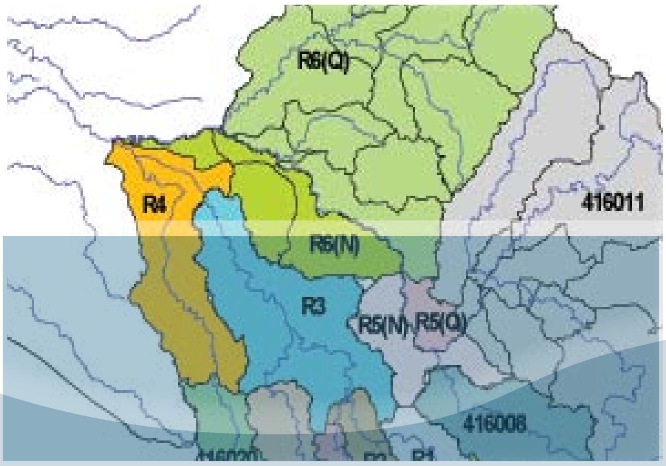
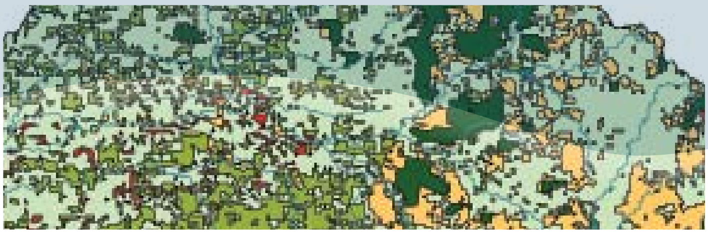
Instream salinity models of NSW tributaries in the Murray-Darling Basin

Volume 1 – Border Rivers Salinity Integrated Quantity and Quality Model





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Volume 1 – Border Rivers Salinity Integrated Quantity and Quality Model

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Volumes in this set:

In-stream Salinity Models of NSW Tributaries in the Murray Darling Basin

- Volume 1 – Border Rivers Salinity Integrated Quantity and Quality Model
- Volume 2 – Gwydir River Salinity Integrated Quantity and Quality Model
- Volume 3 – Namoi River Salinity Integrated Quantity and Quality Model
- Volume 4 – Macquarie River Salinity Integrated Quantity and Quality Model
- Volume 5 – Lachlan River Salinity Integrated Quantity and Quality Model
- Volume 6 – Murrumbidgee River Salinity Integrated Quantity and Quality Model
- Volume 7 – Barwon-Darling River System Salinity Integrated Quantity and Quality Model

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Contents

Figures

Page

Tables

Page

1. Introduction

1.1. PURPOSE OF REPORT

The purpose of this report is to document the results of work carried out to develop a Border Rivers Salt Transport Model. This model was developed to meet the needs of the Murray-Darling Basin Salinity Management Strategy (Basin Strategy – BSMS see Section 1.3.3.1) and the NSW Salinity Strategy (SSS). This report is intended primarily for an audience with a technical and/or policy background concerned with salinity management

The model substantially increases the salinity modelling capability by NSW for salinity management in the Murray-Darling Basin (MDB), and represents the best available interpretation of salinity processes in these NSW Rivers. The geographic scope of the work is extensive, covering an area of about 600,000 km^2. The model can assess in-stream effects of water sharing policies, as well as working jointly with the 2CSalt model to assess in-stream salinity and water availability effects of land use and management. These effects can be assessed at a daily time scale for a 25-year period at key locations within the Border Rivers Basin. The model can also link with other models to assess effects at key locations in the Darling River and/or Murray River.

1.1.1. Report structure

This modelling has taken place against a historical background of basinwide salinity management, which is discussed in Section 1.2. A number of basinwide and statewide natural resource management policies are relevant to salinity management and the need for this model. The modelling requirements are clearly set out in Schedule C of the Murray Darling Basin Agreement. The policies are discussed in Section 1.3, with a focus on Schedule C in Section 1.3.3. This model is one of a suite of models and decision support systems that have been developed for salinity management, and this is discussed in Section 1.4. The steps taken to develop this model are discussed in the final section of this chapter.

The processes affecting salinity behaviour in a catchment are influenced by many physical factors, and the most important of these are described in Chapter 2. Whereas the actual salinity behaviour is best described by data, and the data available to characterise this behaviour is described in Chapter 3. The salt transport model was developed using a daily water balance model as the platform. The Border Rivers Integrated Quantity Quality Model (IQQM) has been used for water resource management for several years in the NSW, and was converted to the salt transport model in this project. The software used for the model was thoroughly tested and enhanced to eliminate any technical faults. The Border Rivers IQQM and software testing is described in Chapter 4.

Estimating salt loads entering the river system is the key task to develop a model that will reliably estimate in-stream salinity behaviour so that it is suitable for the intended purpose. The results of existing and calibrated estimates are documented in Chapter 5. The calibrated model is intended to be used evaluate scenarios, the most important of which is a baseline condition (described in Section 1.3.3), as well as impacts of changing land use, management, and water sharing. The results for the baseline condition are reported and discussed in Chapter 6. The development of models for salinity management is a comparatively new field of work in the MDB, when compared to water balance modelling. The Schedule C foresees the need to improve estimates in light of both limitations of the current work, additional data, and improved technical capability of the scientific organisations. An assessment of the limitations of the model, and some recommendations for future improvement are discussed in Chapter 7.

1.1.2. Related reports

This report is one of seven similar reports for each of the major NSW tributaries of the MDB. The reports are:

- Volume 1 - Border Rivers (jointly with Queensland);
- Volume 2 - Gwydir River;
- Volume 3 - Namoi and Peel Rivers;
- Volume 4 - Macquarie, Castlereagh and Bogan Rivers;
- Volume 5 - Lachlan River;
- Volume 6 - Murrumbidgee River; and
- Volume 7 - Barwon-Darling River.

Each tributary report is complete and self-explanatory, describing what was done for each stage of model development. However, these descriptions have been kept brief to ensure the report content is more focused on information and results specific to that tributary. Note that this report primarily summarizes the modeling work undertaken prior to 2005.

1.2. HISTORICAL BACKGROUND TO WORK

Modelling in-stream salinity has a history extending to before the development of the Murray-Darling Basin Commission (MDBC) 1988 Salinity and Drainage Strategy, which focused on irrigation induced salinity. The complexity and scope of modelling of dryland salinisation processes has evolved in line with the needs of natural resource management. With the concerns about dryland salinity came additional water quality data to provide evidence of the salinity trends. The increased data led to broad policy and greater demands on models to provide useful results to guide the cost effective selection of salinity management options. The following sections give a brief history of the development of salinity policy and its implications on the development of salinity modelling.

1.2.1. 1988 Salinity and Drainage Strategy

The Murray Darling Basin Ministerial Council (MDBMC) adopted the Salinity and Drainage Strategy (SDS) in 1988. The objectives of the strategy revolved around:

- improving the water quality in the Murray River for the benefit of all users;
- controlling existing land degradation, prevent further degradation and where possible rehabilitate resources to ensure sustainable use; and
- conserving the natural environment.

The SDS set out specific salinity reduction targets against benchmark conditions. The strategy also defined the rights and responsibilities of the State and Commonwealth Governments. Implementation included applying the strategic direction and allocating salinity credits and construction of various projects (under cost sharing arrangements). The salinity assessment work required a combination of observed salinity data and in stream river modelling. Assessments of salinity impacts were at a local or semi-regional scale, eg. Beecham and Arranz (2001), and the results from these were assessed by the MDBC for salinity impact in the Murray River.

The 1999 SDS review identified major achievements of the SDS as: (i) reducing salt entering the Murray River by constructing salt interception scheme; and (ii) developing land, water and salt management plans to identify and manage the problems.

1.2.2. 1997 Salt trends

Concerns about the increase in the extent of dryland salinisation prompted an assessment of water quality data to look for evidence of a corresponding increase in in-stream salinities. The resultant Salt Trends study (Jolly et al., 1997) reported increasing trends in Electrical Conductivity (EC) over time in major and minor tributaries of the MDB.

The factors controlling salt mobilisation were identified and included a wide range of processes including climatic distribution, groundwater hydrology and chemistry, landuse, surface water hydrology and chemistry, geology, topography, soil characteristics and land degradation. The study recommended a broad range of activities be undertaken to better understand the dry land salinisation processes.

1.2.3. 1999 Salinity Audit

The awareness from studies such as Salt Trends highlighted that instream impacts of dryland salinisation were greater than first though prior to development of the SDS. This prompted further investigations to provide information on the possible future magnitude of increased instream salinity. To this end, the MDBC coordinated a Salinity Audit of the whole MDB (MDBC, 1999). The Salinity Audit was intended to establish trend in salt mobilisation in the landscape, and corresponding changes in in-stream salinities for all major tributaries, made on the basis that there were not going to be any changes in management.

The methods adopted by NSW (Beale et al., 1999) to produce these outputs linked statistical estimates of flow and salt load in tributaries of the MDB, with rates of groundwater rise in their catchments. The results of this study indicated that salinity levels in the NSW tributaries of the MDB would significantly increase over the next 20-100 years, with major associated economic and environmental costs.

The results of the Salinity Audit resulted in the MDBMC and NSW Government developing strategies to manage salinity. These are reported in Sections 1.3.3 and 1.3.6 respectively.

1.2.4. 2006 Salinity Audit

Additional biophysical data has recently been analysed which confirm the actual extent of salinity outbreaks and current status of in-stream salinity. However, these studies have also cast serious doubt on trends predicted using rising groundwater extrapolations (DECC 2006). A concerted effort to improve understanding of the extent of salinity, and its relationship with climatic regime and groundwater behaviour in the hydrological cycle in different contexts, has shown inconsistencies with the general regional rising water tables theory (Summerell et al. 2005).

In particular, the new work indicates that climate regime so dominates that it is difficult to detect the impacts of land-use or management interventions, and that response times between recharge and discharge, especially in the local-scale fractured rock aquifer systems that dominate in the tablelands and slopes of eastern NSW, are much shorter than previously thought. This leads to the conclusion that the impacts of clearing on groundwater levels have already been incurred, so no continuing effect can be attributed to this cause. Many (not all) of the NSW MDB subcatchments are in a state of 'dynamic equilibrium', and their groundwater levels fluctuate about a new average value in response to climate regime (long periods of above or below average rainfall) (DECC, 2007).

1.3. CURRENT POLICY FRAMEWORK

A range of natural resource polices provide reasons for developing the salt transport models. These include basinwide policies developed through the MDBC, and Statewide policies developed through the NSW Government. The interrelationship of the key policies to this work are shown in Figure 1.1.

1.3.1. MDBC Integrated Catchment Management

Integrated Catchment Management (ICM) is the process by which MDBC seeks to meet its charter to:

> "…promote and coordinate effective planning and management for the equitable, efficient and sustainable use of the water, land and other environmental resources of the Murray–Darling Basin." (MDBC, 2001)

The ICM process requires that stakeholders consider the effect on all people within the catchment of their decisions on how they use land, water and other environmental resources. The process uses management systems and strategies to meet targets for water sharing and water quality. Two strategies that fall under ICM are described in Section 1.3.2 and Section 1.3.3.

1.3.2. Murray-Darling Basin Ministerial Council Cap on water diversions

In 1997 the MDBMC implemented a cap on water diversions ("The Cap") in the MDB. The Cap was developed in response to continuing growth of water diversions and declining river health, and was the first step towards striking a balance between consumptive and instream users in the Basin. The Cap limits diversions to that which would have occurred under 1993/4 levels of:

- irrigation and infrastructure development;
- water sharing policy; and
- river operations and management.

1.3.3. Murray-Darling Basin Ministerial Council Basin Salinity Management Strategy

The MDBMC responded to the salinity problems predicted in the Salinity Audit with the Basin Salinity Management Strategy (BSMS). The objectives of the strategy are:

- maintain the water quality of the shared water resources of the Murray and Darling Rivers;
- control the rise in salt loads in all tributaries of the basin;
- control land degradation; and
- maximise net benefits from salinity control across the Basin.

These BSMS is implementing nine elements of strategic action, including:

- capacity building;
- identify values and assets at risk;
- setting salinity targets;
- managing trade-offs;
- salinity and catchment management plans,
- redesigning farming systems;
- targeting reforestation and vegetation management;
- constructing salt interception works; and
- ensuring Basin-wide accountability by monitoring, evaluating and reporting.

The last of these is particularly relevant to this work. The statutory requirements for the BSMS are specified in Schedule C of the Murray-Darling Basin Agreement, replacing those parts that previously referred to the 1988 SDS. The key parts of Schedule C that relate to the modelling work are discussed in the following subsection.

1.3.3.1. Schedule C of the Murray-Darling Basin Agreement

Clauses 5(2), 5(3), 37(1) and 36(1)(a) of Schedule C dictate that the MDBC and the Contracting States must prepare estimates of baseline conditions flow, salt load, and salinity for the benchmark period at the end-of-valley target site for each of the major tributaries by 31 March 2004. These estimates must be approved by a suitably qualified panel appointed by the MDBC.

The baseline conditions refers to the physical and management status of the catchment as of 1 January 2000, specifically:

- land use (level of development in landscape);
- water use (level of diversions from the rivers);
- land and water management policies and practices;
- river operation regimes;
- salt interception schemes;
- run-off generation and salt mobilisation; and
- groundwater status and condition.

The benchmark climatic period refers to the 1 May 1975-30 April 2000 climate sequence; ie., rainfall and potential evapotranspiration.

Part VIII of Schedule C refers specifically to models, and sets out the performance criteria for the models. The models must be able to:

(i) Simulate under Baseline Conditions, the daily salinity, salt load and flow regime at nominated sites for the Benchmark Climatic period.

(ii) Predict the effect of all accountable Actions and delayed salinity impacts on salinity, salt load and flow at each of these nominated sites for each of 2015, 2050, and 2100,

These model capabilities must be approved by a suitably qualified panel appointed by the MDBC. There is specific prevision that the models are reviewed by the end of 2004, and at seven-yearly intervals thereafter.

1.3.4. Catchment Action Plans

The NSW Government established the Catchment Management Boards Authorities in 2003, whose key roles include developing Catchment Action Plans (CAPs), and managing incentive programs to implement the plans. These are rolling three-year investment strategies and are updated annually.

The CAPs are based on defining investment priorities for natural resource management, and salinity is one aspect that is considered where appropriate. Models can play an important role in identifying where to target investment to achieve the best environmental benefit value for money which supports prioritisation. Models also have a crucial role in monitoring, evaluation and reporting, if only because they provide a means of separating the effects of the management signal from the dominant climate signal. The models bring consistency and rigour to analysis of alternate management options, and help comply with the Standard for Quality Natural Resource Management (NRC, 2005).

1.3.5. NSW Water Sharing Plans

The Water Management Act 2000 aims to provide better ways to equitably share and manage NSW's water resources. Water Sharing Plans are ten year plans that outline how water is to be shared between the environment and water users. These plans cover both surface water and groundwater and both inland and coastal areas and contain both rules for resource access and use.

1.3.6. NSW Salinity Strategy

In 2000, the NSW Government released the NSW Salinity Strategy. The Strategy brought together previously divided approaches into one strategy revolving around salinity targets. The salinity targets enable:

- Quantification of desirable salinity outcomes;
- Management of cumulative impacts of various actions at various sites
- Comparison of the environmental, economic and social benefits and costs for various actions; and
- Choice of the most cost effective action to treat the problem.

The salinity targets were developed and recommended through the Catchment Management Boards. To monitor the salinity targets and to assess the impacts of management options for land use changes on these salinity targets, numerical modelling tools to estimate salt load wash off and salt load transport became high priority. The modelling framework to meet these salinity strategies is described in Section 1.4..

1.3.7. NSW Environmental Services Scheme

In 2002, the NSW Government launched the Environmental Services Scheme (ESS) seeking expressions of interest from landholder groups. The aim was to identify the environmental benefits that could be achieved by changed land use activity and to have them valued by the community. This recognised that good farm management can slow the march of salinity, reduce acid sulfate soil and improve water quality. The scheme provides financial support for some of these activities, and is one of the actions under the NSW Salinity Strategy.

To judge the impacts of the proposed land use changes on end of valley and within valley salinity targets has again put pressure on the need for numerical models that can simulate salt wash off processes and salt transport processes.

1.3.8. CMA Incentive schemes

CMA incentive schemes are used as mechanisms for funding on ground works and measures. As with the ESS, the aim is to buy environmental outcomes rather than output. Models are critical to evaluating the expected outcomes from given outputs. Property Vegetation Plans (PVPs) are evaluated with a Decision Support Tool which uses two salinity models. There is provision for incentive PVPs as well as clearing PVPs and continuing use PVPs.

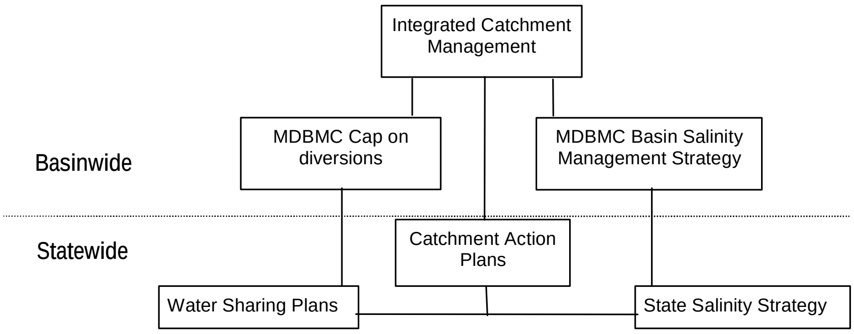


Figure 1.1. Relationship of Basinwide and Statewide policies and plans

1.4. DWE MODEL FRAMEWORK

NSW has developed a framework of models that link the surface water hydrology and salinity processes to support salinity management. A range of processes are represented in models that vary from the property scale to the basin scale. The scale of application of a model, in both spatial sense and temporal sense, influences the model structure and detail. Aspects of natural processes that are important at one scale may not matter at another. Figure 1.2 shows the linkages between the surface water and salinity models, their application at different scales and the desired outcomes of within valley and end of valley salinity targets.

1.4.1. Objectives of modelling

The primary objective of the modelling is to support the implementation of the CAPs. This requires understanding and appropriate representation of the salt movement in and from the landscape to the streams, and in the streams to the end of valley target locations.

Property scale modelling is required to support decisions on land use change and property investments on-farm. This required modelling of the effect of land use on runoff, salt washoff, and recharge. Decisions at this scale can directly impact on the landholder's income.

Moving from the property scale to catchment and then to basin scale requires the dryland salinisation processes to be modelled together with wash off and groundwater interaction to estimate the water and salt flowing into the river system.

The objectives of the basin modelling are to be able to assess the end of valley salinity levels, and evaluating the performance of salinity management scenarios. To achieve this objective salt needs to be transported down the river, amalgamated with other catchment runoff and salt loads. It is also necessary to deal with such issues as dams and major irrigation developments (eg., Murrumbidgee Irrigation).

Model results for salinity need to be available in both concentrations and total salt loads to meet the needs of the policies. Results for impacts of land use changes on streamflow (runoff yields) are also necessary.

1.4.2. Modelling requirements

The modelling had the following requirements:

- Daily predictions

- Applicable across different scales - local (site, property, farm), landscape, sub-catchment, catchment and basin
- Applicable for all NSW catchments
- Model complexity consistent with available data
- Link to tools to evaluate economics, social impacts, environmental services, cumulative impacts
- Represent land use changes and consequent impacts
- must be able to model water management independently

1.4.3. Strengths and Limitations

The following points detail some of the strengths and weakness of this model framework:

- Only technology available consistent with salinity targets – These models are the best available at present to meet the needs of the policy. As time progresses it is expected advancements with these model will improve the model capabilities and output.
- Complements adaptive management approach in NSW
- State of the art modelling appropriate for the temporal and spatial scales required by State and National policy
- Integrates catchment and instream processes
- Model uncertainty
- Data gaps and data uncertainty
- Error propagation
- Spatial generalisation

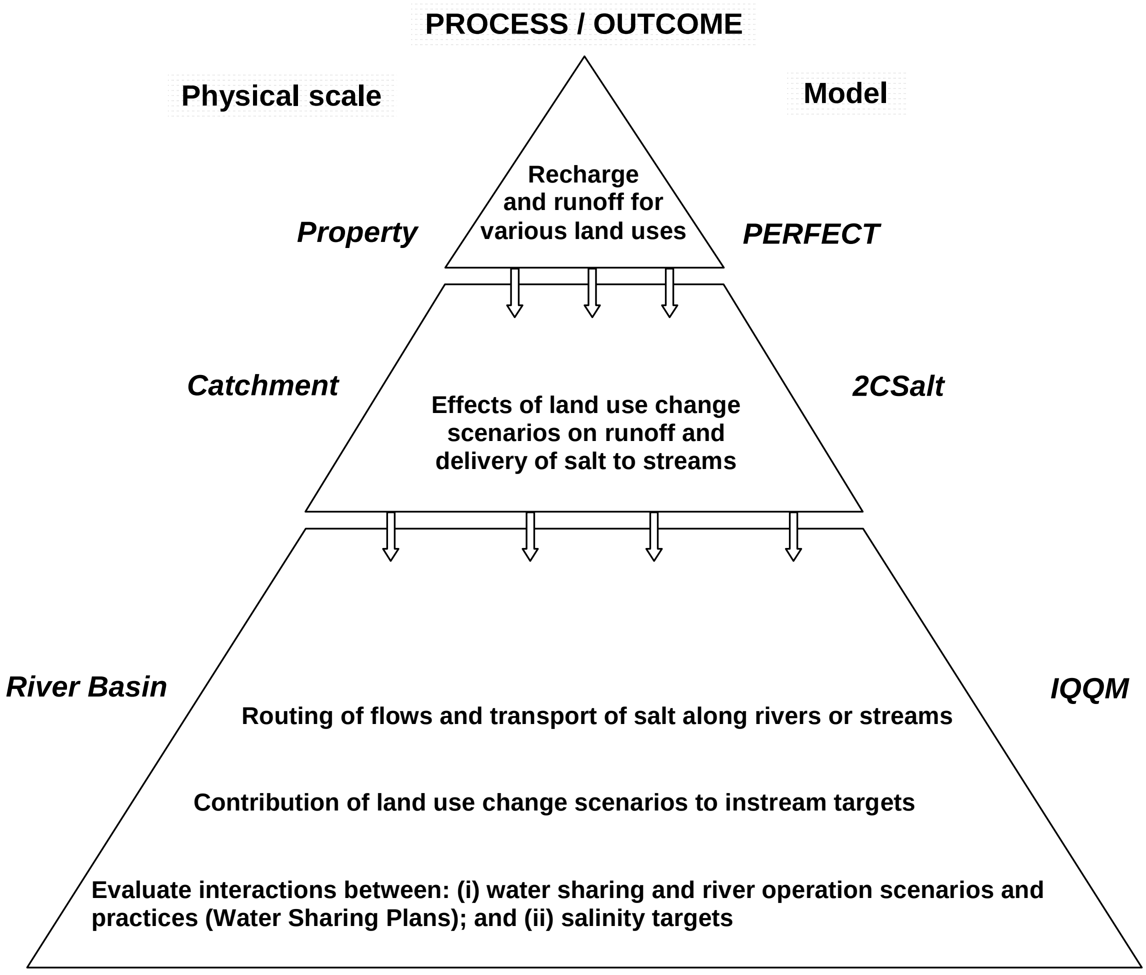


Figure 1.2. Applications and linkages of DECC and DWE models at different scales

1.5. STAGED MODEL DEVELOPMENT

The work reported here was developed in logical stages as shown in Figure 1.3. The tasks in Stage 1 were done in parallel. The initial estimate of salinity behaviour in the river system was done in Stage 2 using the work done for the Salinity Audit (Beale et al., 1999) as the starting point. The results from this task were evaluated in the second task of Stage 2. The first task in Stage 3 was done if the results from the model evaluation were not satisfactory. The final task in model development is running the scenarios. The tasks for all three stages are discussed in more detail in the following subsections.

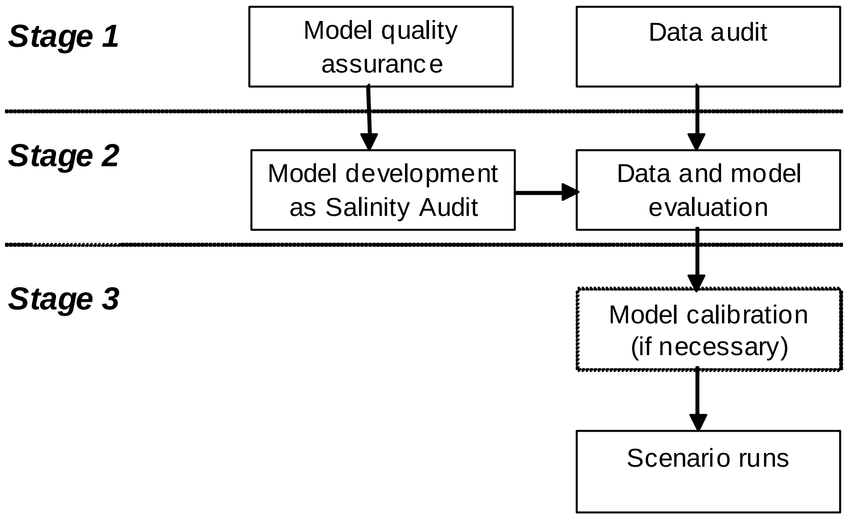


Figure 1.3. Stages of model development

1.5.1. Stage 1: Model QA and Data Audit

The existing IQQM that had been configured and calibrated for the Border Rivers system was the starting point for the in-stream salinity model. The software Fortran 90 source code that simulates the salt transport is relatively untested, and therefore there is the possibility that it contains errors. A set of Quality Assurance (QA) tests was done on the software and tributary model to eliminate any software related errors that could confound interpretation of the results.

Representative data is needed to develop and calibrate the model. Records of discrete and continuous Electrical Conductivity (EC) data are stored on DWE databases. This data was extracted, and an audit of the spatial and temporal characteristics of this data was made. This data was also screened, and some important characteristics analysed. The representativeness of the data was assessed further in Stage 2.

1.5.2. Stage 2: Initial model development and data and model evaluation

This stage was subject to satisfactorily correcting software errors, and completing processing of salinity data. A ‘first cut’ estimate of salinity was made based on the work done for the Salinity Audit, and evaluated against the processed data. This stage tested the possibility that the prior work would produce satisfactory results when converted to a different modelling environment. It would also have the advantage of minimising recalibration of the models and would produce results consistent with those of the Salinity Audit. As these outputs were used to generate salt targets, this is a desirable outcome. For this reason, the similarities and differences between the results are analysed in some depth in Appendix B.

