,701**

Table 26 – CONDAMINE BALONNE AND MARANOA ANNUAL LOADS AND FLOW

Balonne Region (includes cond. + Maranoa)

87,625 **Km²**

Year	TN (t)	TP (t)	TSS (kt)	Flow (ML)
1980	6.3	4.5	4.8	10,093
1981	422.9	233.9	221.6	454,130
1982	538.1	278.7	242.9	709,930
1983	27,663.9	28,171.5	773.3	11,629,242
1984	1,622.4	1,131.6	246.8	2,722,321
1985	5.7	2.7	1.9	6,174
1986	13.0	6.2	4.3	9,354
1987	8.0	3.9	2.5	4,493
1988	1,057.6	652.1	178.5	2,094,577
1989	898.0	508.8	501.2	885,558
1990	3,243.0	2,553.8	784.0	3,307,190
1991	57.2	29.3	21.5	80,760
1992	6.6	3.3	2.1	5,230
1993	14.0	7.2	4.5	7,473
1994	695.8	404.7	217.6	569,289
1995	307.7	161.3	157.7	292,028
1996	1,301.5	737.0	190.0	3,011,975
1997	354.5	161.3	158.5	436,419
1998	1,185.6	661.7	686.9	1,408,612
1999	378.3	195.8	201.0	410,843
2000	317.2	181.1	170.5	346,750
2001	307.6	177.2	163.5	278,959

2002	9.2	5.1	4.1	5,335
2003	8.6	4.6	3.4	4,932
2004	303.0	165.7	164.2	271,658
2005	221.4	103.0	109.9	267,886
2006	4.4	1.9	1.9	3,675
2007	54.9	35.5	38.4	25,493
2008	167.2	81.9	70.0	220,137
2009	9.3	4.9	3.5	7,638
2010	12,730.2	12,813.8	345.9	5,512,294
2011	8,442.2	8,155.7	320.4	7,323,379
2012	1,484.5	656.6	385.7	4,106,128
2013	610.1	264.4	141.6	1,445,890
2014	385.3	199.1	215.6	430,635
2015	144.7	77.2	61.5	168,460
Total	64,980	58,837	6,802	48,474,936
Average	**1,805**	**1,634**	**189**	**1,346,526**

Condamine **28,963** **Km²**

Year	TN (t)	TP (t)	TSS (kt)	Flow (ML)
1980	43	27	18	22,403
1981	1,697	1,006	1,003	760,110
1982	280	165	153	122,512
1983	5,697	2,629	2,373	4,882,217
1984	2,282	1,069	979	1,726,279
1985	84	43	25	38,445
1986	15	8	6	5,749
1987	177	79	80	67,322
1988	2,558	1,343	1,029	2,206,734
1989	1,490	791	879	656,261
1990	1,511	835	894	676,451
1991	384	244	197	155,096
1992	63	37	24	31,403
1993	47	24	26	22,227
1994	1,242	683	730	578,355
1995	1,637	945	977	629,422
1996	3,448	1,584	1,347	3,059,081
1997	782	311	465	400,888
1998	2,242	1,167	1,406	1,168,413
1999	1,186	629	723	556,301
2000	47	23	17	19,669
2001	1,131	729	733	331,909
2002	28	16	8	15,445
2003	193	110	109	99,353

Maranoa **18,442** **Km²**

Year	TN (t)	TP (t)	TSS (kt)	Flow (ML)
1980	0	0	0	36
1981	311	173	177	105,388
1982	385	233	225	34,778
1983	1313	714	701	605,518
1984	461	242	223	272,750
1985	106	61	60	8,547
1986	0	0	0	0
1987	32	24	14	2,873
1988	232	139	137	20,188
1989	502	328	282	106,391
1990	1158	597	441	773,517
1991	25	16	17	2,775
1992	41	30	19	4,451
1993	173	106	85	21,359
1994	383	216	219	54,575
1995	15	9	9	1,698
1996	425	283	225	40,875
1997	663	382	338	230,997
1998	428	239	242	81,338
1999	129	94	57	10,322
2000	597	372	317	72,863
2001	27	16	13	3,531
2002	5	3	2	264
2003	0.00	0	0	0

2004	633	330	382	298,043
2005	574	259	361	309,309
2006	3	2	0	800
2007	69	37	32	31,964
2008	726	452	420	245,572
2009	50	27	18	19,595
2010	3,388	1,677	1,652	2,418,709
2011	3,995	1,629	794	5,102,875
2012	569	236	327	287,253
2013	2,430	1,152	984	2,171,857
2014	1,235	668	785	607,797
2015	422	270	215	178,126
Total	42,358	21,238	20,171	29,903,944
Average	**1,177**	**590**	**560**	**830,665**