The outputs required from the salt transport model are similar to those required for the Salinity Audit ‘current’ case as reported in Beale et al., 1999. There are two principal differences in the specifications for the output.

(iii) The Baseline Conditions: water sharing policies used to estimate diversions and corresponding river flow were for the 1993/4 levels of development; whereas this work uses 1 January 2000 conditions.

(iv) Benchmark climatic period: was 1 January 1975-31 December 1995; whereas the current benchmark period is 1 May 1975-30 April 2000.

(v) Time step: monthly was needed for the Salinity Audit, whereas daily is needed for the BSMS.

There are also important differences in the methods used:

(vi) Combining tributary flows and salt loads. The Salinity Audit was done using monthly flows processed in EXCEL spreadsheets, whereas this work uses the IQQM daily simulation model.

(vii) Salt balances: The checks to ensure tributary salt loads were consistent with observed data in the mainstream was done using salt loads in the Salinity Audit, whereas this work will be using resultant concentrations.

The results were evaluated by first evaluating how representative the data was, then by comparing model results with salinity observations at target locations to assess the model’s performance. The model evaluation uses objective statistical methods, supported by interpretation and presentation of time series graphs. The statistical methods express measures of confidence in: (i) the ability of the data to represent the system behaviour; and (ii) with what levels of confidence do the model results reproduce the data. These statistical measures were developed to reflect judgements made from traditional visual interpretations of graphs of time series or exceedance plots of the results from simulations compared against observations. The rationale behind this approach is to have a consistent and rigorous way to assess and report results.

1.5.3. Stage 3: Model calibration and scenario modelling

Pending the results of the model evaluation, the inflows to the river system will be revised to better match distributions of salinities at the evaluation points.

The model will then be adjusted to represent various conditions of the river valley. The adjustments would be made to river management operations such as environmental flow rules, irrigation diversion rules. The first scenario will be the *Baseline Conditions* model to represent the flow and salt loads that represent catchment conditions as at 1 January 2000.

2. The Border Rivers System

2.1. PHYSICAL FEATURES OF THE CATCHMENT

2.1.1. General

The Border Rivers system is one of the major subcatchments of the Murray-Darling Basin (Figure 2.1). It straddles the border between New South Wales (NSW) and Queensland (Qld) from the Great Dividing Range near Tenterfield to Mungindi, 300 km to the west. The catchment covers a total area of about 49,470 km^2, of which 25,580 km^2 is in NSW.

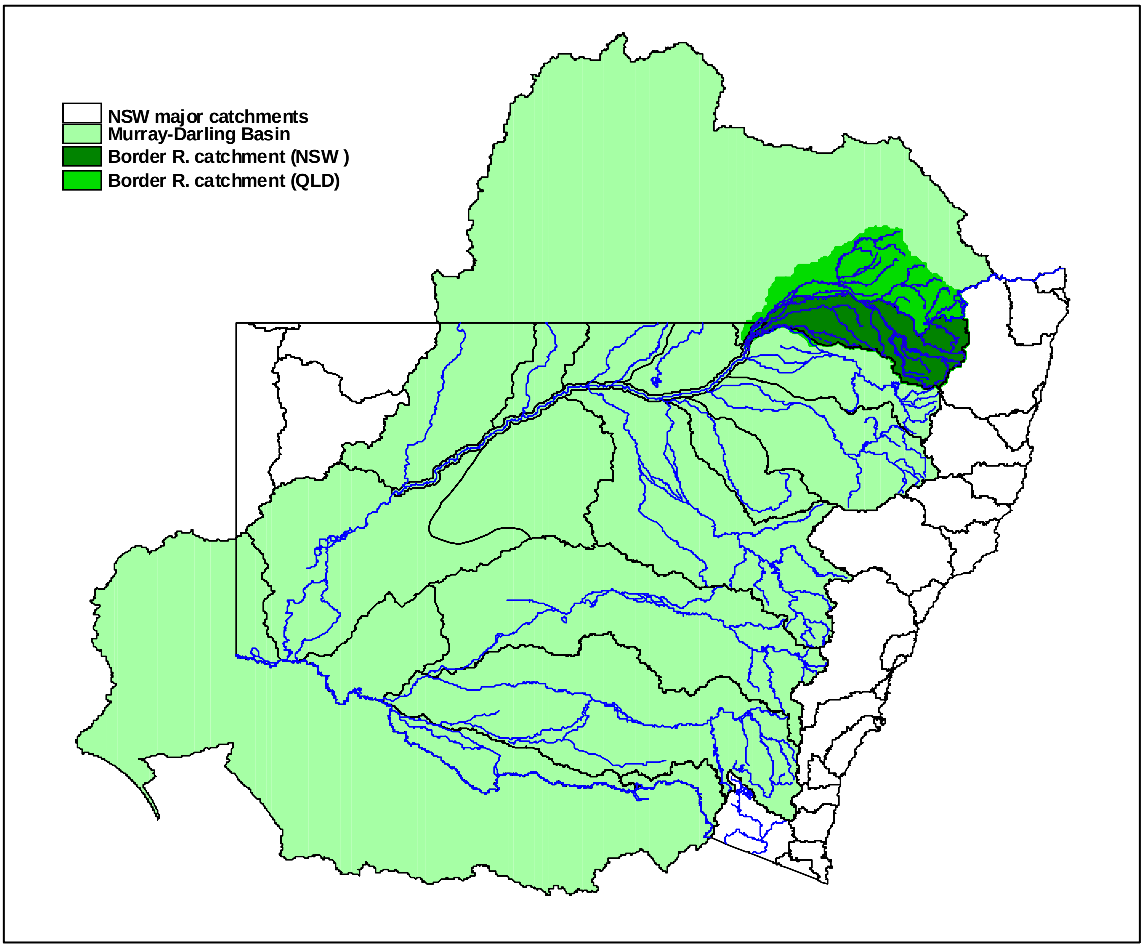


Figure 2.1. Relationship of Border Rivers catchment to Murray-Darling Basin

There are no cities or large towns in the Border Rivers catchment; the largest town is Inverell with a population of about 10,000 people. There are several smaller towns, such as Glen Innes and Tenterfield in NSW and Goondiwindi and Stanthorpe in Queensland, with populations of 3,000 to 6,000 people as well as numerous settlements of less than 1,000 people (Figure 2.2).

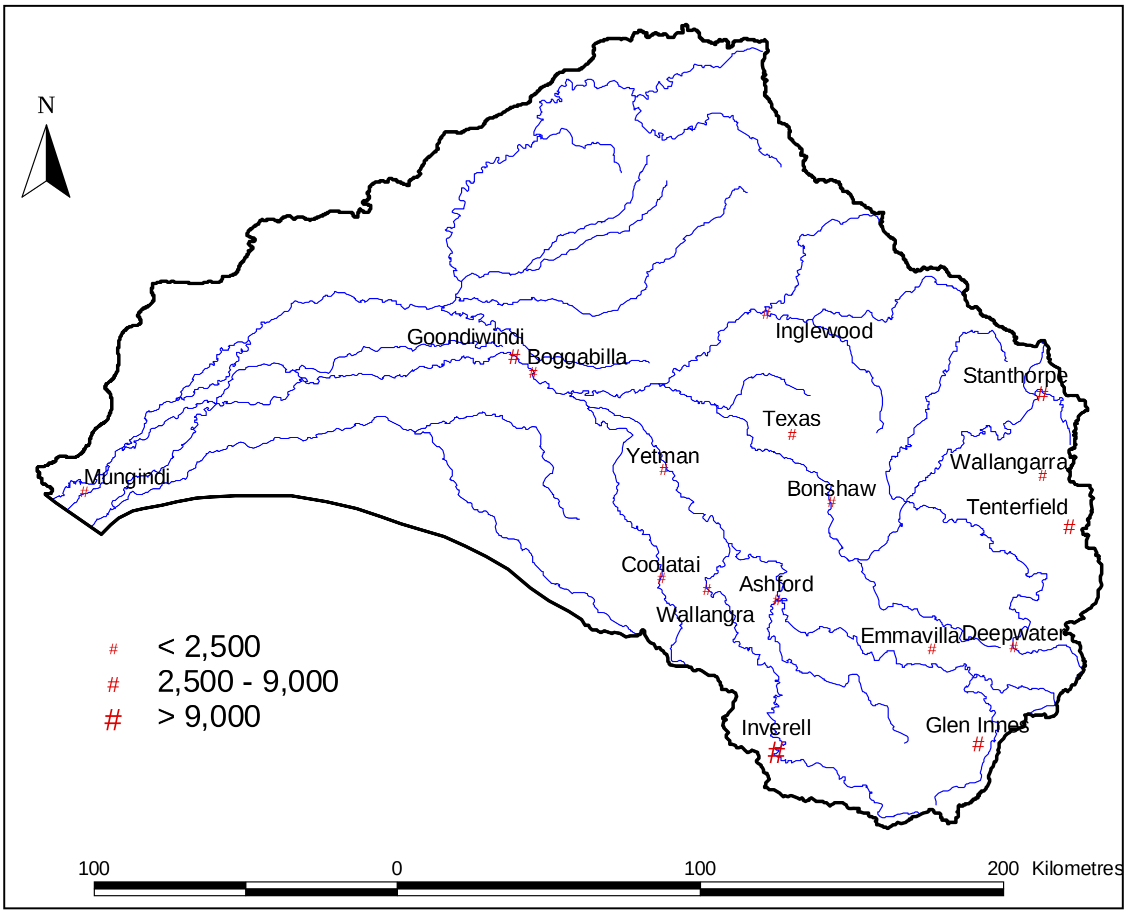


Figure 2.2. Cities and towns in Border Rivers catchment

The catchment can be considered as five regions (Figure 2.3), based on whether it is principally a source region of streamflow, or whether it is a region of extraction:

(i) Dumaresq River (source region)

(ii) Macintyre Brook (source & extraction region)

(iii) Severn-Macintyre Rivers upstream of Dumaresq River junction (source region)

(iv) Macintyre-Barwon Rivers from Dumaresq River junction to end of system at Mungindi (extraction region)

(v) Weir River (source region)

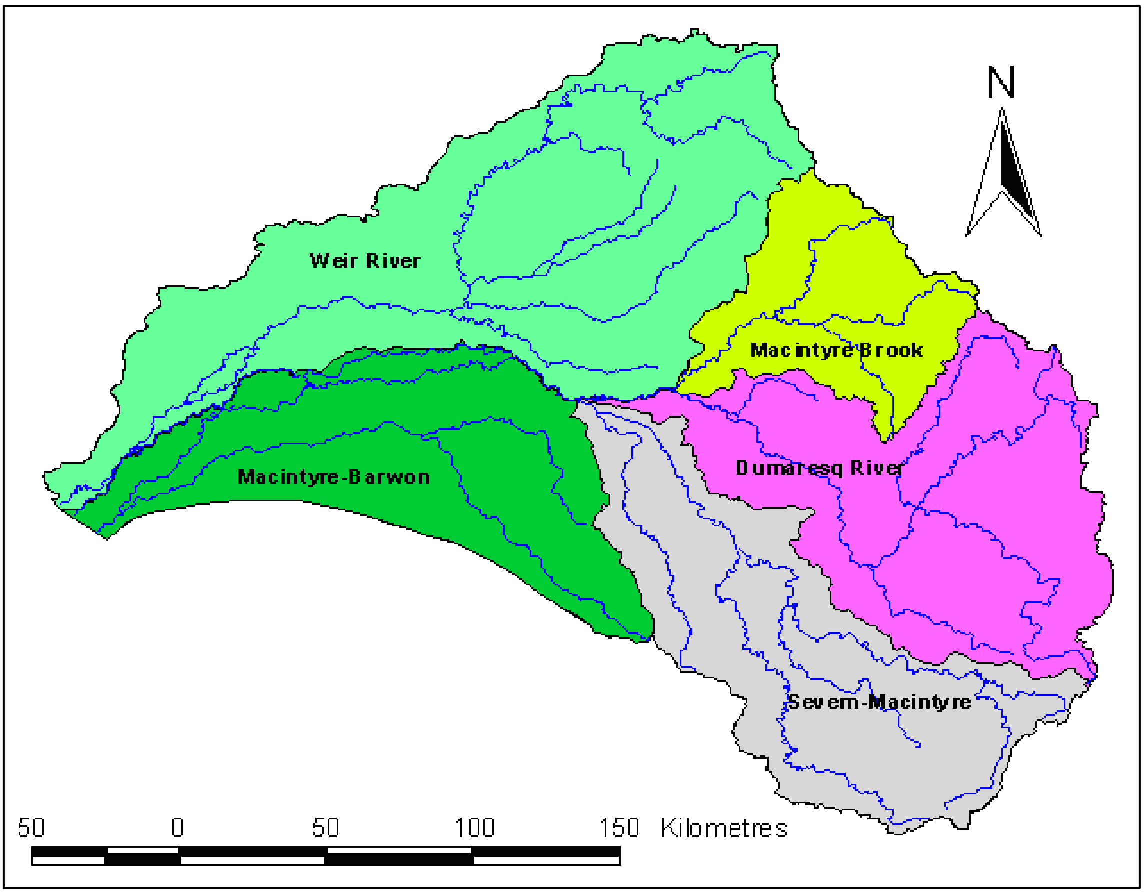


Figure 2.3. Major regions of Border Rivers Catchment

2.1.2. Stream network

2.1.2.1. Dumaresq River

The eastern boundary of this subcatchment is formed by the Great Dividing Range from Stanthorpe (Qld) to Tenterfield and further south. The Dumaresq River is formed by the junction of the Severn River (Qld) and Tenterfield Creek, about 50km west of Tenterfield. The only major storage in this region is Glenlyon Dam, which is a shared facility between the two states and is located on Pike Creek, about 7km upstream of its junction with the Dumaresq River. Further along the Dumaresq River's course, a series of tributaries namely Reedy, Brush and Campbell Creeks, and Beardy River join it. About halfway between Texas and Boggabilla, the Dumaresq River is joined by the Macintyre Brook (Qld). The combined stream flows of this river join the Macintyre River about 20 kilometres upstream of Boggabilla.

The upper reaches of the Dumaresq River and its tributaries flow through narrow valleys with only limited floodplains.

2.1.2.2. Macintyre Brook

The Macintyre Brook originates in the eastern part of the Border Rivers catchment not far from Inglewood (Qld) and is located totally within Queensland. Macintyre Brook together with Bracker and Sandy Creeks provide the inflow to Coolmunda Dam. Downstream of Coolmunda Dam four unregulated tributaries, Canning, Mosquito, Paragiara and Catfish Creeks flow into Macintyre Brook before it's junction with the Dumaresq River some 70 km downstream.

2.1.2.3. Severn-Macintyre Rivers (to Dumaresq River Junction)

The Macintyre River originates near Inverell (NSW). Through its lengthy course, it has confluences with the Severn River, Dumaresq River, and later with the Weir River. For convenience, the Macintyre River was delineated at the Dumaresq confluence and the river upstream of the confluence is considered as the Severn-Macintyre River subcatchment.

The Severn River originates in the south-west of the catchment near Inverell (NSW). Pindari Dam is located on the Severn River about 60 km upstream of the its junction with the Macintyre River. Downstream of Pindari Dam, the Severn River is joined by Frazers Creek, before its confluence with Macintyre River downstream of Ashford. The Macintyre River rises adjacent to the Great Dividing Range near Inverell and flows in a north-westerly direction. Major tributaries in the upper reaches include Swan Brook, Middle and Kings Creeks. In its lower reaches, it is joined by the Severn River and Ottleys Creek prior to its confluence with the Dumaresq River.

The total area of the subcatchment is 8,400 km^2, about 19% of the overall Border Rivers system catchment area, and is situated wholly in NSW. Topography of the catchment downstream of the Severn and Macintyre Rivers confluence is considerably different from the upper part. Here the catchment slopes slightly to the north-west, becoming almost flat downstream of Yetman.

Lagoons and effluents first begin to appear along the Macintyre River near Yetman, however all have either high level or no visible offtake (ie effluent) from the river. The only major low level offtake or effluent along the lower reach is that of the Boonal Anabranch.

2.1.2.4. Macintyre-Barwon River

This subcatchment commences at the confluence of Macintyre River with the Dumaresq River and continues downstream as far as Mungindi (ie end of the Border Rivers system). The Macintyre River is renamed the Barwon River after its confluence with the Weir River. The Weir River is the only significant tributary that joins the Macintyre River in this subcatchment. The Weir River's confluence is about 25 km upstream of Mungindi.

The stream passes through a terrain that broadens and flattens out, forming the beginning of the Barwon-Darling flood plain. In this area, the elevation decreases gradually from 250 m to 140 m over a distance of 300 km. The stream network in this section is characterised by numerous effluent channels. Although effluents and anabranches are common, no semi-permanent water bodies exist away from the main river channel. Major effluents include the Boomi River, Little Barwon River and Boomangera Creek on the NSW side, and Callandoon Creek and Little Weir River on the Queensland side.

2.1.2.5. Weir River

This subcatchment is the largest at about 12,000 km^2 and accounts for 38% of the Border Rivers catchment. It is located totally within Queensland. Despite its large size it is often reduced to a chain of water holes (with dry bed "no flow" occurring on about 60 % of days).

2.1.3. Hydrometeorology

2.1.3.1. Rainfall

Average annual rainfall in the Border Rivers catchment ranges from over 800 mm in the east to about 500 mm in the west (Figure 2.4). The catchment receives most of its rainfall in the warmer half of the year (Figure 2.5), peaking in the summer months of December to February. A residual mass curve of the rainfall from 1890 to present (Figure 2.6) shows that:

- the first half of the nineteenth century had extended periods of lower than average rainfall,
- the third quarter had extended periods of higher than average rainfall, and
- the BSMS Benchmark Climatic period (ie the fourth quarter of the figure) has about average rainfall over the whole period, while sampling droughts such as 1979-1982, and some short wet periods. Fuller details of the Benchmark Climatic period can be seen in the detailed annual total rainfall at Mungindi (Figure 2.7).

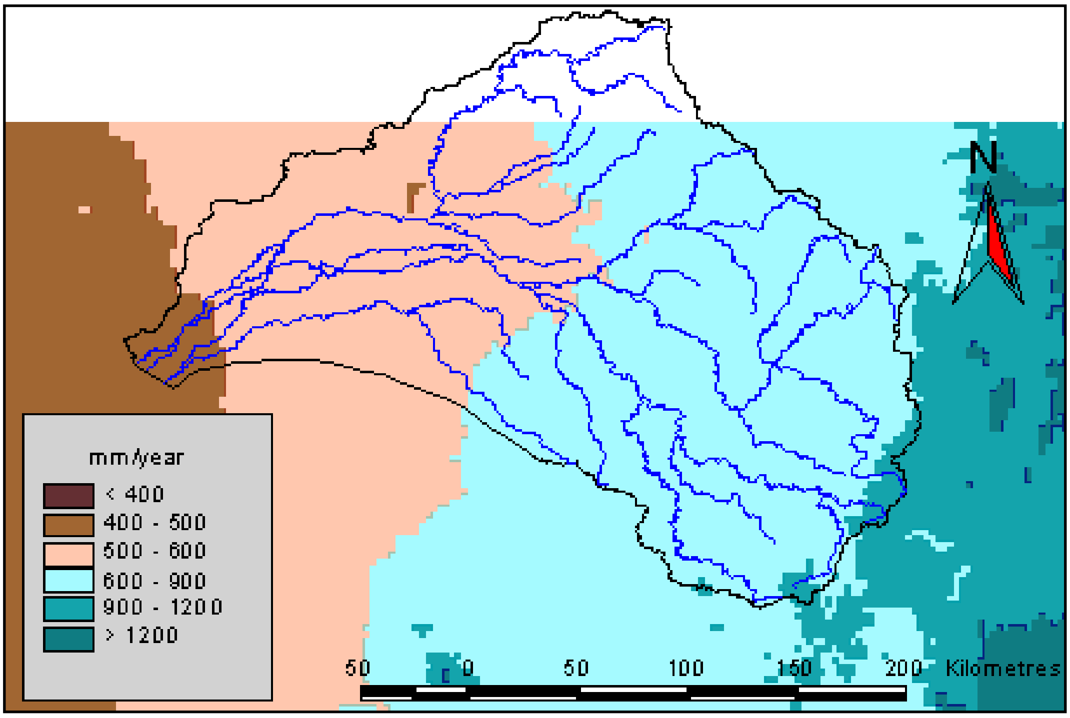


Figure 2.4. Average annual rainfall in Border Rivers catchment

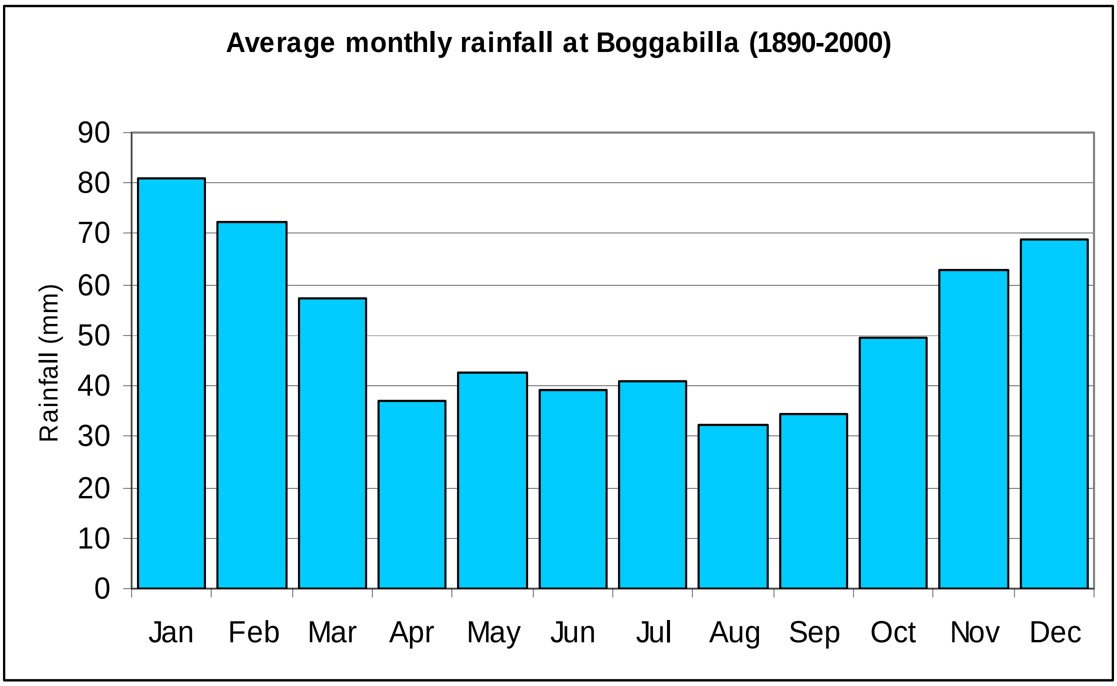


Figure 2.5. Average monthly rainfall at Boggabilla 1890-2000.

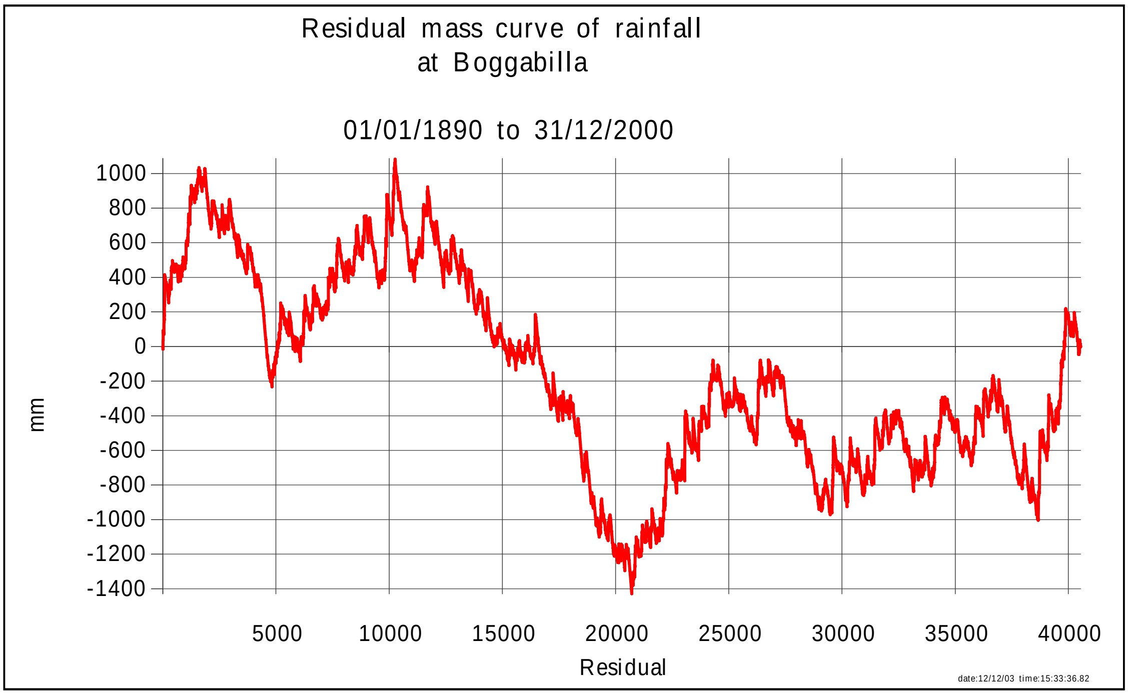


Figure 2.6. Residual mass curve of rainfall at Boggabilla

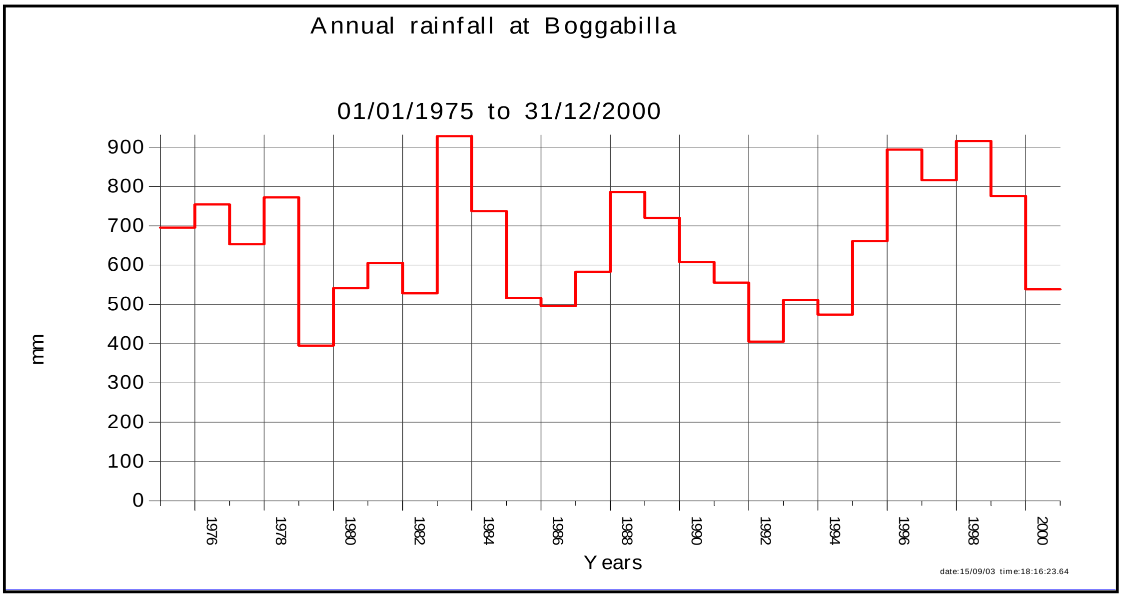


Figure 2.7. Annual rainfall at Boggabilla 1975-2000

2.1.3.2. Evaporation

Pan evaporation in the Border Rivers catchment has a strong east-west gradient (Figure 2.8). Average Class A pan evaporation varies from around 1200 mm/year in the east, to over 1750 mm/year in the west. Evaporation is also strongly seasonal, varying from 1.7 mm/d during June at Boggabilla, to 7.4 mm/d during December.

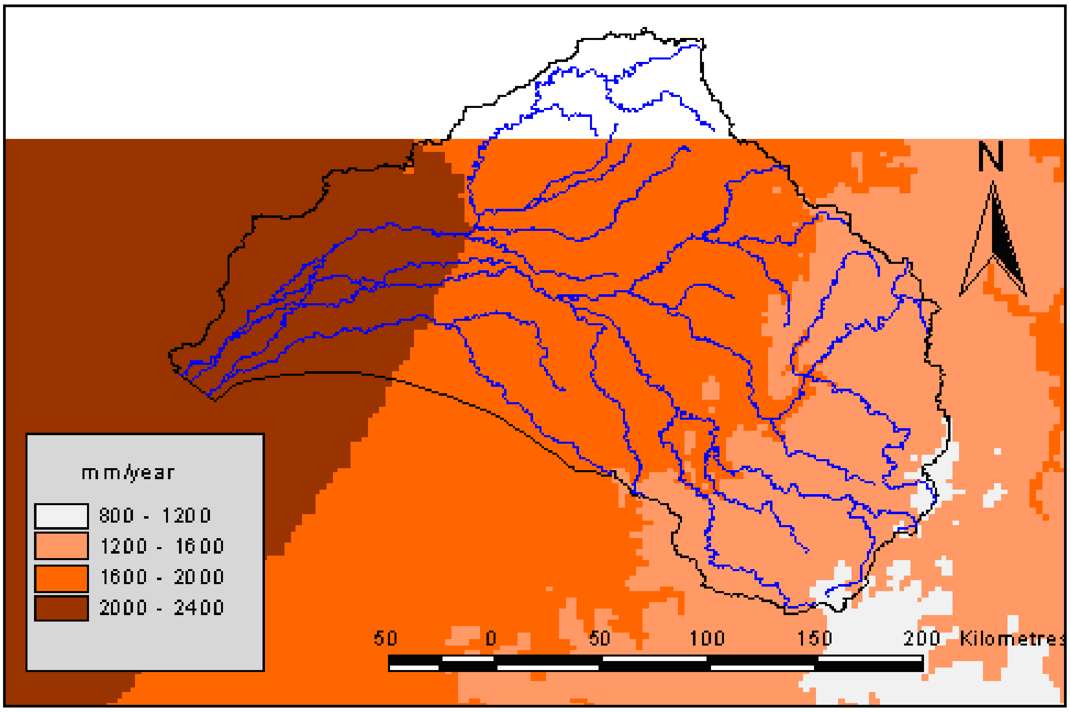


Figure 2.8. Average annual Class A Pan evaporation in Border Rivers catchment (1973-1995)

2.1.4. Groundwater interactions.

Groundwater interaction with river systems is discussed here as it may directly affect salt balance in some reaches of the Macintyre – Barwon Rivers. Salt from groundwater can enter the river system by two pathways: (i) capillary rise from shallow water tables and mobilisation in surface runoff; or (ii) groundwater discharge directly into the river system. The interaction of surface water and groundwater can also result in salt leaving the river system by recharge to the groundwater system.

Movement of groundwater into and out of a river system may have a minimal effect on the overall water balance. However, groundwater is usually more saline, and small volumes may significantly increase river salt loads and salinity.

The way in which surface and groundwater systems interact depends on the depth of the watertable (Figure 2.9). Where the watertable is close to the base of the riverbed, the reach is hydraulically connected and will gain or lose water according to the relative hydraulic heads of the two systems. Disconnected reaches always lose water, with the rate of seepage limited by the hydraulic conductivity of the riverbed.

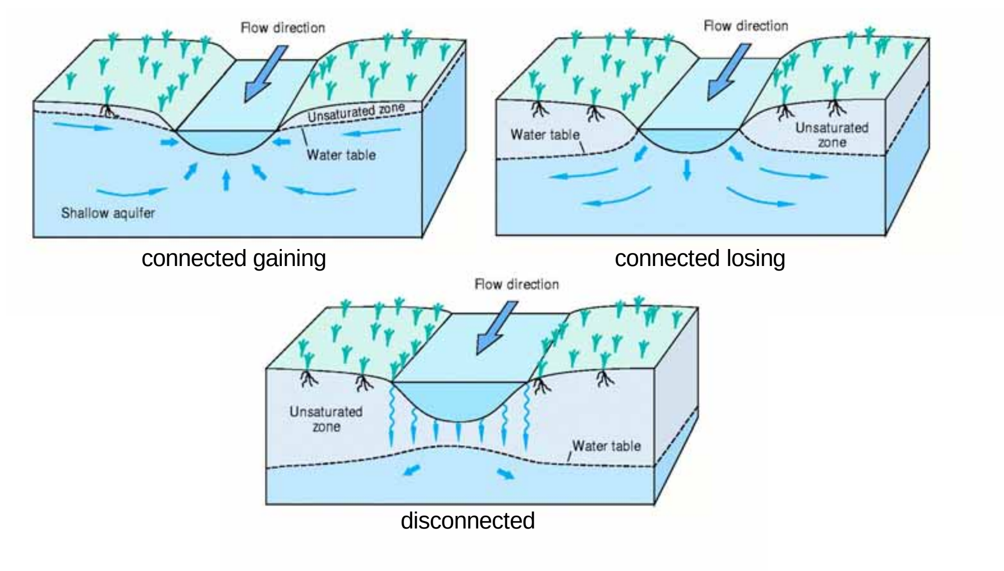


Figure 2.9. Types of river reach with respect to groundwater interaction

(*after Gates and Braaten, 2002*)

Generally, whether a river section is hydraulically connected has a geographic distribution (Figure 2.10). Most upland streams are hydraulically connected, receiving flow from fractured rock aquifers. In the foothills of the ranges, narrow floodplains overlying bedrock and relatively high rainfall produce shallow alluvial water tables and strong hydraulic connections between river and aquifer. The direction of flux can vary over time. Water lost from the river during a flood, and during periods of highly regulated flow will recharge the aquifer, which may then drain back to the river when the flow is lower.

Typically, arid conditions, wide alluvial plains and deep groundwater in the lower parts of the valley lead to long stretches of river which are hydraulically disconnected. This is the case for the Macintyre River below Goondiwindi.

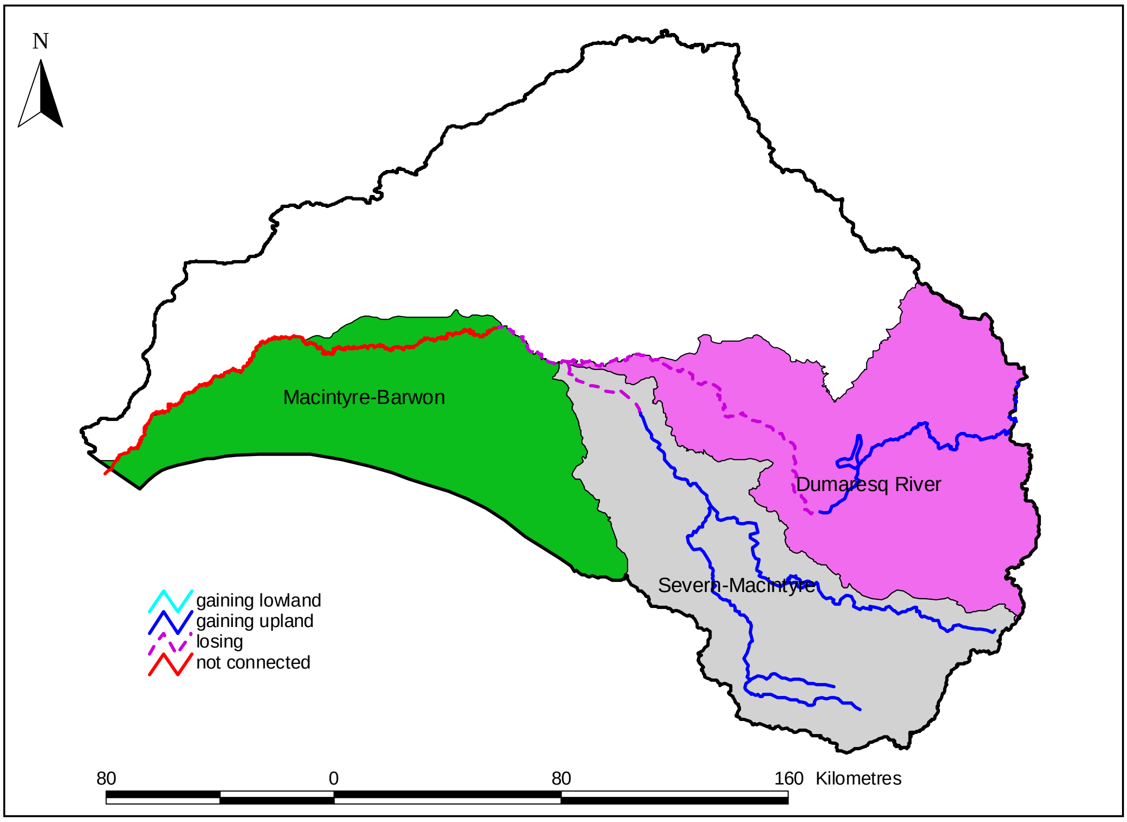


Figure 2.10. Hydraulic connection between rivers and groundwater *(NB. No information was available for the Queensland part of the catchment)*

2.1.5. Land use

Land use in the Border Rivers catchment is dominated by extensive agriculture (Table 2.1) with over half of the catchment used for grazing, and a most of the remainder either for dryland crops or nature conservation / minimal use. Irrigated crops, while economically important, cover only one and half percent of the catchment area. Forests cover about eight percent.

The grazing land is distributed throughout the catchment, and features heavily in all the regions (Figure 2.11). Dryland agriculture (cropping) is mostly lower catchment, with a heavy distribution through the Boomi River-Whalan Creek region. The larger irrigation areas are also located in this lower region, with areas of cotton on both sides of the Macintyre-Barwon River. Forest areas are concentrated in the Upper Weir River Region and adjacent to the Dumaresq and Macintyre Rivers junction.

Table 2.1. Land use statistics for Border Rivers catchment

Land use description	Total extent ('000 Ha)	Total extent (%)
Nature conservation / minimal use	917	19
Grazing	2,575	54
Forestry	367	8
Dryland agriculture	866	18
Irrigation agriculture	72	1.5
Built environment	5.7	0 1

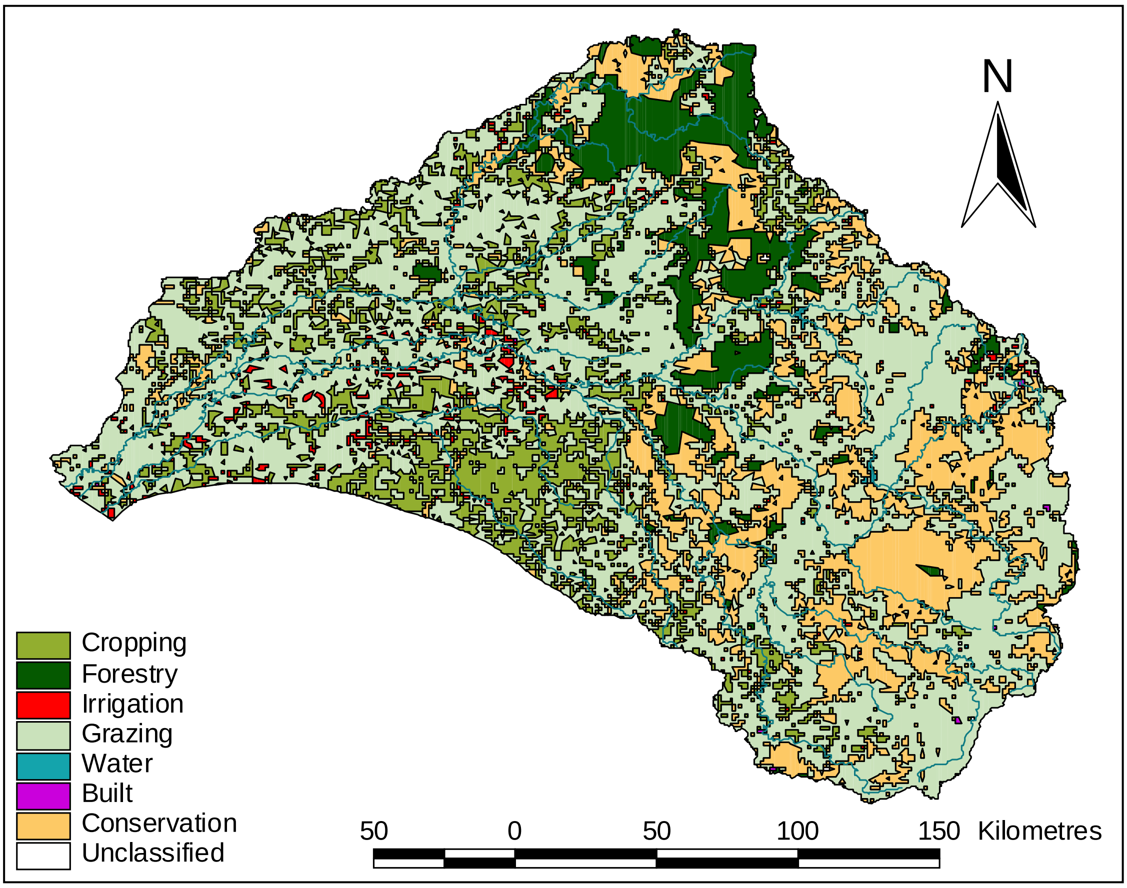


Figure 2.11. Landuse in Border Rivers catchment

2.2. WATER RESOURCE MANAGEMENT

Much of the water resources in the Border Rivers catchment are regulated, with runoff from the Upper Dumaresq (Pike Creek), Macintyre Brook (Qld) and Severn River catchments stored in Glenlyon, Coolmunda and Pindari Dams. Releases are made from these storages for extractive and in-stream uses. Coolmunda Dam supplies water only for irrigators along Macintyre Brook, while Glenlyon Dam being a shared resource between NSW and Queensland, supplies water to irrigators and towns downstream as far as Mungindi. Pindari Dam, a NSW resource, supplies water to downstream NSW users as far as Mungindi. In addition to the above water is released from all storages to meet environmental and other in-stream demands. These features are described in detail in Chapter 4 on the river system model used. The Weir River is unregulated.

2.3. SALINITY IN CATCHMENT

Salinity is currently not as great a threat in the Border Rivers catchment as it is in other catchments in NSW. The most likely reason for this is being that the Border Rivers catchment was developed for intensive agricultural production more recently than southern catchments. However unless resource management practices are changed, modelling has indicated that salinity is likely to increase over time.

Known occurrences of dryland salinity in the Border Rivers catchment as identified by aerial photo interpretation are shown in Figure 2.12. These are heavily concentrated in the upper part of the Border Rivers region in the Severn and Mole River catchments.

Salt loads from subcatchments in the Severn-Macintyre and Upper Dumaresq regions were estimated as part of the Salinity Audit (Beale et al., 1999) and are shown in Figure 2.13. This distribution of salt loads has interesting features compared with the mapped occurrences of dryland salinity. The high export rates from the Upper Macintyre and Severn Rivers are consistent with the concentration of dryland salinisation and high flows from these catchments. However, Ottleys Creek seems to have a high export rate although there are no known occurrences of dryland salinity in this catchment.

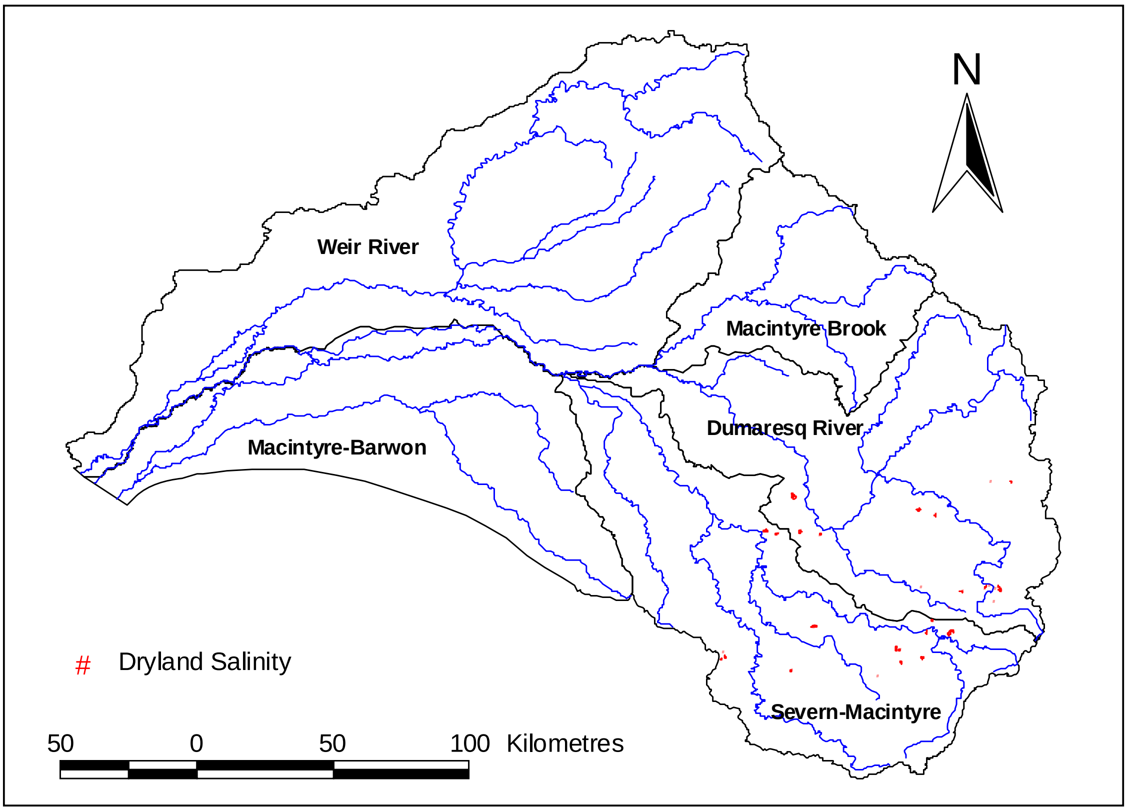


Figure 2.12. Dryland salinity occurrences in Border Rivers catchment (mapped pre-1999) ***(NB No information was available for the Queensland part of the catchment)***

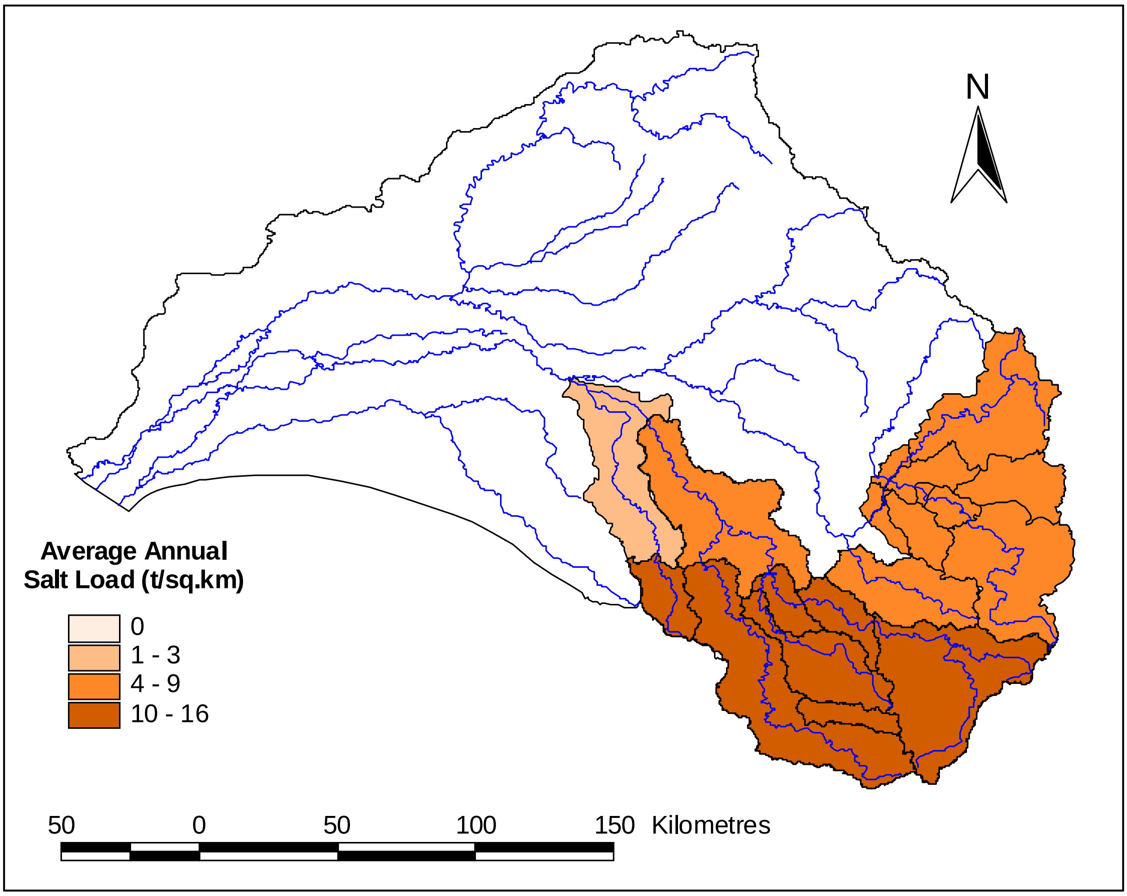


Figure 2.13. Modelled average annual salt export rates (tonnes/km^2) from Border Rivers catchment.

3. Salinity Data

3.1. AVAILABLE DATA

All data for NSW stations in the Border Rivers catchment was extracted from the DWE databases. The locations and length of records of the NSW stations is tabulated in Table A.8.1 of Appendix A, and Queensland stations is tabulated in Table A.8.2. The distribution and relative length of the data is shown in Figure 3.1 for discrete EC data stations and in Figure 3.2 for continuous EC data stations.

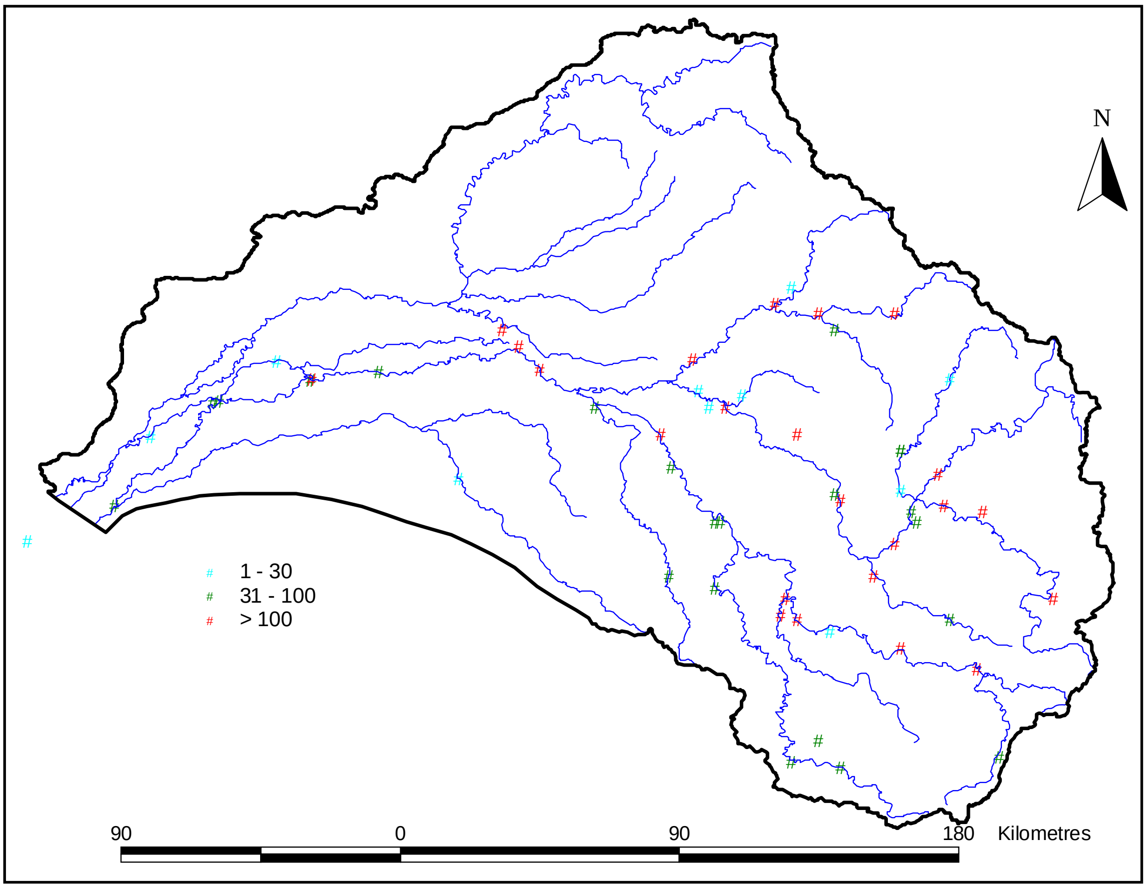


Figure 3.1. Location and record length size for discrete EC data stations (NSW stations).