2004	370	222	199	96,960
2005	114	67	69	12,480
2006	0	0	0	0
2007	70	48	31	6,313
2008	188	96	78	141,369
2009	0	0	0	0
2010	885	464	335	622,251
2011	983	554	534	375,154
2012	690	276	88	946,170
2013	0	0	0	0
2014	216	140	112	27,282
2015	210	127	111	32,942
Total	11,138	6,272	5,361	4,715,955
Average	**309**	**174**	**149**	**130,999**

11.7 Load Validation Results

TABLE 27 – PERCENTAGE OF SITES THAT MEET THE GIVEN MORIASI STATISITICS

		RSR				PBIAS				R^2				NSE Monthly				Total			
Model	**Modelled parameter**	*Very Good*	*Good*	*Satisfactory*	*Indicative*	*Very Good*	*Good*	*Satisfactory*	*Indicative*	*Very Good*	*Good*	*Satisfactory*	*Indicative*	*Very Good*	*Good*	*Satisfactory*	*Indicative*	*Very Good*	*Good*	*Satisfactory*	*Indicative*
TSS	*SWNRM*	-	33%	33%	33%	-	33%	67%	-	-	33%	33%	33%	-	33%	33%	33%	-	33%	42%	25%
	CB	-	-	17%	83%	-	17%	17%	67%	-	-	33%	67%	-	-	33%	67%	-	4%	25%	71%
	MNBD	-	-	-	100%	25%	-	-	75%	-	-	25%	75%	-	-	-	100%	6%	-	6%	88%
	Total	-	8%	15%	77%	8%	15%	23%	54%	-	8%	31%	62%	-	8%	23%	69%	2%	10%	23%	65%
TN	*SWNRM*	67%	-	-	33%	33%	33%	33%	-	67%	-	-	33%	67%	-	-	33%	58%	8%	8%	25%
	CB	-	17%	17%	67%	33%	-	-	67%	-	50%	33%	17%	17%	17%	33%	33%	13%	21%	21%	46%
	MNBD	75%	25%	-	-	25%	-	25%	50%	75%	25%	-	-	100%	-	-	-	69%	13%	6%	13%
	Total	38%	15%	8%	38%	31%	8%	15%	46%	38%	31%	15%	15%	54%	8%	15%	23%	40%	15%	13%	31%
TP	*SWNRM*	33%	33%	-	33%	33%	-	67%	-	33%	33%	-	33%	67%	-	-	33%	42%	17%	17%	25%
	CB	17%	-	17%	67%	-	33%	17%	50%	17%	17%	67%	-	17%	17%	33%	33%	13%	17%	33%	38%
	MNBD	-	-	50%	50%	50%	-	-	50%	25%	25%	50%	-	-	75%	25%	-	19%	25%	31%	25%
	Total	15%	8%	23%	54%	23%	15%	23%	38%	23%	23%	46%	8%	23%	31%	23%	23%	21%	19%	29%	31%

TABLE 28 – YEARLY TSS CALIBRATION RESULTS

Catchment	Gauging Station	Modelled parameter	RSR		PBIAS		R^2		NSE Yearly		Total Load
			Value	Rating (Moriasi 2007)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	(predicted /observed)
Bulloo	011202a	TSS	0.502	Good	-19.470	Satisfactory	0.764	Good	0.748	Good	1.1947
Paroo	424201a	TSS	0.619	Satisfactory	-11.981	Good	0.629	Satisfactory	0.616	Satisfactory	1.1198
Warrego	423202c	TSS	0.287	Very good	-18.163	Satisfactory	0.933	Very good	0.917	Very good	1.1816
Condamine	422310c	TSS	0.871	Indicative	-77.744	Indicative	0.467	Satisfactory	0.242	Indicative	1.7774
	422333a	TSS	0.537	Good	-22.075	Indicative	0.797	Good	0.711	Good	1.2207
	422325a	TSS	0.582	Good	-8.749	Very good	0.689	Good	0.661	Satisfactory	1.0875
Maranoa	422404a	TSS	0.698	Satisfactory	-30.024	Indicative	0.545	Satisfactory	0.512	Satisfactory	1.3002
Balonne	422213a	TSS	0.599	Good	18.362	Satisfactory	0.704	Good	0.641	Satisfactory	1.2249
	422204a	TSS	0.793	Indicative	29.075	Indicative	0.440	Satisfactory	0.372	Indicative	1.4099
Moonie	417205a	TSS	0.560	Good	-0.270	Very good	0.730	Good	0.686	Satisfactory	0.9973
Border Rivers	416201a	TSS	0.803	Indicative	-72.150	Indicative	0.706	Good	0.355	Indicative	0.5809
	416001*	TSS	1.052	Indicative	-87.979	Indicative	0.405	Satisfactory	-0.107	Indicative	0.5320
Weir	416202a	TSS	0.862	Indicative	27.632	Indicative	0.345	Indicative	0.256	Indicative	1.3818