The legends used in Figure 3.1 and Figure 3.2 are indicative of the usefulness of the data for modelling purposes. A discrete data set with < 30 data points is of little value, from 30-100 is of some value and above 100 is starting to provide a good estimate of salinity behaviour. The class intervals for the continuous data sets are also indicative, for the same purpose.

A feature of the discrete data sets is that of the 50 NSW data sets reported in Appendix A, 20% have less than 30 data points, and 42% have more than 100 data points. Apart from Croppa Creek at Tulloona Bore and the Macintyre River at Boonal, many of the data sets with a small number of points are in areas with other stations nearby. The larger data sets appear to give a good coverage across most of the NSW part of the catchment. However, the upper Macintyre River, Ottleys Creek and the Boomi River have no data sets of more than 100 points and there is no data at all for Whalan Creek.

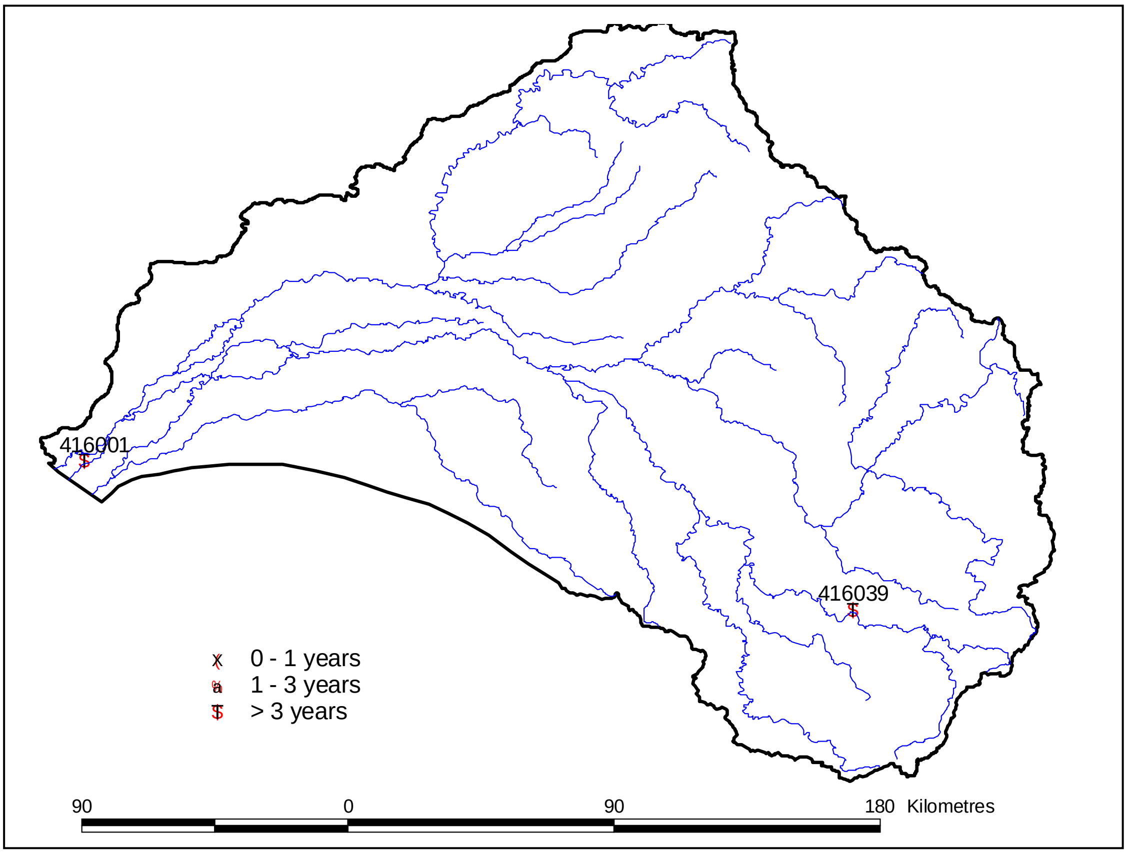


Figure 3.2. Location and record length for continuous EC data stations (NSW stations)

The Border Rivers System has a poor coverage of continuous stations compared with most other NSW MDB valleys, reflecting the low level of salinity management activity in the catchment to date. Of the two stations, the Barwon River at Mungindi (416001) is more useful as it has over six years of data and is located at the end of the system. The other station, Severn River at Strathbogie (416039), has five years of data but it is well upstream of Pindari Dam and continuous data collection ceased in 1998.

3.2. DATA USED FOR INFLOW ESTIMATES AND MODEL EVALUATION

The subset of stations that can potentially be used for the salinity models are those located at either inflow points, or at gauging stations used to evaluate results of the quantity model. Thirteen of the fifty NSW stations with discrete EC data and both of the stations with continuous EC data can potentially be used for these purposes.

The stations at inflow points were used to estimate the parameters of the salt load relationships for the Salinity Audit, and may be used to re-estimate salt load inflows, depending on the outcomes of the model evaluation. There are ten stations with discrete EC data in this list (Table 3.1), one of which also has continuous EC data. This data was screened to remove outliers and observations on days with no flow records. A further twenty stations (sixteen river gauges and five stations in Pindari Dam) with discrete EC data are located at points that could be used to evaluate model results (Table 3.2). One of these stations also has continuous EC data (Table 3.3).

3.2.1. Exploratory analysis of data

A simple representation of the data was prepared to get some insight into the contributions of inflows to salinity and the variations in salinity along the mainstream. This analysis was based on looking at the patterns of the median salinity and median flow, as reported in Table 3.4.

A plot of the median salinity against median inflow of inflow points (Figure 3.3) shows that catchments in the NSW side of the Border Rivers tend not to produce flows with high salinity. The Ottleys Creek catchment (416020) contributes low quantities of moderately high salinity water, the Macintyre River (416010) produces significant amounts of moderate salinity water, and the Severn River (416039) and Mole River (416032) contribute large amounts of low salinity water.

The longitudinal overview of median salinities (Figure 3.4) shows that median salinities in the upper reaches of the Dumaresq River are generally low but increase downstream. Conversely, the moderately low median salinity in the upper Severn River is reduced by Pindari Dam because of storage effects. As the Severn-Macintyre River flows north-west, increasingly salty tributaries cause the median salinity to almost double by the time it joins the Dumaresq River. Downstream of the confluence, the median salinity remains in the order of 150 to 160 kg/ML to the end of the system.

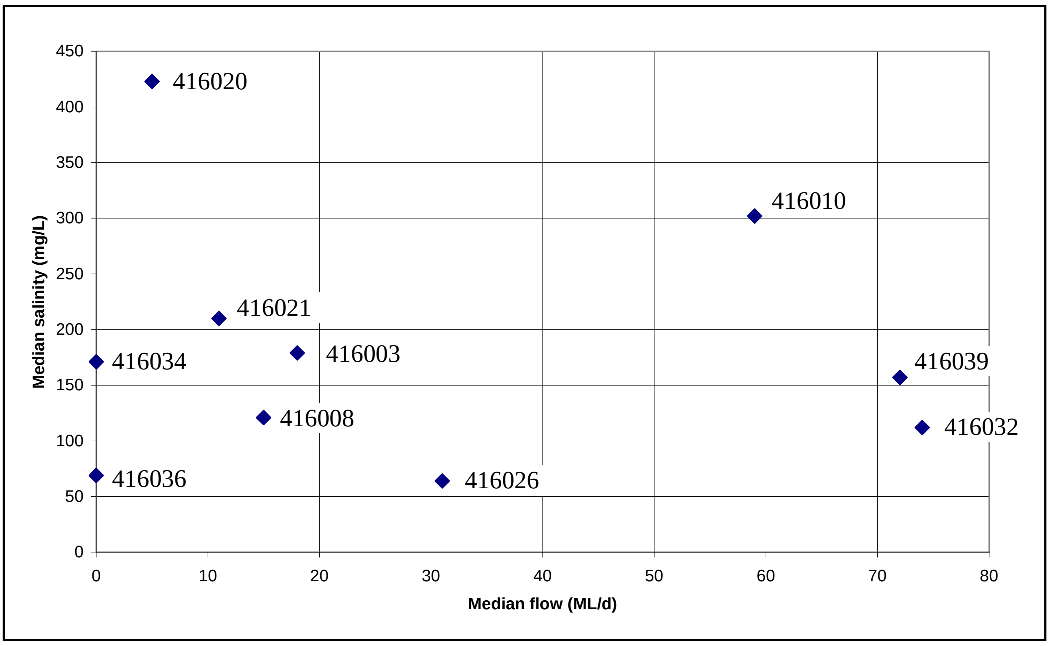


Figure 3.3. Median salinity versus median flow for inflow sites with discrete EC data (NSW stations)

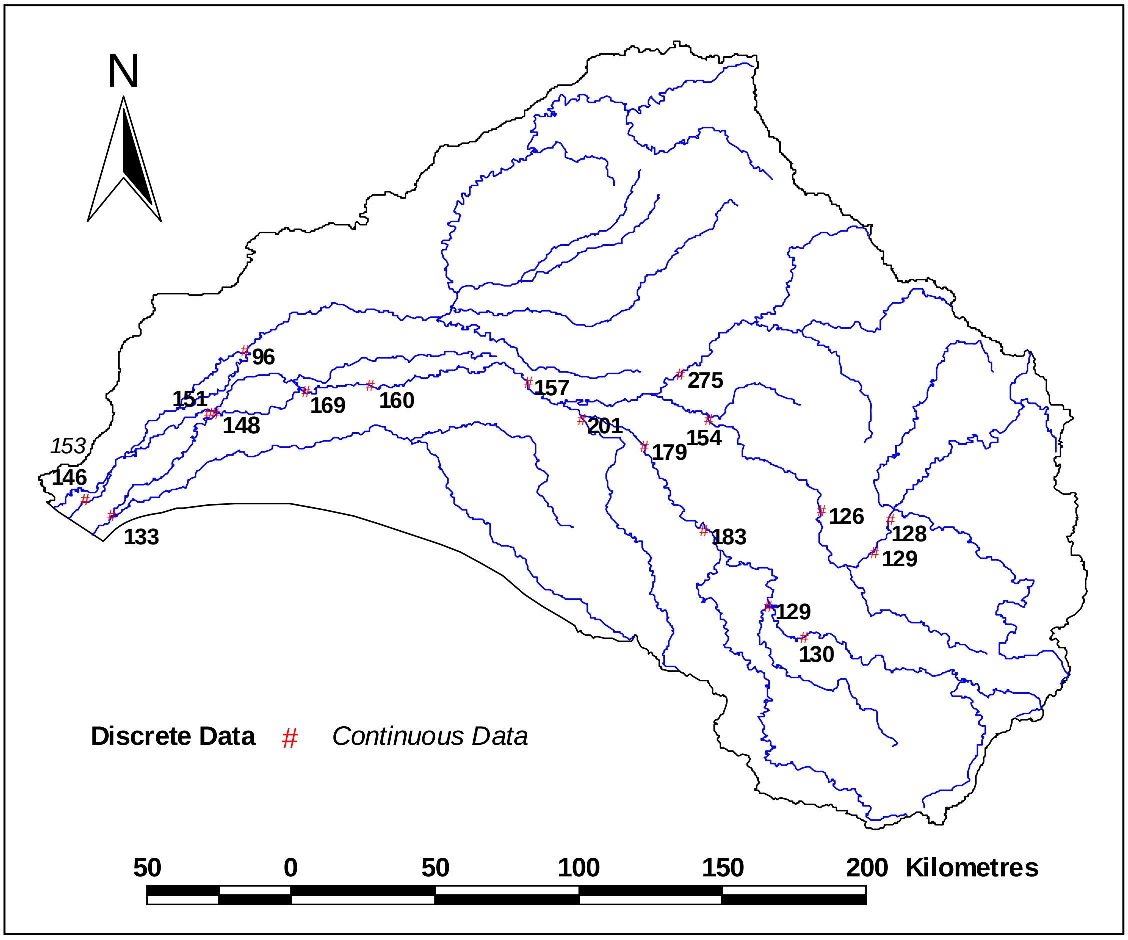


Figure 3.4. Median salinity along main stream

Table 3.1. Stations at inflow points with discrete and continuous EC data, with results of preliminary screening (NSW stations)

Station Number	Station Name	Data points removed			Final data days
		<15 µS/cm	*zero or missing flow*	*outliers*	
416003	Tenterfield Creek @ Clifton	0	7	1	208
416008	Beardy River @ Haystack	0	27	2	176
416010	Macintyre River @ Wallangra	0	2	0	77
416020	Ottleys Creek @ Coolatai	0	2	0	93
416021	Frazers Creek @ Ashford	0	38	0	97
416026	Reedy Creek @ Dumaresq	0	35	1	36
416032	Mole River @ Donaldson	0	12	1	182
416034	Croppa Creek @ Tulloona Bore	0	3	0	10
416036	Campbells Creek near Beebo	0	7	0	21

Station Number	Station Name	Data points removed			Final data days
		<15 μS/cm	*zero or missing flow*	*outliers*	
416039	Severn River @ Strathbogie	0	1	2	199
416039	*Severn River @ Strathbogie*	*0*	*140*	*0*	*1626*
416303C	Pike Creek @ Glenlyon	0	3	0	91
416305B	Brush Creek @ Beebo	0		0	22
416306A	Pike Creek @ Pikedale	0		0	6
416310A	Dumaresq River @ Farnbro	0	44	0	199
416312A	Oaky Creek @ Texas	0	4	0	129
416404C	Bracker Creek @ Terraine	0	3	0	82
416407A	Canning Creek @ Woodspring	0		0	16
416410A	Macintyre Brook @ Barongarook	0	2	0	124
4163016	Pike Creek @ Glenlyon Dam 0.5km U/S	0	28	0	28
4163017	Pike Creek @ Glenlyon Dam D/S of Outlet	0	7	0	7
4164053	Macintyre Brook @ Barongarook MRHI Site	0	2	0	2
416039	*Severn River @ Strathbogie*	*0*	*140*	*0*	*1626*

Note: Stations in italic font are continuous, others are discrete

Table 3.2. Stations at evaluation points with discrete EC data, with results of preliminary screening (NSW stations)

Station Number	Station Name	Data points removed			Final data days
		<15 μS/cm	*zero or missing flow*	*outliers*	
416001	Barwon River @ Mungindi	*8*	*83*	*1*	562
416002	Macintyre River @ Boggabilla	*0*	*2*	*0*	251
416006	Severn River @ Ashford	*0*	*5*	*0*	123
416007	Dumaresq River @ Bonshaw Weir	*0*	*2*	*1*	261
416011	Dumaresq River @ Roseneath	*0*	*14*	*2*	221
416012	Macintyre River @ Holdfast (Yelarbon Crossing)	*0*	*6*	*0*	223
416014	Dumaresq River @ Mingoola	*0*	*5*	*1*	71
416018	Macintyre River @ dam site	*0*	*1*	*0*	63
416019	Severn River @ Pindari	*0*	*52*	*1*	996
416028	Boomi River @ Neeworra	*0*	*32*	*0*	41
416029	Boomi River @ Kanowna	*1*	*25*	*1*	49

Station Number	Station Name	Data points removed			Final data days
		<15 µS/cm	*zero or missing flow*	*outliers*	
416038	Macintyre River @ Boonal	*0*	*0*	*0*	41
416043	Macintyre River @ Boomi Weir	*0*	*13*	*0*	144
416047	Macintyre River @ Terrewah	*0*	*2*	*1*	55
416048	Macintyre River @ Kanowna	*0*	*16*	*1*	78
416049	Dumaresq River @ Mauro	*0*	*71*	*0*	81
41610001	Pindari Dam (Dam Wall) Stn. 1	*0*	*0*	*0*	155
41610002	Pindari Dam (Dead Trees) Stn. 2	*0*	*0*	*0*	108
41610003	Pindari Dam (Rockface) Stn. 3	*0*	*0*	*0*	148
41610004	Pindari Dam (Inflow) Stn. 4	*0*	*1*	*0*	211
41610005	Pindari Dam (Outflow) Stn. 5	*0*	*0*	*1*	36
416201B	Macintyre River @ Goondiwindi	0	5	0	232
416202A	Weir River @ Talwood	0	4	0	131
416303C	Pike Creek @ Glenlyon	0	3	0	91
416307A	Dumaresq River @ Bonshaw Weir	0	16	0	57
416402C	Macintyre Brook @ Inglewood	0	150	0	150
416409A	Macintyre Brook @ Coolmunda Dam H/W	0	90	0	90
416415A	Macintyre Brook @ Booba Sands	0	5	0	133
4164042	Macintyre Brook @ Coolmunda Da M	0	189	0	189
4164051	Macintyre Brook @ Inglewood Weir	0	73	0	73

Table 3.3. Stations at evaluation points with continuous EC data, with results of preliminary screening (NSW stations)

Station number	Station name	Data use	Data days		Comments for data errors	Final data days
			Missing flow	*Data errors*		
416001	Barwon River @ Mungindi	Evaluation	208	9	Instrument malfunction	2101

Table 3.4. Cumulative distribution statistics of screened EC data sets (NSW stations)

Station Number	Station name	Data type	Data use	Salinity statistics kg/ML			Q_{50} ML/d
				C_{25}	C_{50}	C_{75}	
416001	Barwon River @ Mungindi	Discrete	Evaluation	117	146	178	290
416001	Barwon River @ Mungindi	Continuous	Evaluation	124	153	184	
416002	Macintyre River @ Boggabilla	Discrete	Evaluation	131	157	195	748

Station Number	Station name	Data type	Data use	Salinity statistics kg/ML C_{25}	C_{50}	C_{75}	Q_{50} ML/d
416003	Tenterfield Creek @ Clifton	Discrete	Inflow	136	179	234	18
416006	Severn River @ Ashford	Discrete	Evaluation	101	129	148	138
416007	Dumaresq River @ Bonshaw Weir	Discrete	Evaluation	106	126	150	398
416008	Beardy River @ Haystack	Discrete	Inflow	91	121	158	15
416010	Macintyre River @ Wallangra	Discrete	Inflow	234	302	390	59
416011	Dumaresq River @ Roseneath	Discrete	Evaluation	108	129	154	334
416012	Macintyre River @ Holdfast (Yelarbon Crossing)	Discrete	Evaluation	145	179	230	227
416014	Dumaresq River @ Mingoola	Discrete	Evaluation	106	128	151	322
416018	Macintyre River @ dam site	Discrete	Evaluation	151	183	240	233
416019	Severn River @ Pindari	Discrete	Evaluation	101	130	149	109
416020	Ottleys Creek @ Coolatai	Discrete	Inflow	365	423	504	5
416021	Frazers Creek @ Ashford	Discrete	Inflow	173	210	309	11
416026	Reedy Creek @ Dumaresq	Discrete	Inflow	49	64	83	31
416028	Boomi River @ Neeworra	Discrete	Evaluation	104	133	175	3
416029	Boomi River @ Kanowna	Discrete	Evaluation	124	151	192	25
416032	Mole River @ Donaldson	Discrete	Inflow	92	112	136	74
416034	Croppa Creek @ Tulloona Bore	Discrete	Inflow	142	171	174	0
416036	Campbells Creek near Beebo	Discrete	Inflow	56	69	76	0
416038	Macintyre River @ Boonal	Discrete	Evaluation	157	201	253	288
416039	Severn River @ Strathbogie	Discrete	Inflow	125	157	207	72
416039	Severn River @ Strathbogie	Continuous	Inflow	124	157	211	
416043	Macintyre River @ Boomi Weir	Discrete	Evaluation	139	169	207	306
416047	Macintyre River @ Terrewah	Discrete	Evaluation	136	160	191	414
416048	Macintyre River @ Kanowna	Discrete	Evaluation	130	148	172	278
416049	Dumaresq River @ Mauro	Discrete	Evaluation	131	154	188	314
41610001	Pindari Dam (Dam Wall) Stn. 1	Discrete	Evaluation	95	112	141	storage
41610002	Pindari Dam (Dead Trees) Stn. 2	Discrete	Evaluation	97	125	147	storage
41610003	Pindari Dam (Rockface) Stn. 3	Discrete	Evaluation	98	113	145	storage
41610004	Pindari Dam (Inflow) Stn. 4	Discrete	Evaluation	86	116	151	storage
41610005	Pindari Dam (Outflow) Stn. 5	Discrete	Evaluation	85	98	107	storage

4. The Border Rivers IQQM

4.1. QUANTITY MODEL

The Border Rivers IQQM consists of three river systems: the Macintyre Brook (Coolmunda) system; the Severn-Macintyre (Pindari) system; and the Dumaresq-Macintyre (Glenlyon) system. It extends from the headwaters of Coolmunda, Pindari and Glenlyon Dams down to the outlet of the valley at Mungindi. The model also includes the Whalan Creek-Boomi River sub-system down to Neeworra, about 10 km south-east of Mungindi; but not the Gil Gil Creek sub-system, which is a part of the Gwydir IQQM.

The Border Rivers IQQM was initially developed and calibrated separately for the three sub-system models in 1998. The three models were then joined together and new infrastructure and operational changes were incorporated. The combined model was then validated over the period October 1995 to September 1996.

The Border Rivers IQQM is a very complex model with nearly 500 nodes and a wide range of node types and sub-types. These represent the natural system configuration and the variety of human-influenced processes associated with the Border Rivers Valley. A full description of the features and calibration of the Border Rivers IQQM is presented in McDermott et al. (2001).

The model has been refined to enable it to simulate emerging water management modelling needs. Further refinements were anticipated during the course of this project to improve its capability to reliably model salt transport. The overall structure of the initial Border Rivers IQQMs are shown in Figure 4.1, Figure 4.2 and Figure 4.3.

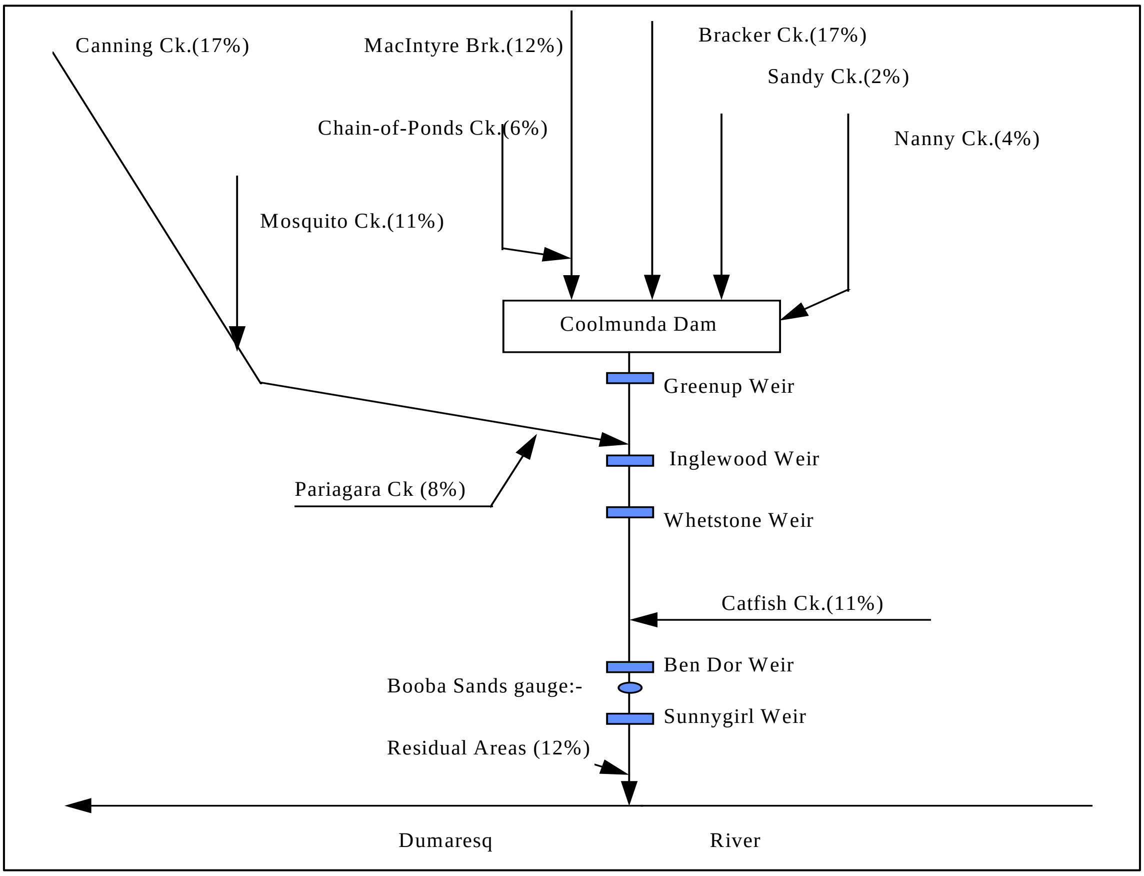


Figure 4.1. Schematic of Macintyre Brook System IQQM.

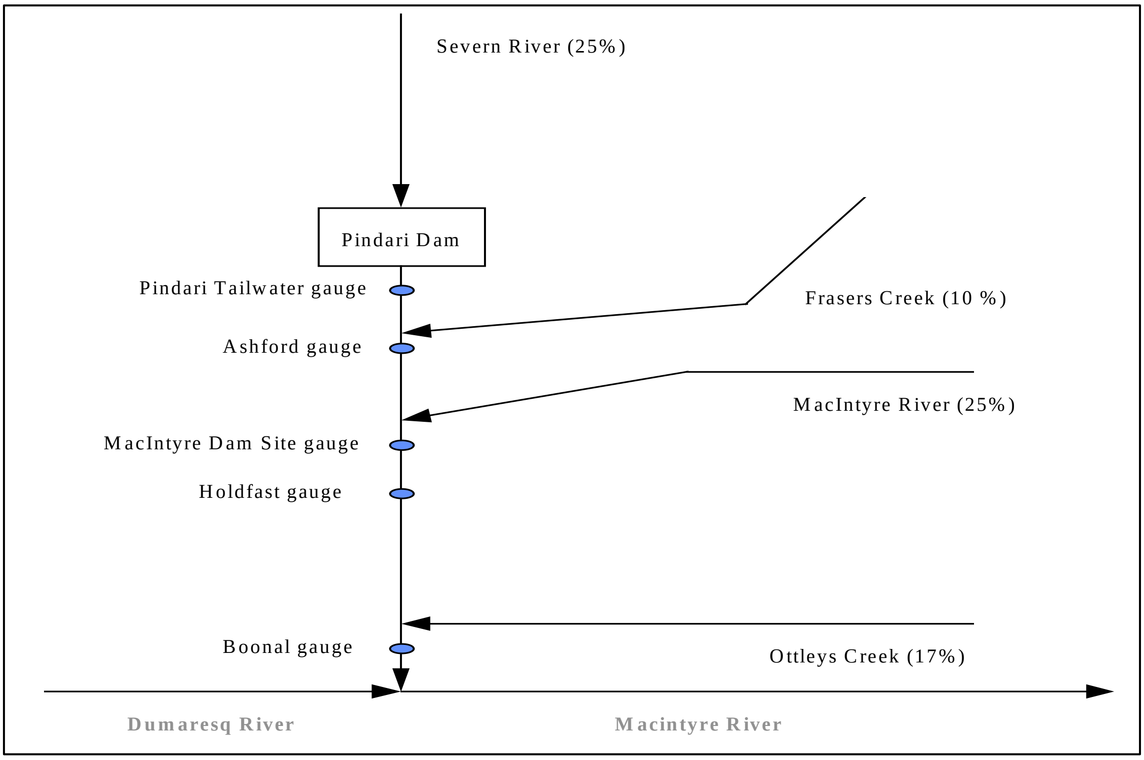


Figure 4.2. Schematic of Severn-Macintyre System IQQM.

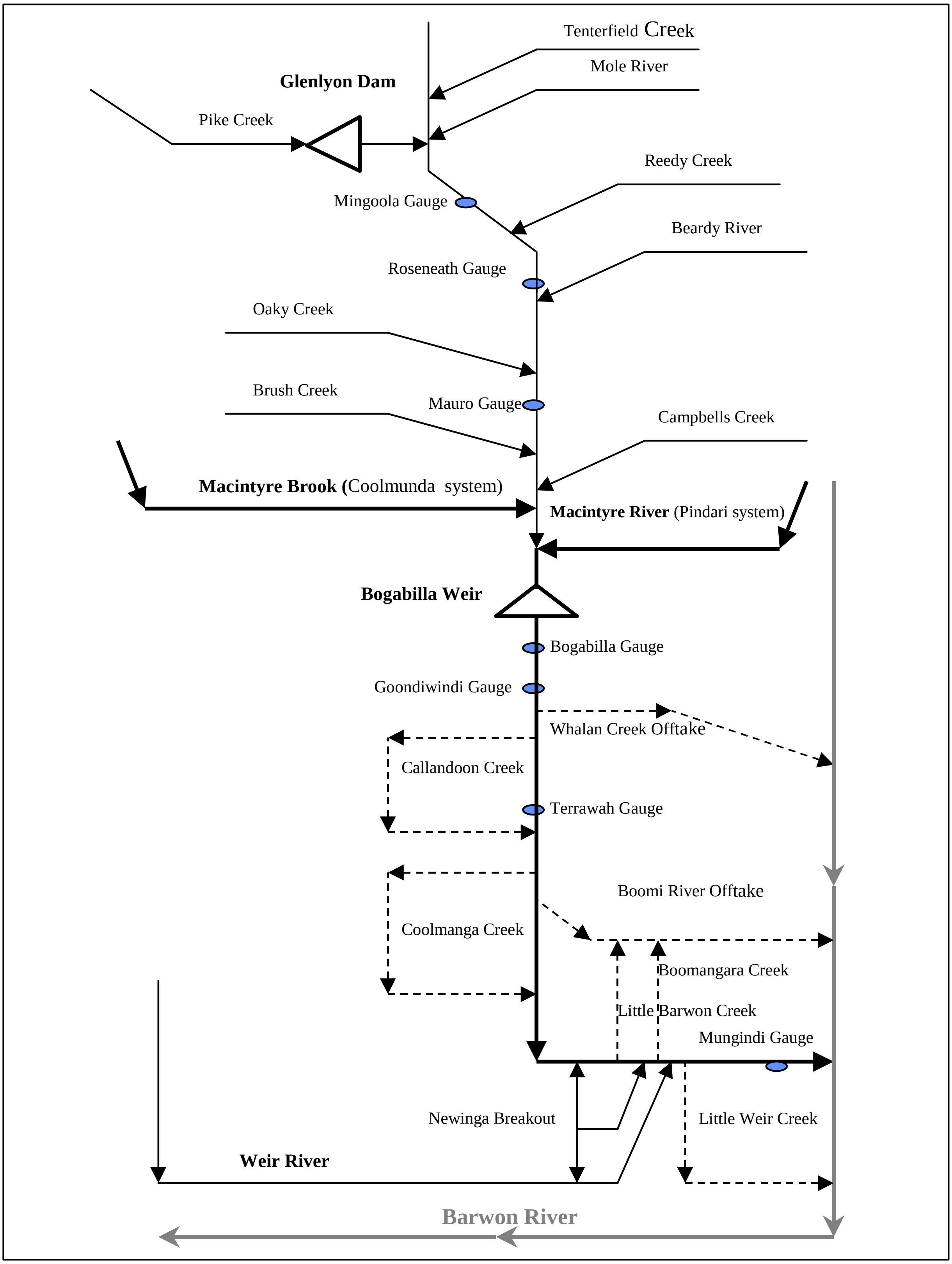


Figure 4.3. Schematic of Dumaresq-Macintyre-Barwon System IQQM.

These figures can only present an overview of the Border Rivers IQQM. This limitation has been addressed by presenting the major types of nodes as separate figures, showing the geographic location and relative magnitude, where possible, of:

- inflows (Figure 4.4 to Figure 4.8);
- storages (Figure 4.9);
- irrigation demands (Figure 4.10 to Figure 4.14); and
- instream and environmental nodes (Figure 4.15).

These features are discussed in Sections 4.1.1 to 4.1.4.

4.1.1. Inflows and calibration

Border Rivers IQQM uses a total of sixty-four inflow nodes to represent inflows into headwater storages (6), gauged inflows (13), ungauged/residual inflows (27) and water management and natural processes in the system (18). The model includes 45 effluent nodes used to represent transmission losses (35) and effluents (10). There are also eighteen gauge nodes used for flow calibration along the main stream. The magnitude and distribution of the inflow and effluent nodes is shown in Figure 4.4 to Figure 4.8. These inflow nodes match catchment boundaries as described in Section 5.1.

Most of the total unregulated inflow in the Border Rivers IQQM, about 1,325 GL/year (68% of total inflow), joins the system upstream of the Dumaresq-Macintyre Rivers confluence. Almost 65% of that inflow is gauged and comes from tributaries including:

- Tenterfield Creek, Mole River, Reedy Creek, Beardy River, Campbells Creek, Oaky Creek and Brush Creek in the Glenlyon sub-system;

- Canning Creek in the Coolmunda sub-system; and

- Macintyre River, Frazers Creek and Ottleys Creek in the Pindari sub-system.

In the Coolmunda sub-system, gauged inflow makes up about 37% of the total tributary inflow, whilst in the Pindari sub-system, the figure is about 60%.

Ungauged inflow in the Border Rivers IQQM consists predominantly of the residual catchment inflows and groundwater inflows. There are two groundwater inflow nodes in the model: one is located in the Glenlyon sub-system downstream of Glenlyon Dam; the other is in the Coolmunda sub-system downstream of the Canning Creek inflow. Inclusion of these nodes was based on regional evidence and was necessary to achieve a good flow calibration.

There are thirty-five nodes in the model that represent instream losses and which where derived in the process of flow calibration. These nodes are located either immediately upstream of calibration nodes and headwater storages or on the tributaries before they join the main stream. Consequently, the upper part of the Border Rivers system (upstream of the Dumaresq-Macintyre Rivers junction) has a much higher density of loss nodes due to a higher number of tributary inflows and calibration nodes (reliable gauges used in flow calibration).

There are also ten loss nodes used in the model to represent system effluents, eight of which return to the system. They include regulated effluents such as the Boomi River and Callandoon Creek and unregulated effluents such as Whalan Creek, Dingo Creek, Coomonga Creek, Little Barwon Creek, Boomangera Creek and the Little Weir River. All of these effluents are located in the lower part of the system downstream of the Dumaresq-Macintyre Rivers junction).

Inputs to the model are observed data. Where the data has gaps and/or needs to be extended, appropriate hydrologic and statistical techniques have been developed to fit with data limitations and model needs. Details of the streamflow and climatic data are available in the Border Rivers Cap calibration report (McDermott et al 2001). For climatic and streamflow variables the following approach was used:

- Rainfall – observed data was gap filled and/or extended by statistical correlation with surrounding long-term rainfall sites.
- Evaporation – observed data was gap filled and/or extended by generated data that was derived by statistically relating total evaporation and number of rain days for each month.
- Streamflow – observed data was gap filled and/or extended by generated data from a calibrated Sacramento rainfall runoff model. Ungauged catchment inflows are generally estimated by correlation with surrounding gauging stations and mass balance on the main river.
- Dam inflow – may be either observed data generated by mass balance approach at the dam or upstream flows routed to the dam. As outlined above streamflow data has been gap filled and/or extended by Sacramento rainfall runoff model.

4.1.2. Storages

Twelve storages are modelled in the Border Rivers IQQM but only three; Coolmunda, Pindari and Glenlyon Dams, are true regulating storages; whilst Boomi Weir is the only major re-regulating storage. The locations and sizes of these major storages are shown in Figure 4.9 and the purpose of each is described below. Although there are also a few minor re-regulating storages in the Border Rivers system associated with weirs on a number of regulated effluents, they were not modelled due to order pulsing problems. These problems are associated with the modelling of weirs with a very low re-regulating capacity compared with the magnitude of the orders from downstream users.

Coolmunda Dam releases water for:

- General and high security irrigators along Macintyre Brook as well as a group of Queensland irrigators in the Glenlyon sub-system downstream of the Macintyre Brook-Dumaresq River confluence (the Dumaresq River Irrigation Project or DRIP);
- Environmental releases as described in Section 4.1.4; and
- Town water supplies for Inglewood of 450 ML/year.

Pindari Dam releases water for:

- NSW general and high security irrigators along the Severn, Macintyre, Boomi and Barwon Rivers;
- Environmental and instream releases as described in Section 4.1.4;
- Town water supplies for Ashford (156 ML/year) and Boggabilla (320 ML/year); and
- Stock and Domestic replenishments for users along Boomi River as described in Section 4.1.4.

Glenlyon Dam releases water for:

- NSW and Queensland general and high security irrigators along the Dumaresq, Macintyre and Barwon Rivers as well as NSW irrigators along the Boomi River and Queensland irrigators along Callandoon Creek; and
- Town water supplies for Texas (276 ML/year), Goondiwindi (1,800 ML/year) and Mungindi (268 ML/year).

All three headwater storages are used for flood mitigation purposes. When the volume of water in any of the dams exceeds its respective Full Supply Level, water is released according to operational guidelines at a maximum rate (via both the valve outlets and the spillway).

Glenlyon and Pindari Dams are operated under a ‘Harmony Rule’ that aims to maximise the water resources of the Valley. Therefore, releases to satisfy the irrigation and town water requirements of NSW users downstream of the Dumaresq-Macintyre Rivers junction are made from either Glenlyon or Pindari in order to minimise potential spills.

4.1.3. Extractive demands

Allocation of water to irrigators in the Border Rivers System occurs under a volumetric allocation system, as with other regulated river systems. The total active regulated licence entitlement in the system is about 365.5 GL, of which 72% is for NSW irrigators and 28% for QLD irrigators (82% in the Glenlyon sub-system 82% and 18% in the Coolmunda sub-system). There are virtually no high security irrigation licences in the system (only small stock and domestic licences which are included in the total).

However, there is a substantial portion (near 8%) of “A” class general security licences, although, in NSW only. The notion was introduced in NSW in 1986 in order to improve the reliability of the system with the small Pindari Dam (only 32 GL total capacity). It applies to the first 60 ML of each individual licence without taking into consideration its total volume. The NSW system has a very high portion (19%) of “A” class licences component in the Glenlyon system upstream of the Dumaresq-Macintyre Junction. This is because of the high number of the small irrigation licences in that part of the system. The rest of the NSW system does not exceed 7% of the total licences.

There is no similar arrangement in Queensland. Queensland irrigation demand and TWS requirements along the Dumaresq and Macintyre Rivers are supplied almost entirely by releases from Glenlyon Dam and partial tributary inflow (43% of the total tributary inflow along the Dumaresq River and Macintyre River downstream of its confluence with Dumaresq River). An additional 6,400 ML/year is supplied to QLD irrigators along the Dumaresq and Macintyre Rivers downstream of the Macintyre Brook-Dumaresq River junction from Coolmunda Dam. Most of the regulated water usage is downstream of the Dumaresq-Macintyre Rivers junction (>79% of the total valley regulated irrigation extractions). However, for NSW and QLD 89% and 40% respectively, of the total valley regulated irrigation extraction takes place downstream of the Dumaresq-Macintyre Rivers junction. There is also significant usage along Macintyre Brook in QLD (almost 48% of the QLD total regulated extractions).

The distribution of water usage for irrigation is shown in Figure 4.10 to Figure 4.14.

4.1.3.1. Surplus water usage

Unregulated river water, in addition to that released from Glenlyon, Pindari and Coolmunda Dams, can also be extracted by all regulated licence holders except those along Macintyre Brook. These extractions are not debited against the licence holder’s allocation for that year.

This water originates as either higher than expected flows from tributaries, or as flood mitigation releases from the three headwater dams. Water extracted is typically stored in on-farm storages for later use. Restrictions are set on the flow thresholds that trigger access to these extractions. The total volume that can be extracted by NSW irrigators is restricted to 120 GL/year but there is no similar limit for Queensland irrigators.

4.1.4. In-stream demands

In-stream demands are simulated at five locations in the Border Rivers IQQM (Figure 4.15) using Type 9.0, and Type 10.2 nodes. The purpose of these particular nodes is described in Table 4.1.

Table 4.1. Function of in-stream ordering nodes in Border Rivers System IQQM

Node type	In-stream ordering node name	Purpose
9.0 Flow control	Coolmunda Dam Minimum Flow Requirement (MFR)	Orders from Coolmunda Dam to maintain minimum 1 ML/day immediately down stream of the Dam.
9.0 Flow control	DRIP MFR	Orders water from Coolmunda Dam (up to a maximum of 6,400 ML/year) to maintain a minimum flow of 250 ML/day at the Macintyre Brook-Dumaresq River confluence (ie. orders water only if Canning Creek inflows fall below 250 ML/d).
9.0 Flow control	Large Pindari EIS Minimum Flow Requirement	Orders water from Pindari Dam to maintain a minimum flow of: ❑ 150 ML/day from July to March (if inflow to the storage is equal or in excess of this flow requirement); ❑ 50 ML/day from April to June (if inflow to the storage are equal or in excess of this flow requirement); ❑ the flow equal to storage inflow (if storage inflow is less than these seasonal flow requirements); ❑ 10 ML/day at any time immediately downstream of the dam
10.2 Environment (on river)	Boomi River Replenishment 1	A maximum of 6,666 ML/year (2/3 of the total 10,000 ML/year entitlement – subject to announced allocation) is released from Pindari Dam if demand is not met from surplus flows within the preceding 3 months. Release rate: 110 ML/day (2 blocks in October and January).
10.2 Environment (on river)	Boomi River Replenishment 2	A maximum 3,333 ML/year (1/3 of the total 10,000 ML/year entitlement – subject to announced allocation) is released from Pindari Dam if demand is not met from surplus flows within the preceding 3 months. Release rate: 110 ML/day (1 block in May).

The Boomi River is a NSW effluent creek of the lower Macintyre River, flowing to the south and rejoining the Barwon River below Mungindi. Replenishment releases are made into the Boomi River on an annual basis in recognition of the reduction in natural flows due to increased river regulation. Surplus flows, when available, are used to meet replenishment requirements. A volume of 10 GL is set aside in Pindari Dam on an annual basis for replenishment flows should surplus flows not occur. Diversions into the Boomi River are controlled by a weir on the main river and an offtake regulator, which is capable of diverting up to approximately 170 ML/day during periods of regulated flows. Replenishment flows are generally timed to coincide with stock and domestic requirements.

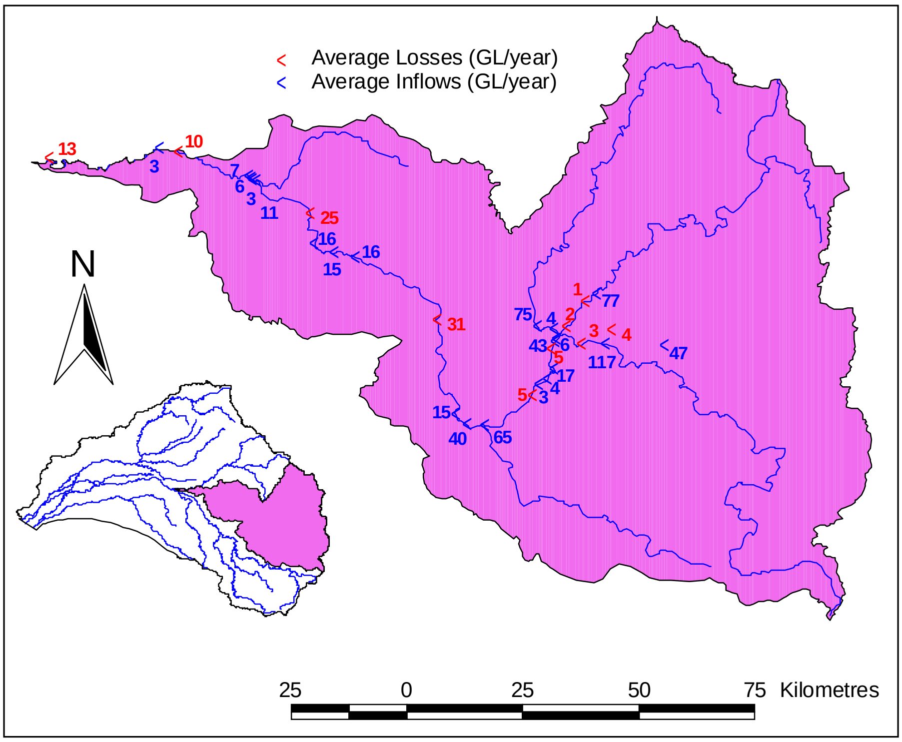


Figure 4.4. Distribution of modelled annual average (1975-2000) inflows and losses in Dumaresq River region of Border Rivers catchment.

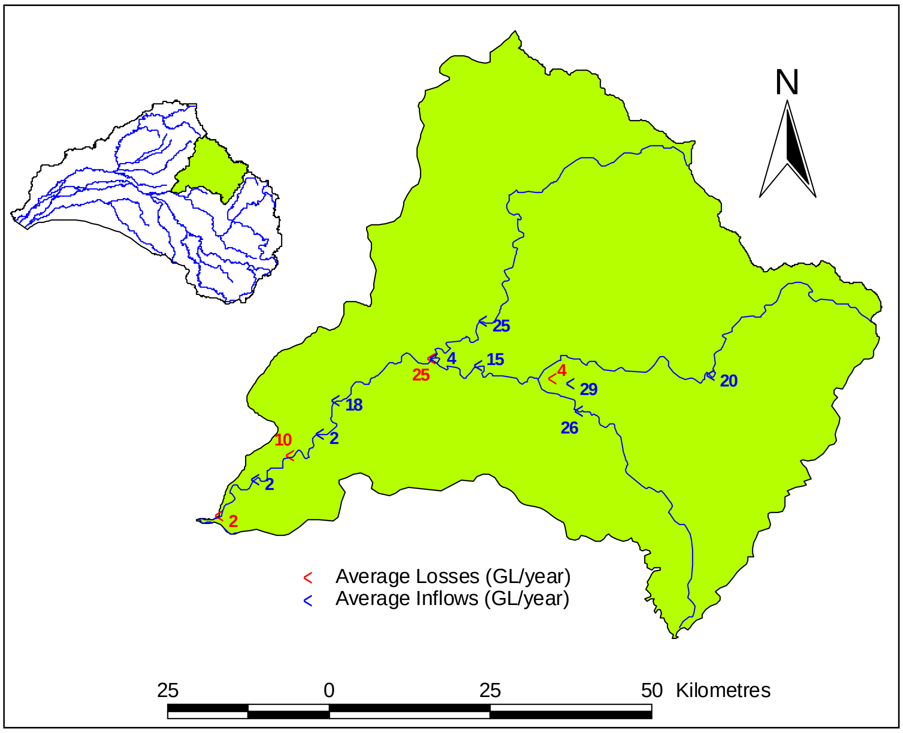


Figure 4.5. Distribution of modelled annual average (1975-2000) inflows and losses in Macintyre Brook region of Border Rivers catchment.

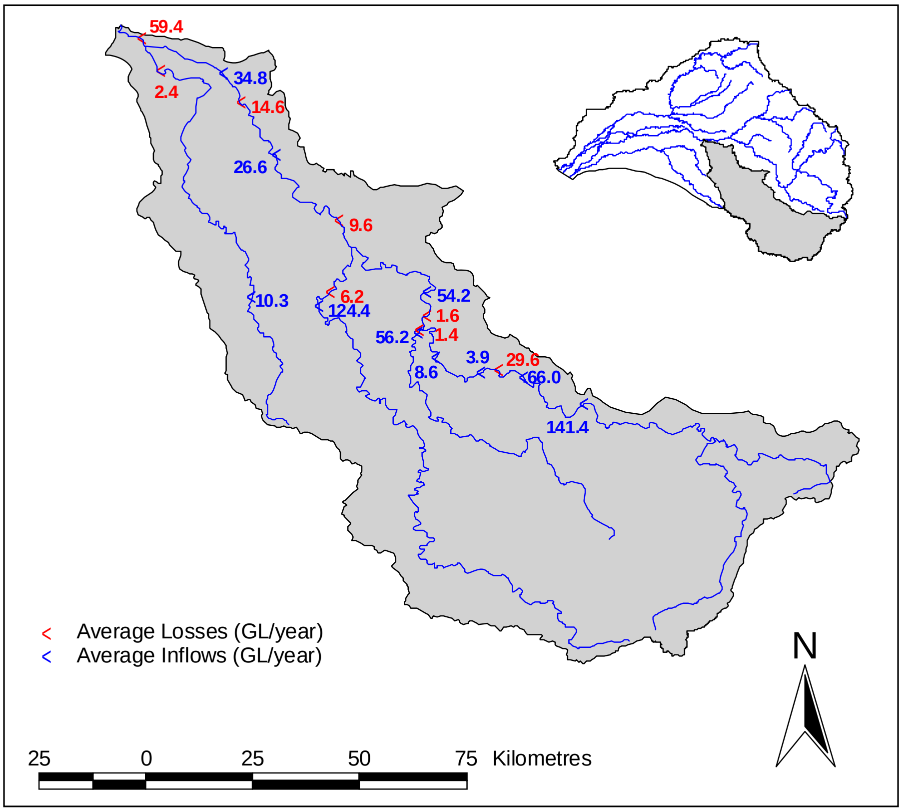


Figure 4.6. Distribution of modelled annual average (1975-2000) inflows and losses in Severn-Macintyre Rivers region of Border Rivers catchment.

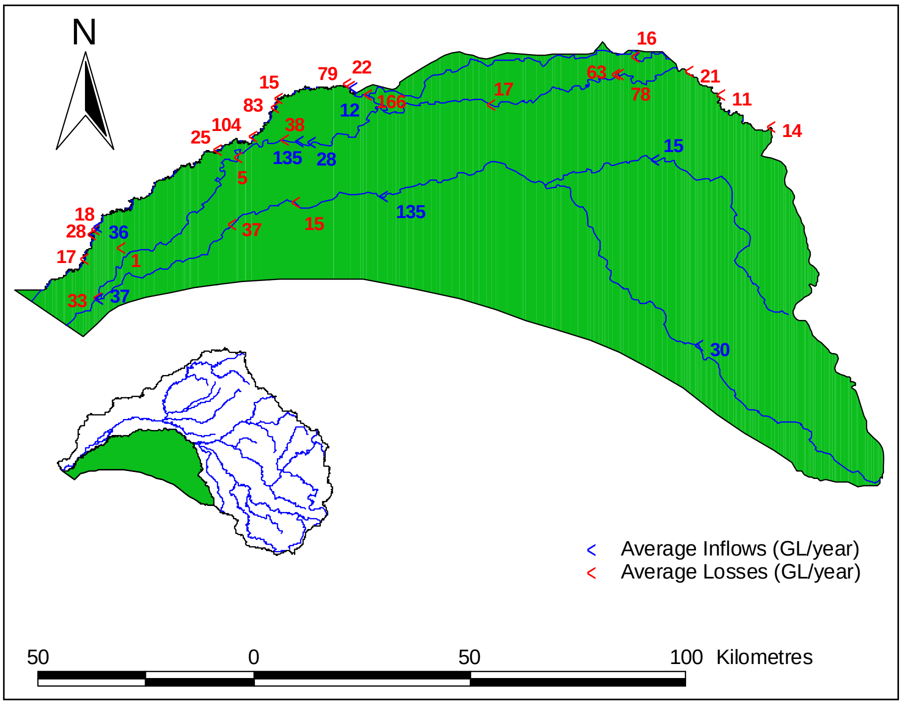


Figure 4.7. Distribution of modelled annual average (1975-2000) inflows and losses in Macintyre-Barwon Rivers region of Border Rivers catchment.