TABLE 29 - MONTHLY TSS CALIBRATION RESULTS

Catchment	Gauging Station	Modelled parameter	RSR		PBIAS		R^2		NSE Yearly		Total Load
			Value	Rating (Moriasi 2007)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	(predicted /observed)
Bulloo	011202a	TSS	0.516	Good	-19.463	Satisfactory	0.736	Good	0.734	Good	1.1946
Paroo	424201a	TSS	0.615	Satisfactory	-11.981	Good	0.624	Satisfactory	0.621	Satisfactory	1.1198
Warrego	423202c	TSS	1.220	Indicative	-18.110	Satisfactory	0.016	Indicative	-0.487	Indicative	1.0401
Condamine	422310c	TSS	0.823	Indicative	-78.171	Indicative	0.354	Indicative	0.323	Indicative	1.7817
	422333a	TSS	0.654	Satisfactory	-22.998	Indicative	0.576	Satisfactory	0.573	Satisfactory	0.9970
	422325a	TSS	0.793	Indicative	-11.344	Good	0.394	Indicative	0.372	Indicative	1.1134
Maranoa	422404a	TSS	0.849	Indicative	-33.971	Indicative	0.327	Indicative	0.280	Indicative	0.9999
Balonne	422213a	TSS	0.735	Indicative	16.365	Satisfactory	0.462	Satisfactory	0.460	Satisfactory	0.8363
	422204a	TSS	0.917	Indicative	25.385	Indicative	0.186	Indicative	0.159	Indicative	0.7462
Moonie	417205a	TSS	0.770	Indicative	-1.174	Very good	0.408	Satisfactory	0.405	Indicative	1.0117
Border Rivers	416201a	TSS	0.939	Indicative	-71.168	Indicative	0.202	Indicative	0.118	Indicative	1.7117
	416001*	TSS	1.084	Indicative	-95.310	Indicative	0.084	Indicative	-0.175	Indicative	1.9531
Weir	416202a	TSS	0.867	Indicative	27.988	Indicative	0.267	Indicative	0.249	Indicative	0.7201

TABLE 30 - YEARLY TN CALIBRATION RESULTS

Catchment	Gauging Station	Modelled parameter	RSR		PBIAS		R^2		NSE Yearly		Total Load
			Value	Rating (Moriasi 2007)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	(predicted /observed)
Bulloo	011202a	TN	0.335	Very good	-4.278	Very good	0.889	Very good	0.888	Very good	1.0428
Paroo	424201a	TN	0.597	Good	-19.053	Good	0.770	Good	0.644	Good	1.1905
Warrego	423202c	TN	0.253	Very good	-22.459	Satisfactory	0.977	Very good	0.936	Very good	1.2246
Condamine	422310c	TN	1.363	Indicative	######	Indicative	0.409	Satisfactory	-0.858	Indicative	2.3690
	422333a	TN	0.473	Very good	-9.667	Very good	0.894	Very good	0.776	Very good	1.0967
	422325a	TN	0.630	Satisfactory	28.526	Satisfactory	0.844	Very good	0.603	Good	0.7147
Maranoa	422404a	TN	0.658	Satisfactory	8.078	Very good	0.689	Good	0.568	Good	0.9192
Balonne	422213a	TN	0.667	Satisfactory	41.997	Indicative	0.851	Very good	0.555	Good	0.5800
	422204a	TN	0.281	Very good	-14.166	Very good	0.947	Very good	0.921	Very good	1.1417
Moonie	417205a	TN	0.474	Very good	31.983	Indicative	0.873	Very good	0.776	Very good	0.6802
Border Rivers	416201a	TN	0.560	Good	28.168	Satisfactory	0.912	Very good	0.686	Very good	0.7183
	416001*	TN	0.451	Very good	9.784	Very good	0.914	Very good	0.797	Very good	0.9022
Weir	416202a	TN	0.573	Good	31.984	Indicative	0.851	Very good	0.672	Very good	0.6802