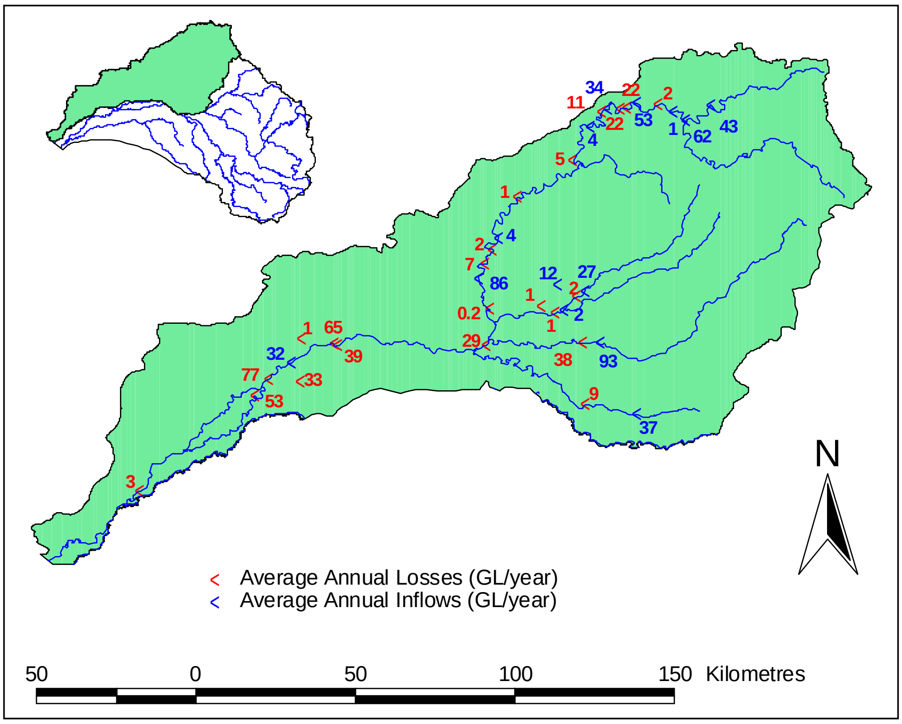


Figure 4.8. Distribution of modelled annual average (1975-2000) inflows and losses in Weir River region of Border Rivers catchment.

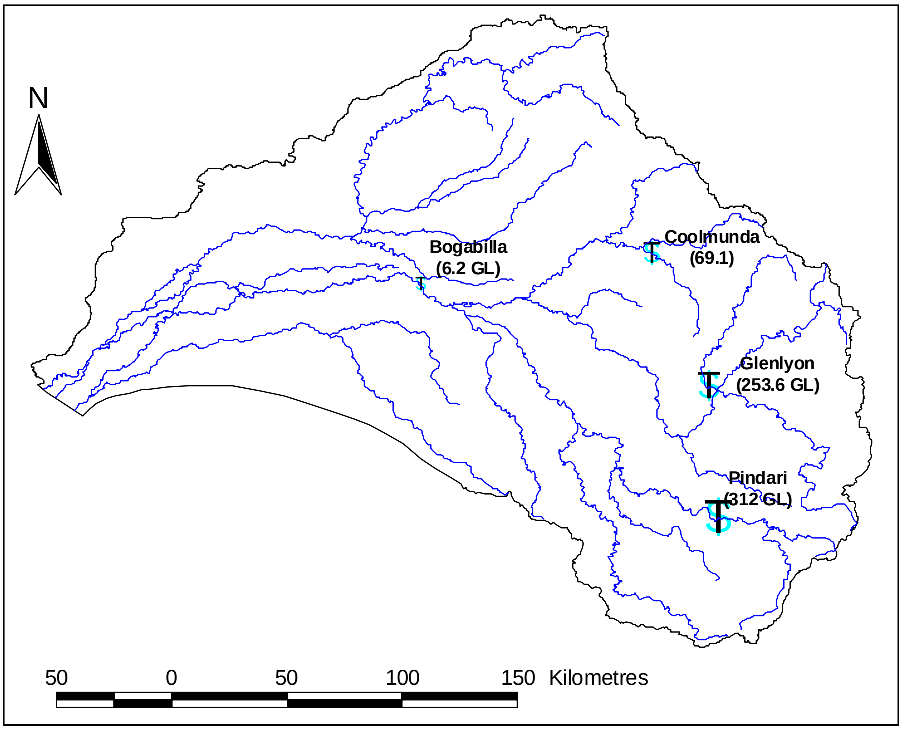


Figure 4.9. Modelled storages in Border Rivers System IQQM.

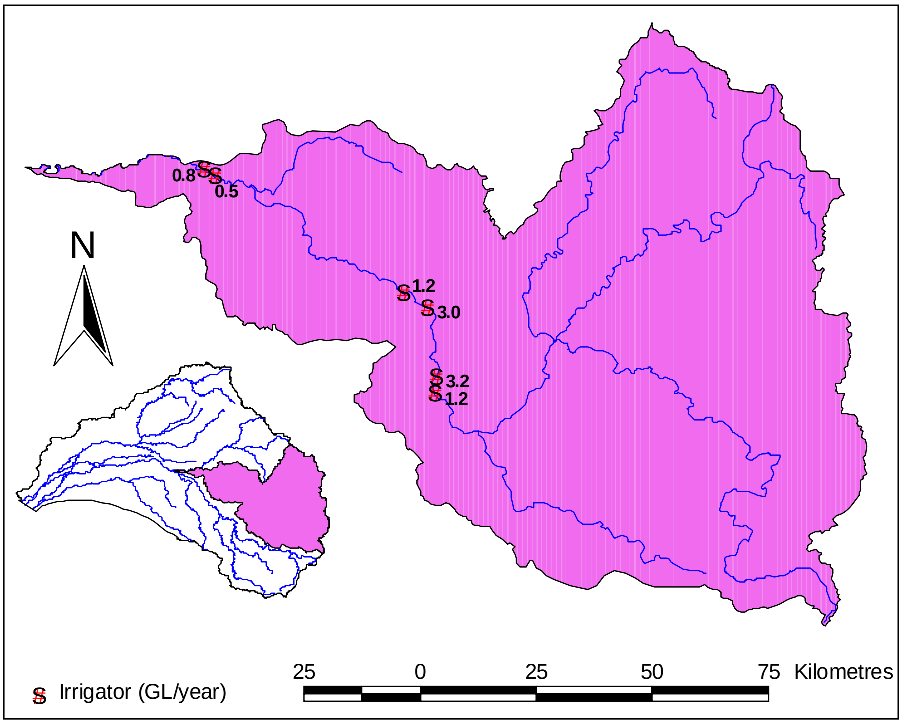


Figure 4.10. Modelled average annual irrigation diversions (GL/year; 1975-2000) for Dumaresq River region.

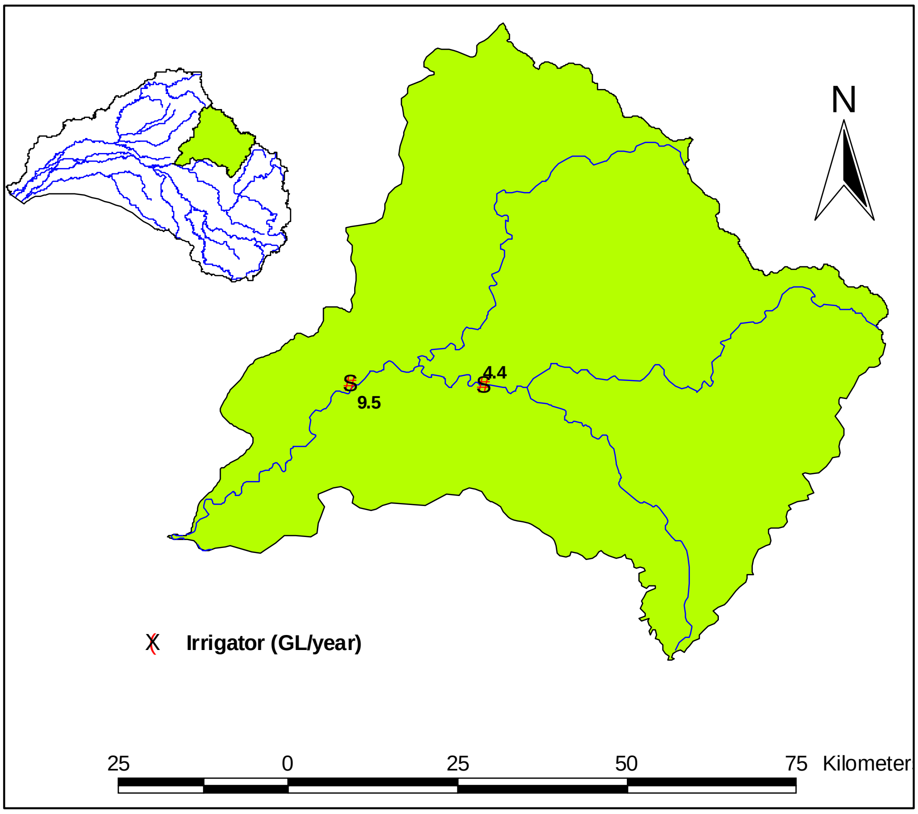


Figure 4.11. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Macintyre Brook region.

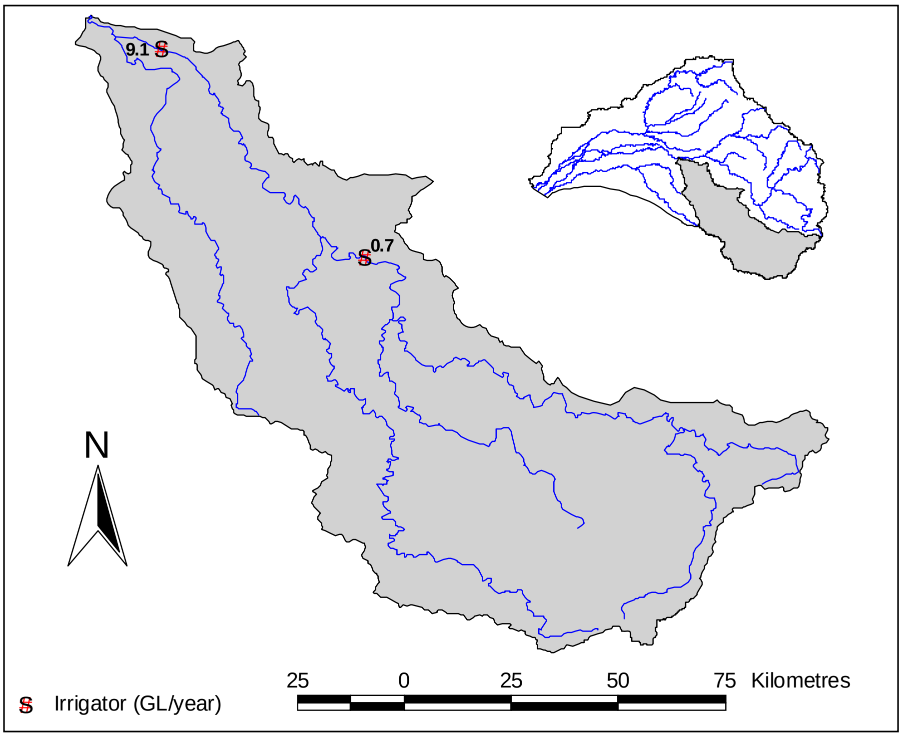


Figure 4.12. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Severn-Macintyre Rivers region.

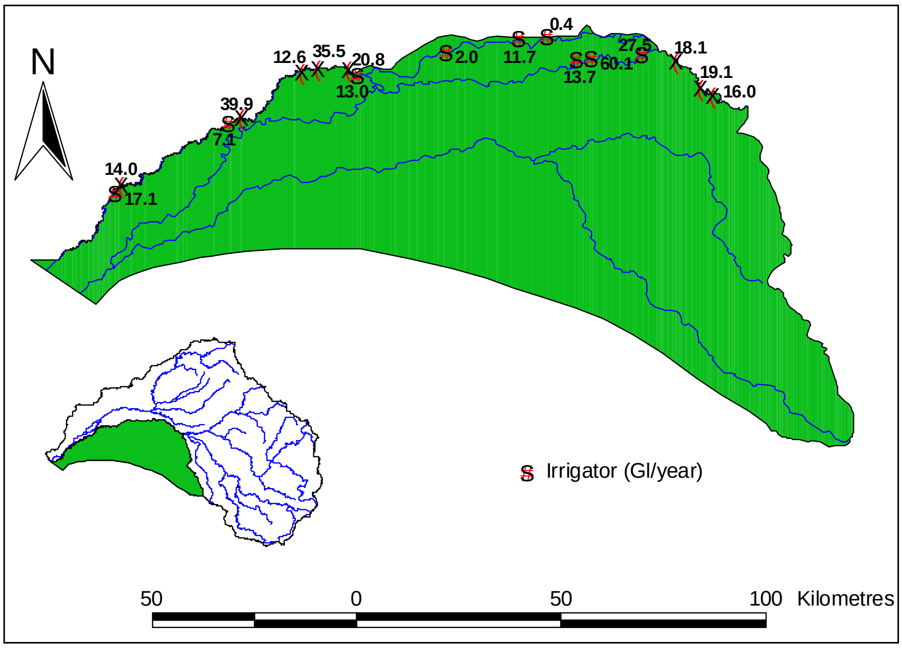


Figure 4.13. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Macintyre-Barwon region.

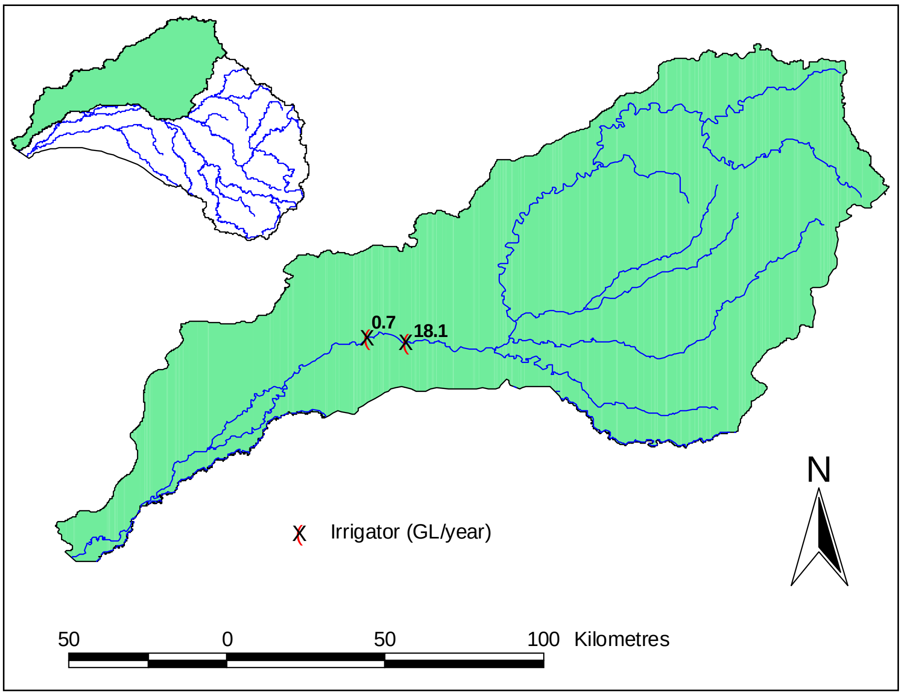


Figure 4.14. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Weir River region.

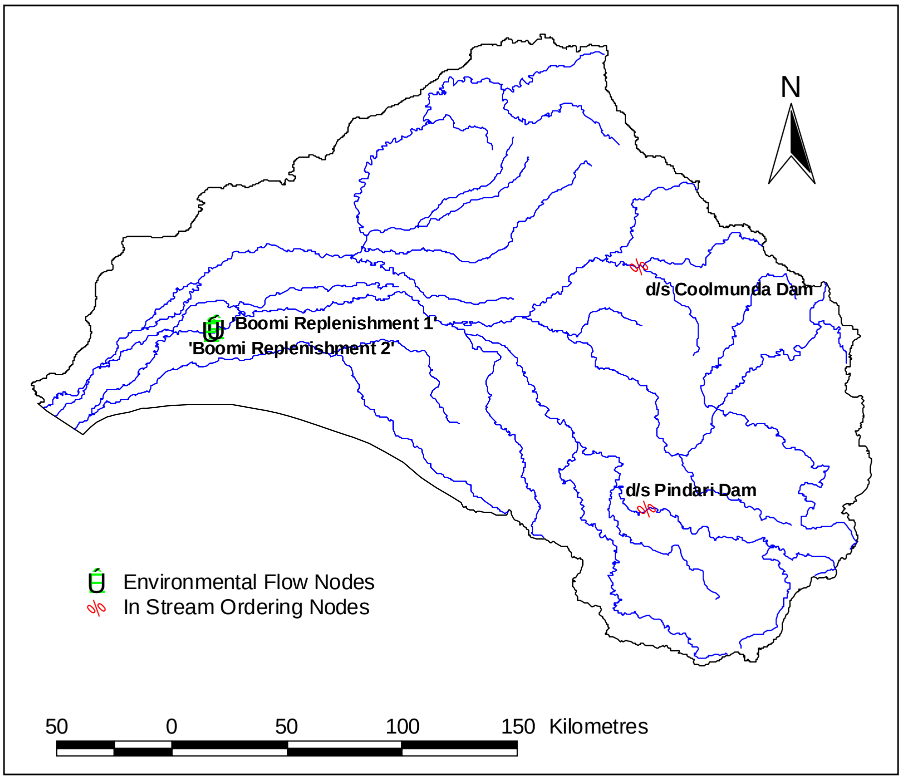


Figure 4.15. Distribution of nodes for ordering in-stream and environmental flow requirements

4.1.5. Peer Review

There has not been any formal peer review of the quantity component of Border Rivers IQQM although there has been checking of the model both by NSW and Queensland modellers. Consultation with Border Rivers irrigators has taken place to ensure input parameters are indicative of on-farm management practices.

The quality component of IQQM was developed from the US EPA model QUAL2E. Several conference papers have been presented and reviewed outlining the IQQM quality modelling and focused on salinity. Additional discussions have occurred with the MDBC outlining the Department’s salt routing procedure. The following quality assurance tests the models salt routing capabilities.

4.2. QUALITY ASSURANCE OF QUALITY MODEL

4.2.1. QA Test 1: Update base quantity model

The results of the mass balance check for the major water balance components of the base quantity model over the simulation period 1975-2000 are shown in Table 4.2. The total error over the period of simulation is 11 ML, out of a total inflow of $94*10^6$ ML, or 0.00001%. The magnitude of these results is typical of the order of magnitude that would be expected from rounding errors in the calculations, and we can conclude that there are effectively no flow mass balance errors in the IQQM software.

Table 4.2. Flow mass balance report for Border Rivers IQQM, 1993/4 Cap Scenario for 1975-2000.

Water balance component	Sum over simulation period (ML)
Inflows	94,286,880
Losses	84,122,986
Extractions	10,130,974
Storage change	-32,909
Error	11

4.2.2. QA Test 2: Initialise salinity module with zero salt load

The purpose of this test was to ensure that introducing salt modelling to the system (i) did not change the magnitude of the quantity mass balance components from that of QA Test 1, and (ii) that no sources or sinks of salt are introduced by software bugs.

The results for the quantity mass balance comparison reported in Table 4.3 show no changes for the water balance components. The salt mass balance report is shown in Table 4.4, and the results show that there are no numerical sources or sinks of salt introduced by the software.

The concentrations statistics at the end-of-system ($\mu \pm \sigma$) are 0.0 ± 0.0 mg/L, supporting the conclusion that no sources or sinks are introduced by the software.

Table 4.3. Flow mass balance comparison report for Border Rivers IQQM after including salt modelling

Water balance component	QA Test 1 Sum over simulation period (ML)	QA Test 2 Sum over simulation period (ML)

Water balance component	QA Test 1 Sum over simulation period (ML)	QA Test 2 Sum over simulation period (ML)
Inflows	94,286,880	94,286,880
Losses	84,122,986	84,122,986
Extractions	10,130,974	10,130,974
Storage change	-32,909	-32,909
Error	11	11

Table 4.4. Salt mass balance report for Border Rivers IQQM, 1993/4 Cap Scenario with zero salt inflows

Water balance component	QA Test 2 Sum over simulation period (Tonnes)
Inflows	0
Losses	0
Extractions	0
Storage change	0
Error	0

4.2.3. QA Test 3: Constant flow and concentration

The purpose of QA Test 3 was to test the stability of the model under constant flow conditions, and to further test that there are no numerical sources or sinks of salt introduced by the software. This was done by setting the flow and concentrations to constant values, and rainfall and evaporation to zero.

The result aimed for at the end of system was ($\mu \pm \sigma$) 100.0 ± 0.0 mg/L. The actual result was 100.0 ± 0.2 mg/L, indicating there were still some minor instabilities that need addressing in the code.

4.2.4. QA Test 4: Variable flow and constant concentration

The purpose of QA Test 4 was to test the stability of the model under variable flow conditions, and to further test that there are no numerical sources or sinks in the model. The full set of inflows from QA Test 1 were used with a constant salinity concentration of 100 mg/L at all inflow nodes, and rainfall and evaporation set to zero.

The result aimed for at the end of system was ($\mu \pm \sigma$) 100.0 ± 0.0 mg/L. The actual result was 99.9 ± 2.7 mg/L, indicating there were still some minor instabilities that need addressing in the code.

4.2.5. QA Test 5: Flow pulse with constant concentration

The purpose of QA Test 5 was to verify that salt load was routed through the system consistently with flow. This was done by having a synthetic flow hydrograph at the top of the system, with constant salinity concentration of 100 mg/L. All other inflow nodes had zero flow and concentration, and all storages, diversions, and effluents were modified to have no effect on water balance.

The results are shown at Figure 4.16. The effects of routing are clearly shown in these results with a lag and attenuation of the hydrograph. The patterns of the flow and salt load match exactly; showing that salt load is routed through the system consistently with the flow. The concentration aimed for at the end of system was ($\mu \pm \sigma$) 100.0 ± 0.0 mg/L. This result was achieved within the time taken for 99.9% of the load to pass through the end of the system. There was some numerical instability in the concentration after this point as the flow became too small to detect but was still carrying a detectable load.

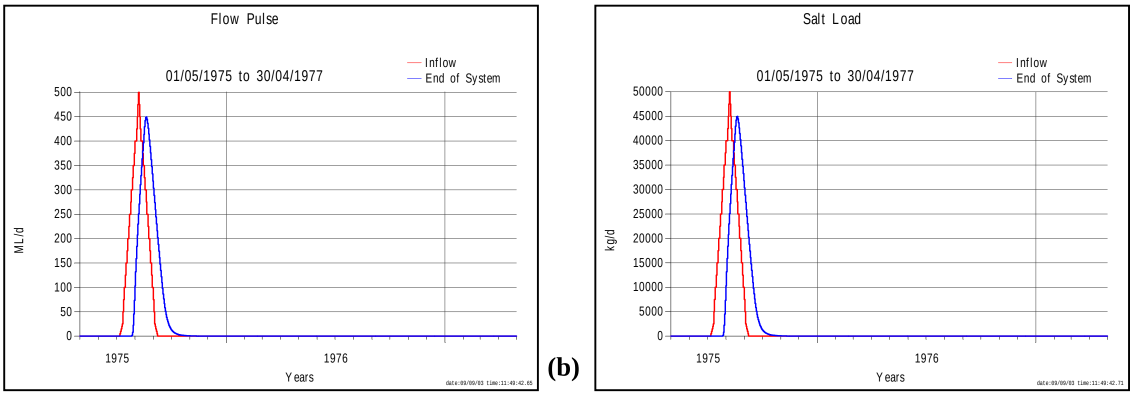
(a)


Figure 4.16. (a) Inflows and resultant EOS flows; (b) Salt load inflows and EOS salt loads

4.2.6. QA Test 6: Salt pulse with constant flow

The purpose of QA Test 6 was to further verify that salt was routed through the system consistently with flow. This was done by having a constant flow at the top of system with a concentration time series at this inflow increasing linearly from 0 to 500 mg/L over a period of one month, then decreasing back to 0 mg/L over the next month. All other time series inflows and concentrations were set to zero. All storages, diversions and effluent nodes were modified to have no effect on water balance.

The results are shown at Figure 4.17. The effects of routing are clearly shown in these results with a lag and attenuation of the salt load hydrograph. The patterns of salt load and concentration exactly match; showing that salt load is routed through the system consistently with the flow.

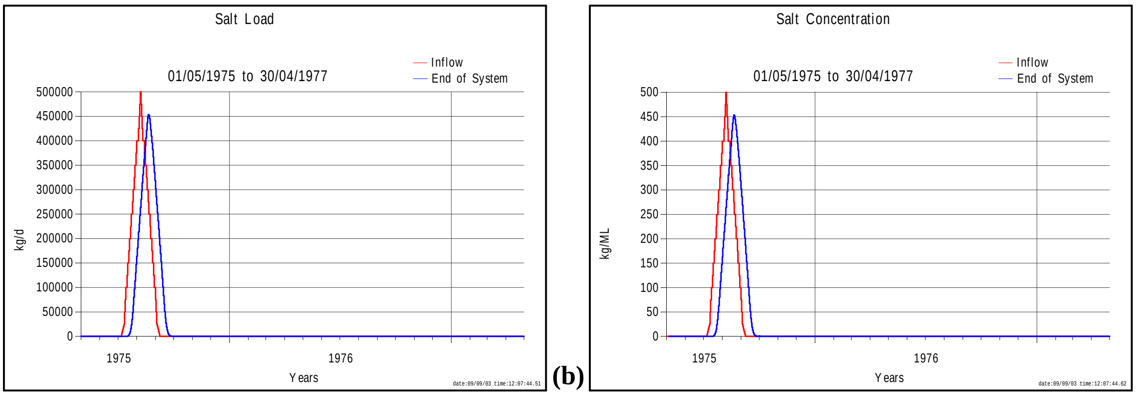
(a)


Figure 4.17. (a) Salt load inflows and EOS salt loads; (b) Inflow concentration and EOS concentration

4.3. QUALITY ASSURANCE CONCLUSIONS

The software passed the QA tests sufficiently well to justify developing the quality model for salt transport under BSMS baseline conditions. Some model limitations that account for salinity fluctuations in QA Tests 3 and 5 were worked around by post-processing the salinity data for the model evaluation work.

5. Salt inflow estimates and evaluation

5.1. INITIAL ESTIMATE

5.1.1. New South Wales

Salt loads were input to the model at all the inflow nodes. The initial estimates for the NSW salt load inflows were based on the relationships documented in Table 5.1 of the Salinity Audit (Beale et al, 1999).

5.1.2. Queensland

The Queensland part of the Border Rivers catchment was represented by two residual inflows in the Audit. Disaggregating these two inputs to the IQQM inflows was too unreliable so salt load inputs for all Queensland inflows were provided by the Queensland Department of Natural Resources and Mines (QDNRM). Initial estimates were based on the relationship shown in Equation 5.1. The development of this relationship is discussed in Appendix C. These relationships were calibrated by QDNRM to match concentrations at evaluation points. The final flow-salinity relationships are referred to in Table 5.1 and Table 5.2.

$$EC = \frac{K_1 - K_2}{1 + K_3 * Q^{K_4}} + K_2 \qquad (5.1)$$

Where: EC = Electrical conductivity (µS/cm)

K_1 = maximum EC under low flow conditions

K_2 = maximum EC in runoff

K_3, K_4 = constants related to curvature

5.1.3. Combined

The NSW relationships are the basis of the 'first cut' models. The flow and salt load results from the 'first cut' models were firstly tested for consistency with the Salinity Audit results (Appendix). These results are then evaluated against in-stream concentration data, and if necessary, the salt inflow estimates are calibrated to improve the match with the concentration data.

The schematisation of the salt load inflows and balance points from Figure 5.2 of the Salinity Audit is reproduced in geographical form for reference in Figure 5.1. The catchment boundaries for these inflow and balance points are shown in Figure 5.2.

The relationships from Table 5.1 in the Salinity Audit were modified in the following ways:

(i) Adapted to different IQQM network structure compared with Salinity Audit.

(ii) Replaced model form IIA with model form IID.

(iii) Modified for different EC→salinity conversion factor.

(iv) Concentration capped to the highest observed.

(v) Accounting for different benchmark climatic conditions in the Audit compared with BSMS.

(vi) Calibrated flow-salinity tables provided by the QDNRM were applied to all of the Queensland inflows.

The relationship between the IQQM network structure and the Salinity Audit inflows referred to in point (i) above is listed in Table 5.1 for gauged catchments and Table 5.2 for residual catchments. In many cases, the parameters of the salt load relationships from the Audit are directly transferable, (eg. catchments 416039 and 416008). In others, the parameters had to be modified as more than one IQQM inflow node was used to model flow from that catchment, eg. R3 with two inflow nodes, or 416011 with ten inflow nodes. The concentration cap adopted for point (iv) above is also shown in Table 5.1 and Table 5.2.

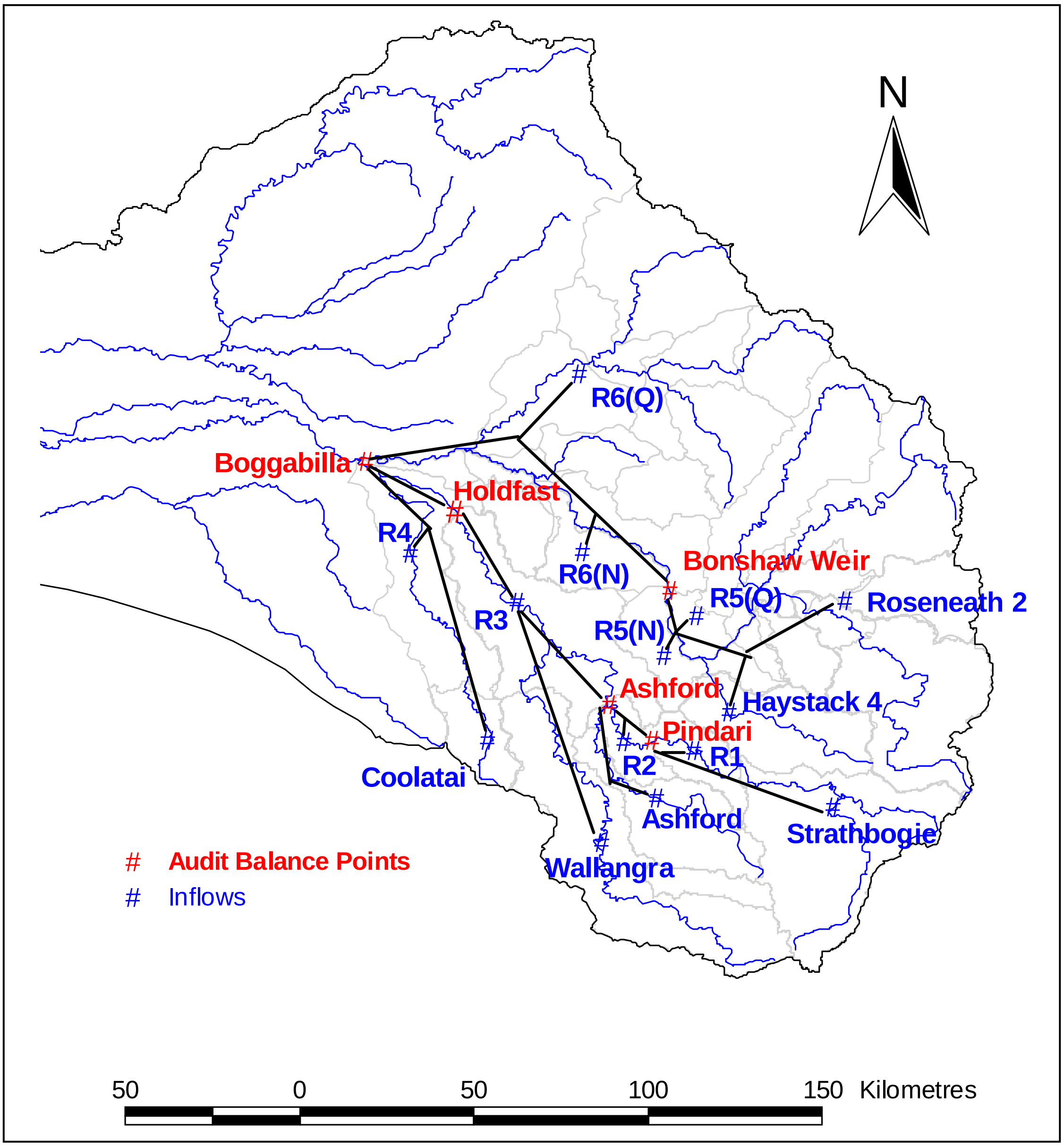


Figure 5.1. Geographic representation of 1999 Salinity Audit schematic of inflows and balance points.

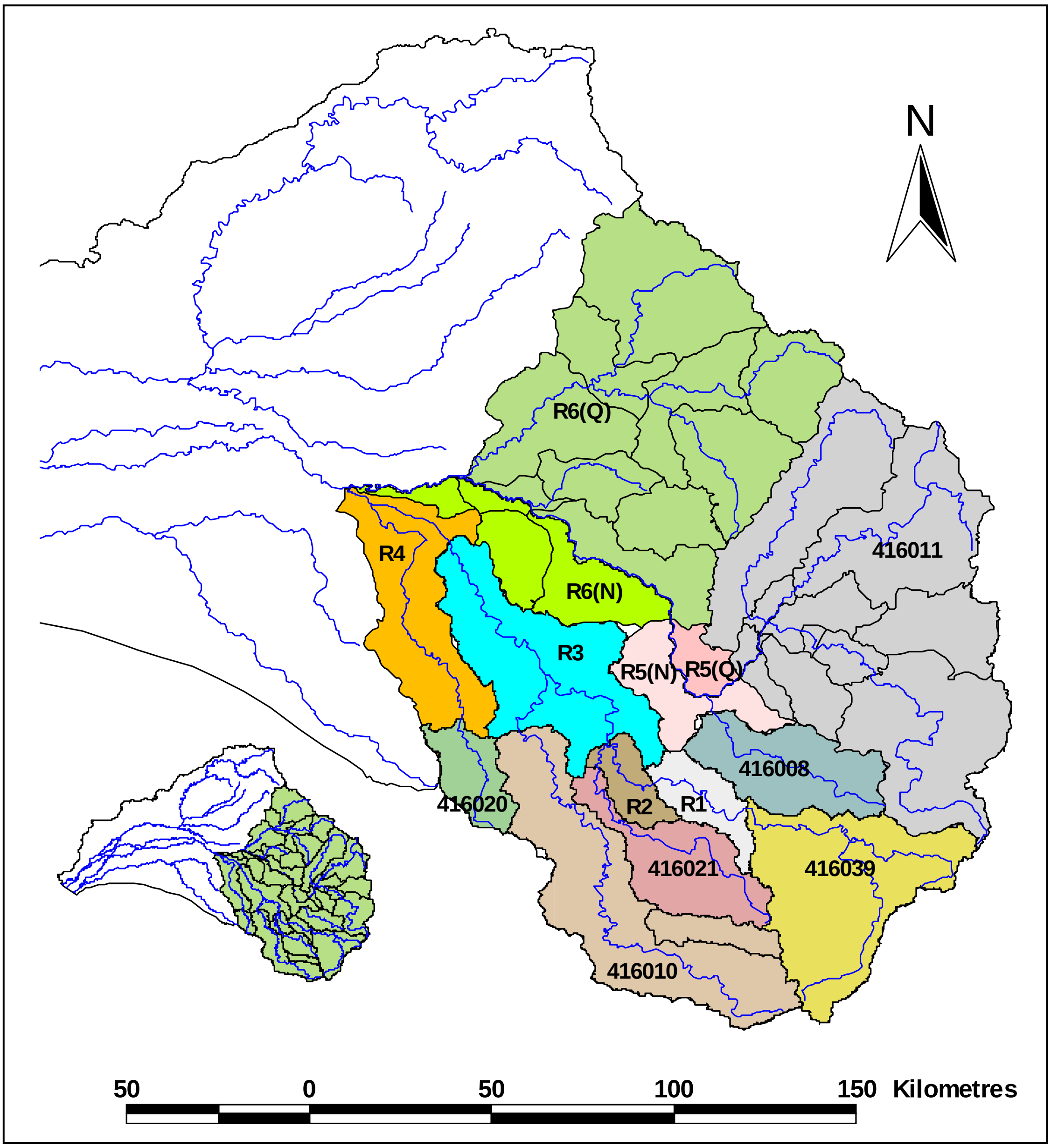


Figure 5.2. Inflow catchments used for 1999 Salinity Audit.

Table 5.1. Salt inflow model parameters for gauged catchments

Subcatchment		IQQM inflow node number	Audit load flow model			
Station number	Station name		*Type*	η	λ	C_{max} (mg/L)
416039	Severn River @ Strathbogie	301	IID	2.67	0.932	312
416021	Frazers Creek @ Ashford	050	IID	2.96	0.954	579
416010	Macintyre River @ Wallangra	057	IIC	27.0	8.76	576
416020	Ottleys Creek @ Coolatai	116	IIA	-6.11	23.0	618
416020		*116*	*IID*	*3.015*	*0.9374*	*618*
416008	Beardy River @ Haystack	187	IIC	7.5100	4.08	518
416011	Dumaresq river @ Roseneath		IIC	18.2	6.78	
011_a(Q)	*Back-calculated Glenlyon Dam inflows (416309)*	*001*	* see Table Q7			*690*
011_b(Q)	*QLD residual (Pike Ck. d/s Glenlyon)*	*153*	* see Table Q8			*690*
416310	*Severn River (QLD) @ Farnbro*	*003*	* see Table Q8			*174*
416003	*Tenterfield Creek @ Clifton*	*182*	*IIC*	*1.8395*	*6.78*	*466*
416032	*Mole River @ Donaldson*	*004*	*IIC*	*4.7849*	*6.78*	*277*
011_c(Q)	*QLD residual (Dumaresq R. u/s Mingoola)*	*005*	* see Table Q8			*690*
011_d(N)	*NSW residual (Dumaresq R. u/s Mingoola)*	*123*	*IIC*	*2.1954*	*6.78*	*466*
416026	*Reedy Creek @ Dumaresq*	*009*	*IIC*	*0.8716*	*6.78*	*135*
011_e(Q)	*QLD residual (Mingoola – Roseneath)*	*165*	* see Table Q8			*238*
011_f(N)	*NSW residual (Mingoola – Roseneath)*	*166*	*IIC*	*0.1482*	*6.78*	*238*

** see Queensland flow versus salinity tables in Table 5.3.*

Table 5.2. Salt inflow model parameters for residual catchments

Subcatchment		IQQM inflow node number	Audit load flow model			
Number	Description		*Type*	*η*	*λ*	C_{max} *(mg/L)*
R1	Ungauged Severn River u/s Pindari (416019)	304	IID	2.67	0.9	312
R2	Ungauged Severn River between Pindari (416019) and Ashford (416006)		IID	2.67	0.9	579
R2_a	*NSW residual (Pindari-Llanarth)*	*045*	*IID*	*2.67*	*0.9*	*312*
R2_b	*NSW residual (Llanarth-Ashford)*	*049*	*IID*	*2.67*	*0.9*	*312*
R3	Ungauged Severn and Macintyre Rivers u/s Holdfast (416012)		IID	2.95	0.89	
R3_a	*NSW residual (u/s dam site)*	*055*	*IID*	*2.74*	*0.89*	*576*
R3_b	*NSW residual (dam site-Holdfast)*	*062*	*IID*	*2.74*	*0.89*	*462*
R4	Ungauged Macintyre River between Holdfast (416012) and the Dumaresq River confluence	070	IID	2.95	0.89	618
R5_NSW	NSW part of ungauged Dumaresq River between Roseneath (416011) and Bonshaw (416007)	125	IIC	12.8	11.1	518
R5_Qld	Qld part of ungauged Dumaresq River between Roseneath (416011) and Bonshaw (416007)	126	* see Table Q8			518
R6_NSW	NSW part of ungauged Dumaresq River between Bonshaw (416007) and the Macintyre River confluence		IIC	20.0	14.8	
R6_Na	*NSW residual (Bonshaw-Mauro)*	*020*	*IIC*	*9.8052*	*14.8*	*296*
R6_Nb	*NSW residual (Mauro-Mac.Brook confluence)*	*128*	*IIC*	*2.0497*	*14.8*	*296*
416036	*Campbells Creek @ Beebo*	*026*	*IIC*	*5.3942*	*14.8*	*296*
R6_Nc	*NSW residual (Mac.Brook-Mac.R. confluence)*	*142*	*IIC*	*2.7509*	*14.8*	*367*
R6_Qld	QLD part of ungauged Dumaresq River between Bonshaw (416007) and the Macintyre River confluence		n/a			
416312	*Oaky Creek @ Texas*	*188*	* see Table Q1			*780*
R6_Qa	*QLD residual (Bonshaw-Mauro)*	*127*	* see Table Q1			*525*
416305	*Brush Creek @ Beebo*	*189*	* see Table Q2			*110*
R6_Qb	*QLD residual (Mauro-Mac.Brook confluence)*	*129*	* see Table Q2			*110*
416410	*Macintyre Brook @ Barongarook*	*226*	* see Table Q3			*402*
416404	*Bracker Creek @ Terraine*	*227*	* see Table Q4			*840*
R6_Qc	*QLD residual (u/s Coolmunda Dam)*	*229*	* see Table Q5			*180*
R6_Qd	*QLD residual (Coolmunda-Inglewood)*	*245*	* see Table Q6			*500*
416407	*Canning Creek @ Woodspring*	*131*	* see Table Q6			*501*
R6_Qe	*QLD groundwater (Coolmunda-Inglewood)*	*247*	* see Table Q6			*500*
R6_Qf	*QLD residual (Inglewood-Booba Sands)*	*238*	* see Table Q6			*500*
R6_Qg	*QLD groundwater (Inglewood-Booba Sands)*	*248*	* see Table Q6			*500*
R6_Qh	*QLD residual (Booba Sands-Mac.R. confluence)*	*136*	* see Table Q6			*500*

** see Queensland flow versus salinity tables in Table 5.3.*

Table 5.3. Flow versus salinity tables for Queensland inflows upstream of Boggabilla

Table Number	Flow (ML/d)	Concentration (mg/L)
Q1	0	525
	10	500
	60	350
	100	300
	200	290
	1,000	280
	22,000	240
Q2	0	110
	2	100
	10	85
	100	55
	100,000	55
Q3	0	360
	3	250
	10	190
	50	180
	100	150
	500	150
	1,000	150
	1,500	130
	5,000	120
	50,000	100
Q4	0	370
	2	320
	5	310
	10	270
	50	240
	200	200
	5,000	200
	10,000	160
	150,000	100
Q5	0	180
	10	160
	50	150
	100	140
	500	120
	1,000	100
	1,500	100
	5,000	90
	50,000	80
Q6	0	500
	2	460
	5	400
	10	370
	50	320
	200	270
	5,000	200
	150,000	100
Q7	0	255
	5	200
	50	190
	100	160
	1,000	120
	10,000	90
	100,000	70
Q8	0	120
	5	120
	50	105
	100	100
	1,000	90
	10,000	70
	100,000	70

5.2. EVALUATION METHOD

5.2.1. Model configuration

The quantity model had to be reconfigured so that model results could be reliably compared against observed data, because the water quality is dependent on water quantity. This is demonstrated by considering Figure 5.3 and Equation 5.1. If either of the two simulated flows that mix are in error then it will result in an incorrect estimate of simulated concentration at the gauge locations (C_{obs}).

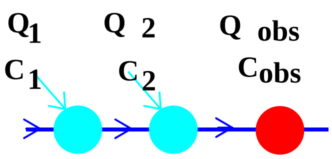


Figure 5.3. Calculating resultant concentration from two tributaries

$$C_{obs} = \frac{Q_1 \times C_1 + Q_2 \times C_2}{Q_1 + Q_2} \qquad (5.1)$$

Where: C_{obs} = Observed concentration at gauge location (mg/L)

C_1 = Concentration of water from tributary 1 (mg/L)

C_2 = Concentration of water from tributary 2 (mg/L)

Q_1 = Flow from tributary 1 (ML/d)

Q_2 = Flow from tributary 2 (ML/d)

The Border Rivers System IQQM provides good estimates of flow for the parts of the model upstream of storages. Downstream of storages observed flows depend a lot on regulation (ie. how much water was released from the storage). No single configuration of the model estimates these releases well over the period when data was collected, because levels of irrigation development and storage operation policies changed within this period.

A good match of the flows downstream of the storages was achieved by forcing the releases from the storages to observed releases. Exceptions occur when diversions are a significant proportion of the flow in the river. Simulated diversions in the Border Rivers System IQQM used to evaluate results are based on 1993/4 levels of development, and any errors in estimating diversions would contribute to errors in the simulated flow compared with observed. However, these errors would not significantly effect simulated concentrations, because most of the inflows have already entered the major rivers (Figure 4.6) upstream of most of the diversions (Figure 4.13).

5.2.2. Selection of evaluation sites

A total of fifteen NSW and two Queensland locations have data that could be used for model evaluation (Table 3.2). Only one of these locations has continuous data (

Table 3.3). At this stage, performance measures have only been developed for discrete data as the continuous data sets are too short and methods have not yet been derived to account for serial correlation within the data sets.

The model results have only been evaluated at locations of interest in NSW: (i) where salinity targets have been set; (ii) the NSW headwater storage at Pindari; and (iii) two locations where there are major inputs from Queensland. (An evaluation of the results for additional Queensland stations is given in Appendix C.)

The BSMS Target site is at the end of the system:

(i) Station 416001: Barwon River @ Mungindi.

Additional sites evaluated within each part of the catchment are:

Downstream of Glenlyon Dam:

(ii) Glenlyon Dam (see Appendix C for evaluation);
(iii) Station 416011: Dumaresq River @ Roseneath;
(iv) Station 416007: Dumaresq River @ Bonshaw Weir;
(v) Station 416049: Dumaresq River @ Mauro;

Downstream of Coolmunda Dam:

(vi) Coolmunda Dam (see Appendix C for evaluation);
(vii) Station 416415: Macintyre Brook @ Booba Sands;

Downstream of Pindari Dam:

(viii) Pindari Dam;
(ix) Station 416019: Severn River @ Pindari;
(x) Station 416006: Severn River @ Ashford;
(xi) Station 416012: Macintyre River @ Holdfast;

Downstream of all three dams:

(xii) Station 416002: Macintyre River @ Boggabilla;
(xiii) Station 416202: Weir River @ Talwood.

These sites are shown in Figure 5.4, and the results presented in the following section.

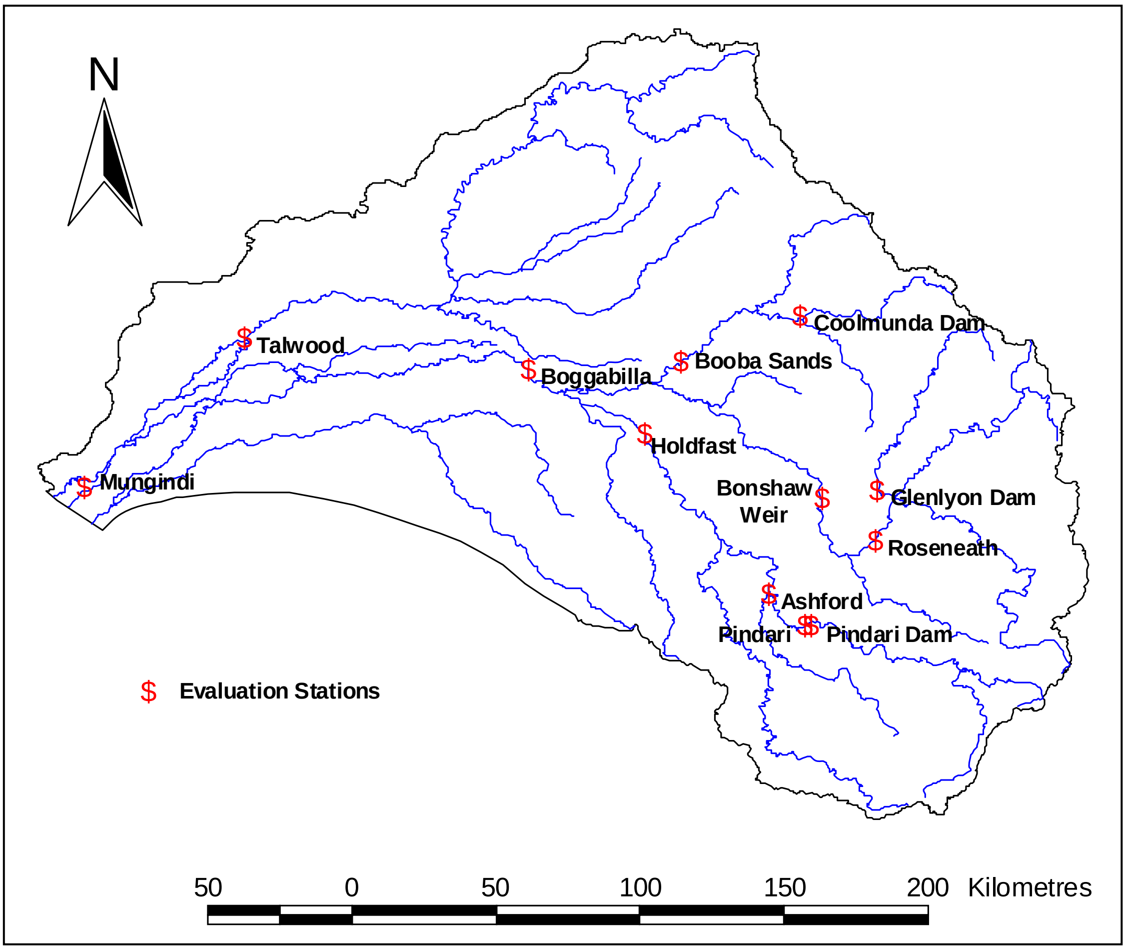


Figure 5.4. Location of evaluation sites.

5.2.3. Data quality performance measures

A component of evaluating model results is to evaluate how representative the data is of the hydrologic conditions in the catchment. Observations of in-stream EC at a location vary considerably depending on many factors. These factors all vary and include total flow; proportion of base flow compared with surface flow; where in catchment flow originated; stream-aquifer interactions; degree of regulation; antecedent conditions; season variability; and underlying trend, if any.

How good a data set is depends on how well it samples this variability. As these sources of variability cannot all be individually quantified, performance measures for data quality include:

(i) how many data points there are;

(ii) what period the data represents;

(iii) what is the seasonal distribution of the data; and

(iv) how the data is distributed within the flow ranges.

The flow ranges referred to in this table are based on observed flow as follows:

- High flows exceeded between 0-20% of the time

- Medium flows exceeded between 20-80% of the time
- Low flows exceeded between 80-100% of the time

These percentiles were selected to approximate the corresponding BSMS reporting intervals for the salinity non-exceedance graphs. The same flow ranges were used as reporting groups for performance measure (iv), which compares the flow variability for that flow range with the flow variability within that range for days with EC data.

A good result for performance measures (i)-(iii) is a uniform distribution across the flow ranges and across all months, as well as the more data the better. A good result for performance measure (iv) is a close approximation of the observed flow statistics (ie. the observations sample the flow variability).

Time series graphs of the full set of screened salinity data (Table 3.1) and observed flow at evaluation locations are shown at the end of this chapter (Figure 5.26 to Figure 5.38). Performance measures (i), (ii), and (iii) are reported in Table 5.4. Performance measure (iv) from above is reported in Table 5.5.

5.2.4. Model result performance measures

5.2.4.1. Storages

Concentrations in storages do not vary in the same way as in streams. Storages accumulate salt load, and daily concentrations vary based on the previous day's concentration, in addition to changes in water and salt into and out of the storage (Equation 5.2). Except for times of very high inflows, the daily variation in salinity is very low.

Dry periods result in gradual changes of concentration because the volume of water in the storage is much larger than the tributary inflow volume. Salinities during these times typically increase because low flows have higher concentrations and because evaporation decreases water volume without changing the salt load. Wet periods will usually result in abrupt changes in concentration because the volume of water in storage and the inflow are a similar size, and the high flows usually have relatively low concentrations. IQQM explicitly simulates all these processes.

$$C_t = \frac{(V_{t-1} \times C_{t-1}) - (V_{out} \times C_{t-1}) + (V_{in} \times C_{in})}{V_{t-1} - V_{out} + V_{in} + V_p - V_e} \qquad (5.2)$$

Where: C_t = Resultant concentration (mg/L)
$V_{t\text{-}1}$ = Volume in storage on previous day (ML)
$C_{t\text{-}1}$ = Concentration in storage on previous day (mg/L)
V_{out} = Volume released from storage (ML)
V_{in} = Tributary inflow volume (ML)
C_{in} = Concentration of tributary inflow (mg/L)
V_p = Volume added to storage by precipitation (ML)
V_e = Volume lost from storage by evaporation (ML)

Five performance measures were developed to evaluate the model results here, as follows:

(i) Pattern match (Equation 5.3), which measures how well the model reproduces the magnitude and direction of the change in concentration.