TABLE 31 - MONTHLY TN CALIBRATION RESULTS

Catchment	Gauging Station	Modelled parameter	RSR		PBIAS		R^2		NSE Yearly		Total Load
			Value	Rating (Moriasi 2007)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	(predicted /observed)
Bulloo	011202a	TN	0.298	Very good	-4.278	Very good	0.911	Very good	0.911	Very good	1.0428
Paroo	424201a	TN	0.468	Very good	-19.053	Good	0.813	Very good	0.781	Very good	1.1905
Warrego	423202c	TN	1.374	Indicative	-22.422	Satisfactory	0.014	Indicative	-0.887	Indicative	1.2242
Condamine	422310c	TN	0.989	Indicative	-136.908	Indicative	0.399	Indicative	0.022	Indicative	2.3691
	422333a	TN	0.531	Good	-9.574	Very good	0.768	Good	0.719	Very good	1.0957
	422325a	TN	0.835	Indicative	64.726	Indicative	0.716	Good	0.303	Indicative	0.3527
Maranoa	422404a	TN	0.727	Indicative	9.489	Very good	0.529	Satisfactory	0.471	Satisfactory	0.9051
Balonne	422213a	TN	0.674	Satisfactory	41.871	Indicative	0.739	Good	0.546	Good	0.5813
	422204a	TN	0.763	Indicative	45.907	Indicative	0.600	Satisfactory	0.417	Satisfactory	0.5409
Moonie	417205a	TN	0.520	Good	31.716	Indicative	0.750	Good	0.729	Very good	0.6828
Border Rivers	416201a	TN	0.496	Very good	28.452	Satisfactory	0.888	Very good	0.754	Very good	0.7155
	416001*	TN	0.473	Very good	10.023	Very good	0.821	Very good	0.776	Very good	0.8998
Weir	416202a	TN	0.471	Very good	32.084	Indicative	0.864	Very good	0.778	Very good	0.6792

TABLE 32 - YEARLY TP CALIBRATION RESULTS

Catchment	Gauging Station	Modelled parameter	RSR		PBIAS		R^2		NSE Yearly		Total Load
			Value	Rating (Moriasi 2007)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	(predicted /observed)
Bulloo	011202a	TP	0.457	Very good	-21.686	Satisfactory	0.829	Very good	0.791	Very good	1.2169
Paroo	424201a	TP	0.615	Satisfactory	-22.721	Satisfactory	0.679	Good	0.622	Good	1.2272
Warrego	423202c	TP	0.226	Very good	-10.060	Very good	0.959	Very good	0.949	Very good	1.1006
Condamine	422310c	TP	1.361	Indicative	######	Indicative	0.404	Satisfactory	-0.854	Indicative	2.5140
	422333a	TP	0.558	Good	-66.504	Indicative	0.833	Very good	0.689	Very good	1.6650
	422325a	TP	0.664	Satisfactory	21.884	Satisfactory	0.763	Very good	0.560	Good	0.7812
Maranoa	422404a	TP	0.696	Satisfactory	-19.395	Good	0.567	Satisfactory	0.516	Good	1.1939
Balonne	422213a	TP	0.701	Indicative	38.589	Indicative	0.775	Very good	0.509	Good	0.6141
	422204a	TP	0.286	Very good	-14.386	Very good	0.931	Very good	0.918	Very good	1.1439
Moonie	417205a	TP	0.489	Very good	34.737	Indicative	0.919	Very good	0.761	Very good	0.6526
Border Rivers	416201a	TP	0.705	Indicative	10.425	Very good	0.758	Very good	0.503	Good	0.8958
	416001*	TP	0.645	Satisfactory	0.736	Very good	0.748	Very good	0.584	Good	0.9926
Weir	416202a	TP	0.723	Indicative	40.813	Indicative	0.811	Good	0.478	Satisfactory	0.5919

TABLE 33 - MONTHLY TP CALIBRATION RESULTS

			RSR		PBIAS		R^2		NSE Yearly		Total Load
Catchment	**Gauging Station**	**Modelled parameter**	Value	Rating (Moriasi 2007)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	Value	Rating (Moriasi 2015)	(predicted /observed)
Bulloo	011202a	TP	0.436	Very good	-21.686	Satisfactory	0.823	Very good	0.810	Very good	1.2169
Paroo	424201a	TP	0.556	Good	-22.346	Satisfactory	0.695	Good	0.691	Very good	1.2235
Warrego	423202c	TP	1.224	Indicative	-10.020	Very good	0.017	Indicative	-0.498	Indicative	1.1002
Condamine	422310c	TP	0.986	Indicative	-151.289	Indicative	0.368	Satisfactory	0.028	Indicative	2.5129
	422333a	TP	0.621	Satisfactory	-66.336	Indicative	0.642	Good	0.615	Good	1.6634
	422325a	TP	0.749	Indicative	21.873	Satisfactory	0.541	Satisfactory	0.439	Satisfactory	0.7813
Maranoa	422404a	TP	0.807	Indicative	-17.430	Good	0.351	Satisfactory	0.349	Indicative	1.1743
Balonne	422213a	TP	0.743	Indicative	38.389	Indicative	0.600	Satisfactory	0.448	Satisfactory	0.6161
	422204a	TP	0.415	Very good	-15.210	Good	0.839	Very good	0.828	Very good	1.1521
Moonie	417205a	TP	0.601	Satisfactory	34.307	Indicative	0.718	Very good	0.638	Good	0.6569
Border Rivers	416201a	TP	0.745	Indicative	11.295	Very good	0.544	Satisfactory	0.444	Satisfactory	0.8871
	416001*	TP	0.702	Indicative	1.406	Very good	0.570	Satisfactory	0.508	Good	0.9859
Weir	416202a	TP	0.626	Satisfactory	41.024	Indicative	0.794	Good	0.608	Good	0.5898

11.8 Nitrogen and Phosphorus Relationship Figures with Flow

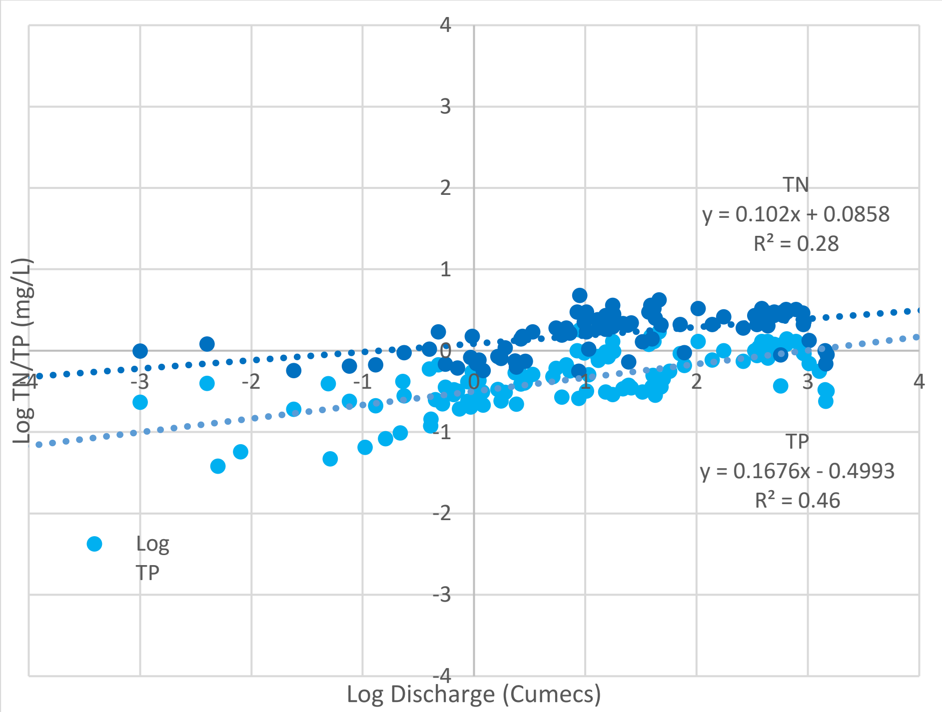


FIGURE 38 - SWNRM LOG DISCHARGE VS LOG TN/TP RELATIONSHIPS

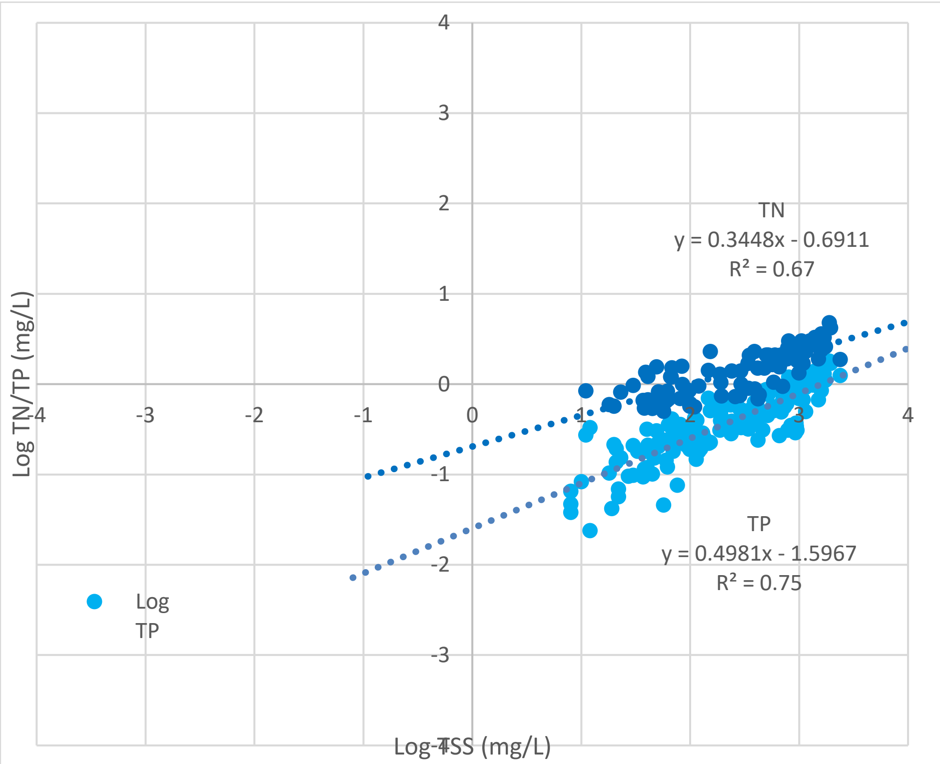


FIGURE 39 - SWNRM LOG TSS VS TN/TP RELATIONSHIPS

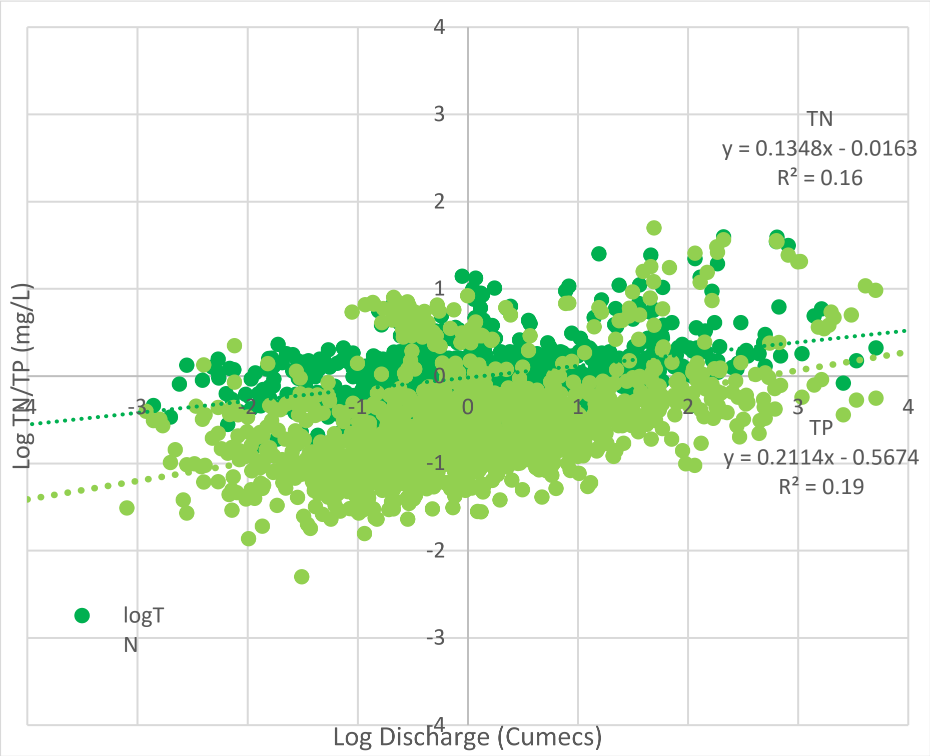


FIGURE 40 - CB LOG DISCHARGE VS LOG TN/TP RELATIONSHIPS

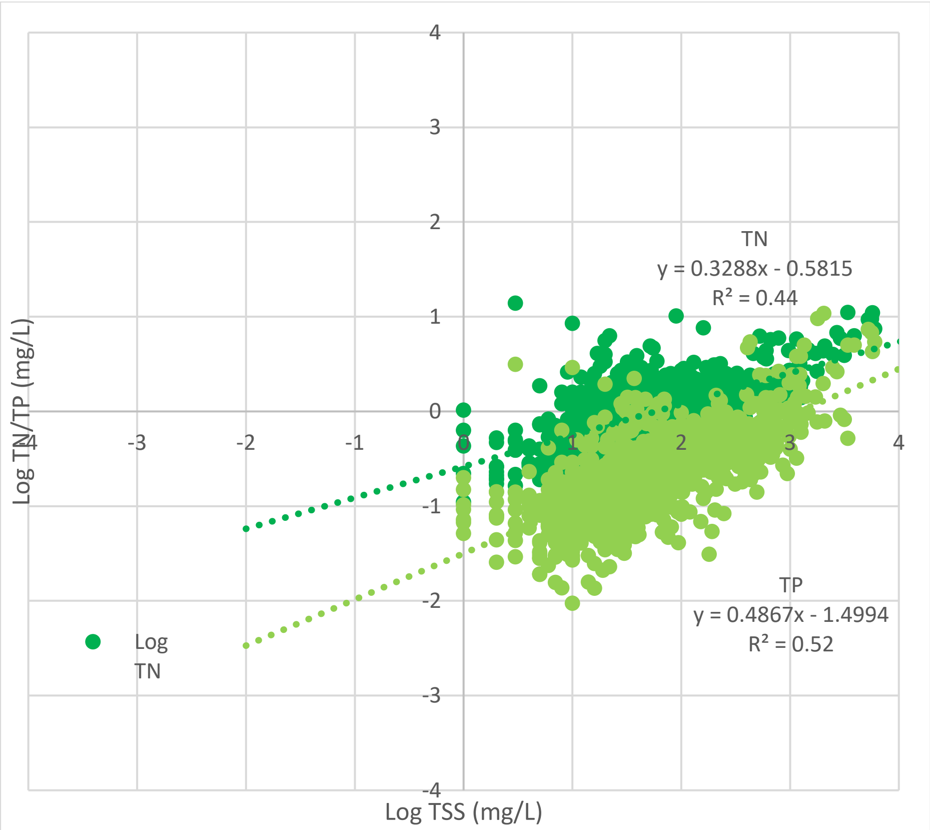


FIGURE 41 - CB LOG TSS VS TN/TP RELATIONSHIPS

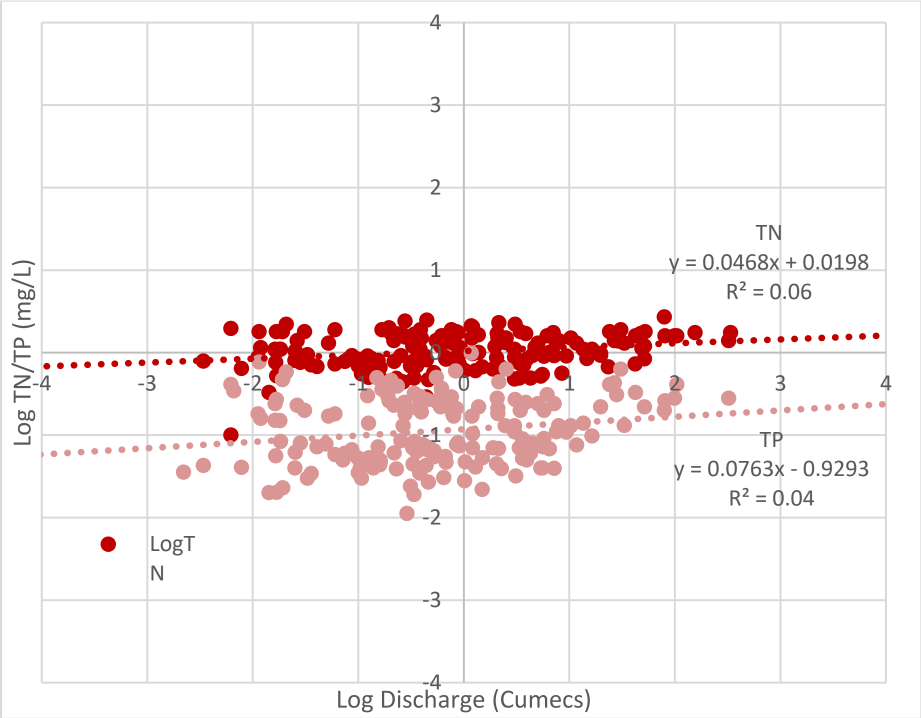


FIGURE 42 - BDMN LOG DISCHARGE VS LOG TN/TP RELATIONSHIPS

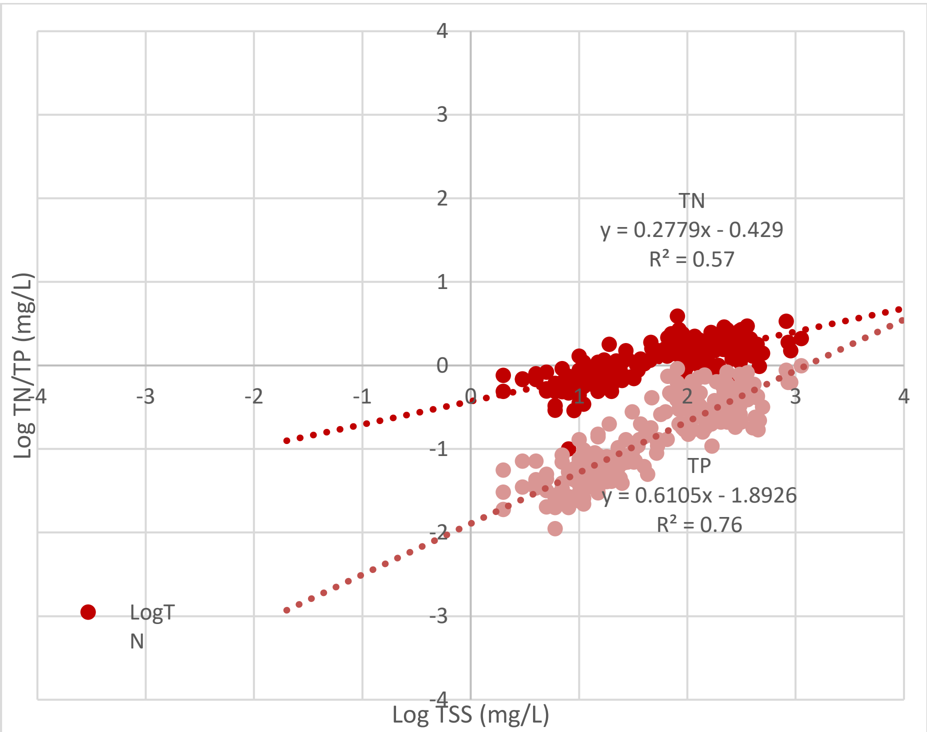


FIGURE 43 - BDMN LOG TSS VS TN/TP RELATIONSHIPS

11.9 COMMUNICATION WITH QMDB STAKEHOLDERS

TABLE 34 - COMMUNICATION WITH MAJOR STAKEHOLDERS IN THE QMDB

Organisation	Communication	Date
AgForce	Letter	Feb, 2016
Cotton Australia	Letter	Feb, 2016
Landcare	Letter	Feb, 2016
Southern Downs Regional Council	Letter	Feb, 2016
Toowoomba Regional Council	Letter	Feb, 2016
Western Downs Regional Council	Letter	Feb, 2016
Condamine Catchment Management Association	Letter	Feb, 2016
Condamine Balonne Water Committee	Letter	Feb, 2016
Queensland Murray Darling Committee	Phone Call/letter/Visit	Feb, 2016; May 2017
Condamine Alliance	Phone Call/letter/Visit	Feb, 2016; May 2017
South West Natural Resource Management	Phone Call/letter/Visit	Feb, 2016; May 2017

TABLE 35 – LANDUSE CONTRIBUTION TO EXPORT PER UNIT AREA EXPRESSED AS A PERCENTAGE OF TOTAL

	Balonne			Condamine			Maranoa			Border Rivers			Moonie			Bulloo			Nebine			Paroo			Warrego		
Land Use	***TSS***	***TN***	***TP***	***TSS***	***TN***	***TP***	***TSS***	***TN***	***TP***	***TSS***	***TN***	***TP***	***TSS***	***TN***	***TP***	***TSS***	***TN***	***TP***	***TSS***	***TN***	***TP***	***TSS***	***TN***	***TP***	***TSS***	***TN***	***TP***
Conservation	7%	7%	8%	11%	8%	9%	1%	5%	6%	19%	7%	9%	8%	6%	5%	3%	7%	4%	12%	7%	11%	10%	8%	10%	7%	7%	9%
Cropping	32%	25%	30%	13%	17%	22%	24%	20%	24%	18%	35%	41%	20%	30%	39%	0%	0%	0%	17%	9%	14%	0%	0%	0%	10%	7%	8%
Grazing	12%	16%	15%	27%	18%	20%	9%	11%	11%	36%	20%	19%	33%	26%	21%	88%	92%	89%	68%	83%	73%	80%	90%	84%	74%	82%	76%
Forestry	1%	3%	2%	7%	7%	8%	1%	3%	3%	5%	3%	3%	5%	16%	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%	2%
Horticulture	4%	5%	5%	3%	4%	6%	7%	7%	8%	7%	4%	5%	7%	6%	8%												
Intensive animal industry	2%	6%	5%	5%	13%	17%	13%	11%	14%																		
Mining	3%	4%	3%	7%	4%	2%	8%	6%	6%	2%	7%	8%	0%	0%	0%												
Other	5%	6%	5%	4%	6%	6%	7%	7%	8%	3%	8%	7%	8%	16%	17%	9%	7%	8%	6%	7%	5%	7%	7%	7%	6%	5%	5%
Rural Residential	2%	5%	2%	6%	9%	3%	7%	11%	6%																		
Stream	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
System Supply	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Urban	5%	7%	4%	3%	9%	1%	8%	11%	4%	5%	15%	8%	0%	0%	0%												
Waste Treatment	4%	3%	4%	7%	2%	2%	7%	4%	5%																		
Water	22%	12%	18%	8%	2%	4%	7%	4%	6%	5%	0%	1%	18%	1%	3%	9%	1%	7%	3%	1%	2%	9%	2%	6%	6%	1%	5%

TABLE 36 - COMPARISON OF MDB LOADS TO GBR LOADS BY BASIN

Catchment	TN (t/yr)	TP (t/yr)	TSS (kt/yr)	Flow ML/yr	Area km^2
Cape York	6,854	682	526	16,400,000	43,000
Wet Tropics	16,577	2,301	1,516	23,500,000	21,700
Burdekin	8,793	2,823	3,781	12,700,000	140,700
Mackay Whit.	4,806	1,306	818	6,200,000	9,000
Fitzroy	10,907	4,665	1,824	9,200,000	155,500
Burnett Mary	7,146	1,642	1,459	5,400,000	53,000
Con+Mar+Bal	1,805	1,634	189	1,346,526	87,625
Bulloo	1,755	832	874	880,657	51,876
Paroo	913	342	326	557,461	32,256
Warrego	727	254	310	355,131	65,682
Moonie	143	17	5	170,136	15,905
Border Rivers	1,001	127	49	1,196,701	50,743