(ii) Mean match (Equation 5.4), which measures how well the model reproduces the mean concentration for the period of simulation.

(iii) Average error (Equation 5.5), which measures the average difference between simulated and observed.

(iv) Range comparison (Equation 5.6) which measures how well the model matches the range of results.

(v) Coefficient of determination (Equation 5.7), which measures the ratio of explained variation to total variation.

Where S_t and O_t are simulated and observed measures at time *t*. All these performance measures are dimensionless to allow for comparison between results at different sites. A perfect result for a performance measure (i-iv) is zero, and for performance measure (v) the perfect result is one.

$$P = \frac{\sum_i \left|(O_{i+1} - O_i) - (S_{i+1} - S_i)\right|}{(n-1) \times \sigma_s} \quad (5.3)$$

$$M = \left|\frac{\sum_i S_i}{\sum_i O_i}\right| - 1 \quad (5.4)$$

$$E = \frac{\left|\sum_i S_i - \sum_i O_i\right|}{\sum_i O_i} \quad (5.5)$$

$$G = \left|\frac{S_{\max} - S_{\min}}{O_{\max} - O_{\min}}\right| - 1 \quad (5.6)$$

$$R^2 = \frac{\sum_i (S_i - \overline{O})^2}{\sum_i (O_i - \overline{O})^2} \quad (5.7)$$

5.2.4.2. In-stream

Performance measures for comparing simulated and observed results for in-stream locations are reported within the three flow ranges defined in Section 5.2.3, as well as for the total flow range. For observed and simulated flow and concentration, the following are reported in tabular format:

(i) mean;

(ii) standard deviation;

(iii) maximum; and

(iv) minimum.

In addition, the following are reported for concentration:

(v) mean error (same formulation as Equation 5.5); and

(vi) coefficient of determination (same formulation as Equation 5.7).

Lastly, mean simulated loads are compared with mean simulated loads are also compared for each flow range. An example with these results is shown in Table 5.6.

5.3. EVALUATION OF INITIAL SALINITY AUDIT ESTIMATES

The model results were evaluated at eleven sites (nine in NSW and two in Queensland) along the main streams of the Border Rivers System. The basis for selecting these sites was discussed in Section 5.2.2. Time series plots comparing observed and simulated salinity for the NSW stations are located at the end of this chapter (Figure 5.39 to Figure 5.49), and discussion of these results with performance measures are presented in Sections 5.3.1 to 5.3.14.

5.3.1. Glenlyon Dam

The performance of the model in Glenlyon Dam is described in Appendix C. For stations on the Dumaresq River downstream of Glenlyon Dam, model results were evaluated over the period for which dam releases could be forced to observed values (31/3/1978 to 29/3/2000).

5.3.2. Station 416011: Dumaresq River @ Roseneath

The gauging station on the Dumaresq River @ Roseneath has had data collected fairly consistently every 1-2 months over the evaluation period, except for large gaps in 1987/88, 1989/90 and 1997-99 (Figure 5.26). The salinity ranges from about 60-240 mg/L, with a median salinity of 138 kg/ML.

The data is representative of all the flow ranges and months (Table 5.4). However, the medium flow range (83-1,077 ML/d) is slightly over-represented (67% of data points) compared with the exceedance probability range (60% of the time), whilst the high flow range is under-represented (only 13% of data points). Table 5.5 indicates that data was not collected during any of the higher flow events. In the high flow range, the maximum, mean and standard deviation of flows with EC data are all significantly lower than those of the complete high flow range data set. In the medium and low flow ranges, the data has similar statistical characteristics to those of the complete flow record in those ranges.

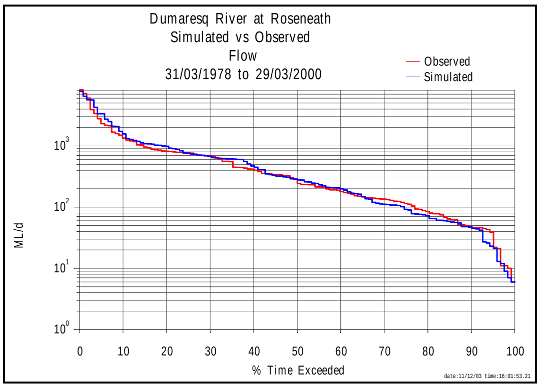
There are ten modelled inflows upstream of Roseneath (Table 5.1). Flow-load relationships derived from the Salinity Audit relationship for station 416011 were used for the five NSW inflows. Flow-salinity tables supplied by the QDNRM were used for the five Queensland inflows. The results show that flows match the observed flow distribution well (Figure 5.5a and Figure 5.39), as would be expected with forced releases from Glenlyon Dam. However, salinity is consistently underestimated for all but the lowest 5% of values (Figure 5.5b) whilst salt loads are slightly overestimated (Table 5.6). Overall, the results are better than expected given the crudeness of the method used to derive inputs for the NSW inflows.

Table 5.4. Distribution of flow with discrete EC across flow ranges and months for Station 416011: Dumaresq River @ Roseneath

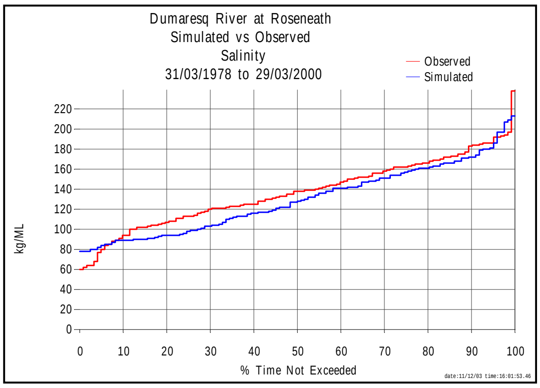
Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1978-2000	24	2	0	1	2	4	3	1	2	4	2	3	0
Medium		82	4	5	11	5	5	5	4	6	7	6	5	10
High		16	4	2	0	1	1	0	2	1	1	1	1	1
All		122	10	7	12	7	9	8	7	9	11	8	9	11

Table 5.5. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Gauging Station 416011: Dumaresq River @ Roseneath

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	42	23	0	83
	With EC obs	47	23	6	80
Medium	*All*	414	280	84	1,077
	With EC obs	407	282	85	1,045
High	*All*	3,577	5,598	1,078	62,806
	With EC obs	2,988	2,236	1,173	8,205
ALL	*All*	958	2,811	0	62,806
	With EC obs	674	1,228	6	8,205



(a)



(b)

Figure 5.5. Station 416011: Dumaresq River @ Roseneath; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.6. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 416011: Dumaresq River @ Roseneath

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)						
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*	*Mean error (mg/L)*	R^2	
Low	*Observed*	47	23	6	80	167	25	121	238			7
	Simulated	50	31	6	116	161	29	99	213	32	0.06	8
Medium	*Observed*	407	282	85	1,045	134	30	60	193			51
	Simulated	440	334	27	1,275	127	30	85	209	16	0.63	51
High	*Observed*	2,988	2,236	1,173	8,205	104	29	62	153			274
	Simulated	3,299	2,079	986	7,754	96	21	78	142	18	0.37	293
All	*Observed*	674	1,228	6	8,205	137	34	60	238			72
	Simulated	738	1,277	6	7,754	129	34	78	213	20	0.51	74

5.3.3. Station 416007: Dumaresq River @ Bonshaw Weir

The gauging station on the Dumaresq River @ Bonshaw Weir has had data collected fairly consistently every 1-2 months over the evaluation period (1978-2000), with a noticeably higher frequency of sampling since early 1990. However, there are two long periods when very few samples were taken (mid-1987 to the end of 1989 and late 1991 to mid-1996 (Figure 5.27)). The salinity ranges from about 50-220 mg/L, with a median of 132 mg/L. These figures are slightly lower than those at Roseneath, indicating that inflows from the Beardy River have a diluting effect.

The data is representative of all the flow ranges and months (Table 5.7). The medium flow range (97-1,348 ML/d) is slightly over-represented (65% of data points) compared with the exceedance probability range (60% of the time). Consequently, both the low and high flow ranges are slightly under-represented (with 18% and 17% of data points respectively). As at Roseneath, Table 5.8 indicates that data was not collected during very high flow events, although the problem is much less pronounced here. In the medium and low flow ranges, the data has similar statistical characteristics to those of the complete flow record in those ranges.

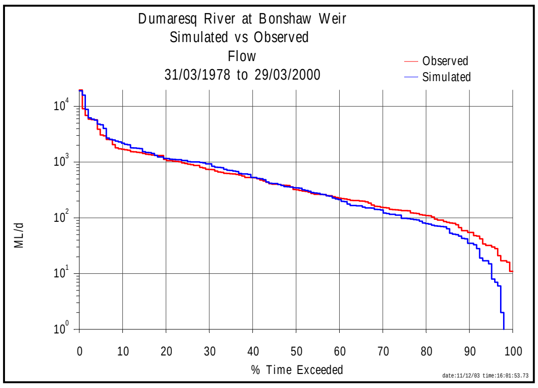
The results show that flows tend to be overestimated, especially in the higher half of the range (Figure 5.6a). Salinity is also significantly overestimated (Figure 5.6b and Figure 5.40) as are salt loads in the medium and high flow ranges (Table 5.9). These results indicate that the salinities of the Beardy River and/or the two residual catchment inflows that enter the Dumaresq River between Roseneath and Bonshaw are being overestimated.

Table 5.7. Distribution of flow with discrete EC across flow ranges and months for Station 416007: Dumaresq River @ Bonshaw Weir

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1978-2000	26	0	0	3	6	3	4	4	2	0	1	0	0
Medium		94	6	9	10	6	7	7	7	5	6	7	8	9
High		24	2	2	2	1	0	1	3	2	4	2	1	2
All		144	8	11	13	14	10	12	13	9	11	10	8	10

Table 5.8. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 416007: Dumaresq River @ Bonshaw Weir

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	51	27	0	97
	With EC obs	52	27	11	95
Medium	*All*	492	339	98	1,348
	With EC obs	462	338	103	1,342
High	*All*	4,302	6,214	1,349	66,777
	With EC obs	3,702	4,004	1,365	19,669
ALL	*All*	1,143	3,165	0	66,777
	With EC obs	928	2,056	11	19,669

(a) 

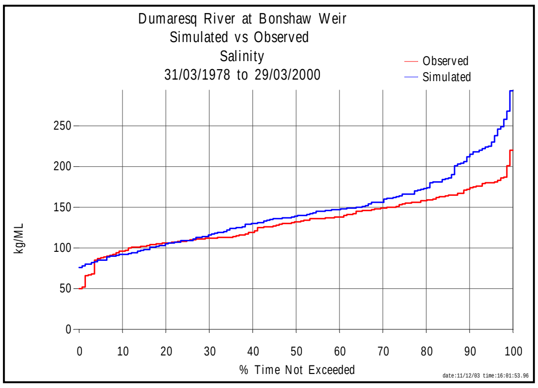
(b) 

Figure 5.6. Station 416007: Dumaresq River @ Bonshaw Weir; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.9. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 416007: Dumaresq River @ Bonshaw Weir

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)				*Mean error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*			
Low	*Observed*	56	26	16	95	164	19	132	220			9
	Simulated	54	45	6	167	181	57	85	293	55	0.13	9
Medium	*Observed*	462	338	103	1,342	131	27	50	201			57
	Simulated	500	433	2	2,309	147	34	96	268	25	0.27	65
High	*Observed*	3,702	4,004	1,365	19,669	103	20	66	136			346
	Simulated	4,326	4,518	1,009	19,026	95	15	76	136	15	0.31	373
All	*Observed*	948	2,073	16	19,669	131	31	50	220			98
	Simulated	1,079	2,384	2	19,026	144	44	76	293	28	0.28	108

5.3.4. Station 416049: Dumaresq River @ Mauro

The gauging station on the Dumaresq River @ Mauro has had data collected every 1-2 months from late 1985 to early 1996 except for gaps in 1987/88 and 1989 (Figure 5.28). Although this site has data for only part of the evaluation period (1978-2000), it is important in the calibration process. The salinity ranges from 56-296 mg/L with a median salinity of 154 mg/L, slightly higher than upstream at Bonshaw Weir.

The data is representative of all the flow ranges and months (Table 5.10). The medium flow range (52-1,211 ML/d) is slightly under-represented (56% of data points) whilst the low flow range is slightly over-represented (23% of data points). In the medium and low flow ranges, the data has similar statistical characteristics to those of the complete flow record in those ranges (Table 5.11). However, although the high flow range was not under-represented in terms of the number of data points, data was not collected during many of the higher flow events.

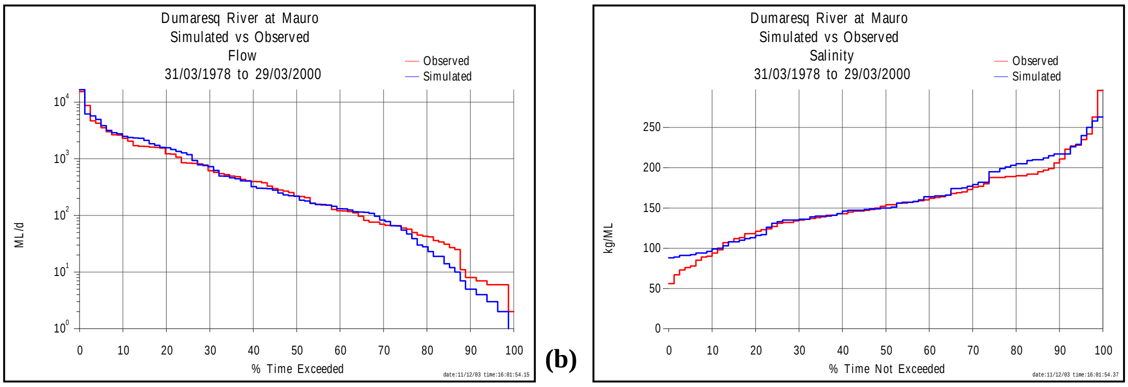
The results show that medium and high flows are slightly overestimated whilst low flows are significantly underestimated (Figure 5.7a). However, salinity matches the observed distribution fairly well, except for the very low and high salinities which are slightly overestimated (Figure 5.7b). This pattern is reflected in the salt load results (Table 5.12).

Table 5.10. Distribution of flow with discrete EC across flow ranges and months for Station 416049: Dumaresq River @ Mauro

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1985-1996	19	0	1	2	3	1	3	2	1	2	0	1	2
Medium		45	1	5	4	3	4	3	2	3	3	3	4	4
High		17	3	4	1	1	0	1	1	1	1	0	0	3
All		81	4	8	7	7	5	7	5	4	6	3	5	8

Table 5.11. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 416049: Dumaresq River @ Mauro

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	17	16	0	52
	With EC obs	21	17	2	50
Medium	*All*	421	329	53	1,211
	With EC obs	348	298	57	1,211
High	*All*	4,510	7,129	1,213	64,193
	With EC obs	3,542	3,556	1,221	15,393
ALL	*All*	1,155	3,607	0	64,193
	With EC obs	942	2,101	2	15,393

(a)


(b)

Figure 5.7. Station 416049: Dumaresq River @ Mauro; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.12. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 416049: Dumaresq River @ Mauro

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)				*Mean error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*			
Low	*Observed*	21	17	2	50	201	39	143	296			4
	Simulated	34	51	2	163	189	43	92	258	52	0.13	6
Medium	*Observed*	348	298	57	1,211	152	34	56	228			50
	Simulated	369	395	14	1,737	163	37	94	263	32	0.13	52
High	*Observed*	3,542	3,556	1,221	15,393	110	29	67	162			360
	Simulated	3,779	3,605	1,455	16,637	112	21	88	148	19	0.17	447
All	*Observed*	953	2,112	2	15,393	154	45	56	296			106
	Simulated	1,018	2,196	2	16,637	158	44	88	263	34	0.21	125

5.3.5. Coolmunda Dam

The performance of the model in Coolmunda Dam is described in Appendix C.

For stations on Macintyre Brook downstream of Coolmunda Dam, model results were evaluated over the period for which dam releases were able to be forced to observed values: 1/1/1983-31/3/2000.

5.3.6. Station 416415: Macintyre Brook @ Booba Sands

The gauging station on the Macintyre Brook @ Booba Sands is run by the Queensland Department of Natural Resources and Mines (QDNRM) but is evaluated here as it is the last station on the Macintyre Brook before it enters the Dumaresq River. Unlike most parts of the model being evaluated, the Macintyre Brook sub-section has already been calibrated; the original Salinity Audit inputs having been replaced with calibrated flow-salinity tables by the QDNRM.

Data was collected fairly consistently every 3-4 months from 1986 to 1997 (Figure 5.29) which unfortunately represents only part of the evaluation period. The salinity ranges from about 56-540 mg/L, with a median salinity of 265 kg/ML. In general, the salinity in Macintyre Brook is significantly higher and more variable than in the Dumaresq River.

The data is representative of all the flow ranges and months (Table 5.13). The high flow range (greater than 121 ML/d) is over-represented (29% of data points) compared with the exceedance probability range (20% of the time). Consequently, both the low (less than 10 ML/d) and medium flow ranges are slightly under-represented (containing 17% and 54% of data points respectively). Despite this, the data in the low and medium flow ranges has similar statistical characteristics to those of the complete flow record in those ranges (Table 5.14). Within the high flow range, sampling was biased towards higher flow events, as indicated by the significantly higher mean and standard deviation of sampled flows compared with those of the complete high flow range data set. This bias is also evident in the statistical characteristics of the complete flow range.

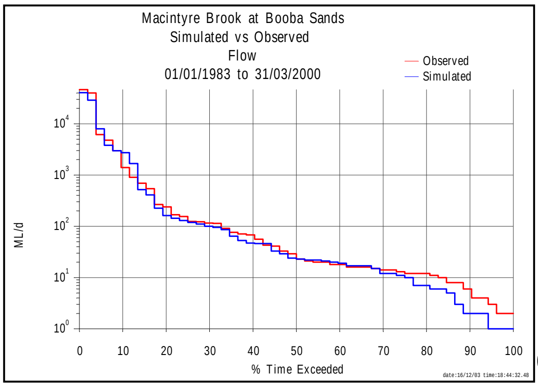
The results show that flows are underestimated, especially in the low flow range (Figure 5.8a). Low salinities are significantly overestimated whilst high salinities are underestimated (Figure 5.8b and Figure 5.41). Salt loads are consistently overestimated, especially in the low and high flow ranges (Table 5.15).

Table 5.13. Distribution of flow with discrete EC across flow ranges and months for Station 416415: Macintyre Brook @ Booba Sands

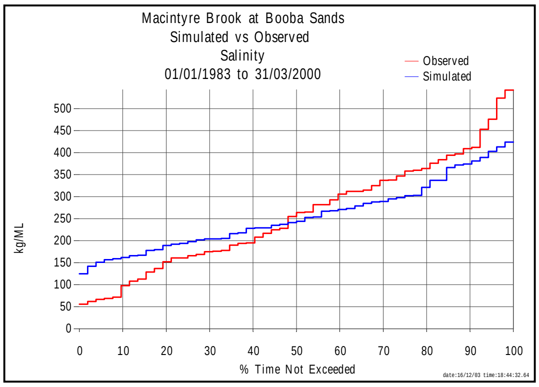
Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1987-2000	9	0	0	0	1	1	0	2	1	1	1	1	1
Medium		28	1	1	3	3	1	2	5	1	2	1	4	2
High		15	3	1	1	1	0	0	1	0	0	1	1	1
All		52	4	2	4	6	2	2	8	2	3	3	6	4

Table 5.14. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 416415: Macintyre Brook @ Booba Sands

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	6	3	0	10
	With EC obs	5	3	2	10
Medium	*All*	33	25	11	121
	With EC obs	36	32	11	116
High	*All*	1,803	6,016	122	69,516
	With EC obs	6,989	14,845	122	46,320
ALL	*All*	382	2,787	0	69,516
	With EC obs	2,036	8,405	2	46,320



(a)



(b)

Figure 5.8. Station 416415: Macintyre Brook @ Booba Sands; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.15. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 416415: Macintyre Brook @ Booba Sands

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)				*Mean error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*			
Low	*Observed*	3	3	0	10	316	115	67	524			1
	Simulated	97	176	2	608	289	70	203	424	111	0.01	25
Medium	*Observed*	37	34	11	116	294	109	113	542			10
	Simulated	42	52	1	226	273	58	189	389	100	0.00	11
High	*Observed*	7,477	15,280	122	46,320	138	61	56	228			646
	Simulated	6,423	12,346	64	40,302	176	32	125	229	57	0.00	995
All	*Observed*	1,993	8,329	0	46,320	259	123	56	542			175
	Simulated	1,743	6,792	1	40,302	252	72	125	424	92	0.13	275

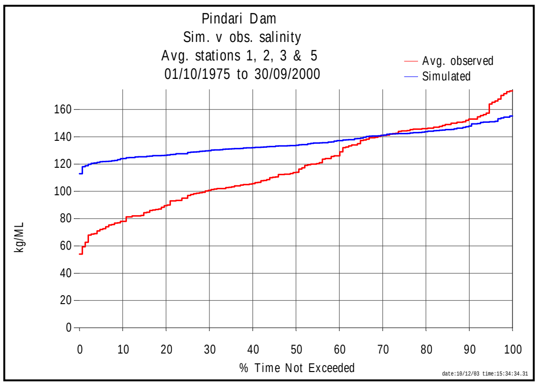
5.3.7. Pindari Dam

For gauging stations on the Severn and Macintyre Rivers downstream of Pindari Dam, model results were evaluated over the period for which dam releases were able to be forced to observed values: 1/10/1975-30/9/2000.

Pindari Dam was commissioned in 1969 and enlarged in 1995. Salinity data was collected at five locations in the storage during the evaluation period. The data from four of these locations was fairly consistent and was combined to create a single data set for evaluating model results. This combined data set has one or two points per month in 1984-1991, 1998/99 and 2000 but data is very sparse over the rest of the period.

Before enlargement, salinity ranged from 59 mg/L after periods of high inflows (1,000 ML/d or more), to 174 mg/L following extended periods of low inflows (Figure 5.30). Following enlargement, the storage filled very quickly with low salinity water and its larger volume made it less responsive to inflows. In this period, the salinity range was only 54-114 mg/L. The median salinities of 126 mg/L before enlargement and 93 mg/L after are both much lower than the median of 157 mg/L recorded upstream at 416039 Severn River @ Strathbogie. This is probably due to the averaging effects of the storage and the relatively short period of data post-enlargement.

The simulation using Salinity Audit relationships generally overestimates salinity in Pindari Dam prior to its enlargement (Figure 5.9a and Figure 5.42). The only exception occurs when the storage is being refilled slowly by small inflows, such as occurred in 1985. These small inflows are less concentrated than they should be because the Audit relationship at Strathbogie greatly underestimates high salinities and overestimates low ones (Figure 5.9b). After enlargement, the simulated salinity is always greatly overestimated because the dam fills very quickly and the high inflows are more concentrated than they should be. The elevated salinity levels are perpetuated because the larger dam is less responsive to subsequent inflows. These problems are responsible for the poor performance scores shown in Table 5.16.

(a)


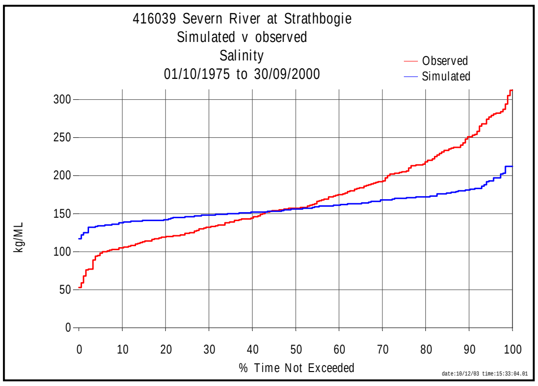
(b)


Figure 5.9. Non-exceedance curve for observed discrete versus simulated salinity; (a) Pindari Dam, (b) Station 416039: Severn River @ Strathbogie (gauged inflow upstream of Pindari Dam)

Table 5.16. Results of performance measures for observed versus simulated salinities in Pindari Dam using Salinity Audit relationships

Performance measure	Result
Pattern match	0.381
Mean match	0.150
Average error	0.200
Range match	0.650
R^2	0.615

5.3.8. Station 416019: Severn River @ Pindari

The gauging station on the Severn River @ Pindari has had data collected fairly consistently every 1-2 weeks over the evaluation period (1975-2000) except for gaps in 1983, 1990-92 and 1997-99. There is also a period with daily data in 1984-85 (Figure 5.31). Before Pindari was enlarged, the downstream salinity ranged from 40-250 mg/L with a median of 130 kg/ML, after enlargement the range contracted to 54-140 mg/L and the median dropped to 102 mg/L. These figures are fairly consistent with those recorded in the storage both before and after enlargement, except that the maximum and median salinities are higher downstream than in the storage. This suggests that the storage is not fully mixed, as assumed in the model, and therefore the samples taken within the storage do not give an accurate indication of its average salinity.

The data is representative of all the flow ranges and months (Table 5.17). In the medium (31-380 ML/d) and low flow ranges, the data has similar statistical characteristics to those of the complete flow record in those ranges (Table 5.18). However, within the high flow range, although data was collected during many periods of high flow, the highest flow events were not sampled (the sample mean and standard deviation are similar to those of the complete data set but the maximum is much lower).

The results for the simulation using Salinity Audit relationships show that flows match the observed flow distribution well (Figure 5.10a), as would be expected with forced releases from Pindari Dam. However, the simulated salinity distribution is much flatter than the observed distribution; which is consistent with the problems reported within and upstream of the dam (Figure 5.10b and Figure 5.43). Consequently, salt loads tend to be overestimated, particularly in the high flow range (Table 5.19).

Table 5.17. Distribution of flow with discrete EC across flow ranges and months for Station 416019: Severn River @ Pindari

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2000	167	4	3	3	1	5	5	6	5	0	4	3	4
Medium		598	12	10	9	8	10	5	8	8	9	11	10	10
High		221	2	3	2	3	3	4	4	7	6	3	3	3
All		986	14	15	11	10	15	12	14	13	11	15	11	13

Table 5.18. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 416019: Severn River @ Pindari

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	21	6	0	30
	With EC obs	21	5	8	30
Medium	*All*	136	96	31	380
	With EC obs	155	94	31	380
High	*All*	1,979	4,977	381	137,176
	With EC obs	2,012	3,824	381	29,471
ALL	*All*	473	2,324	0	137,176
	With EC obs	549	1,973	8	29,471

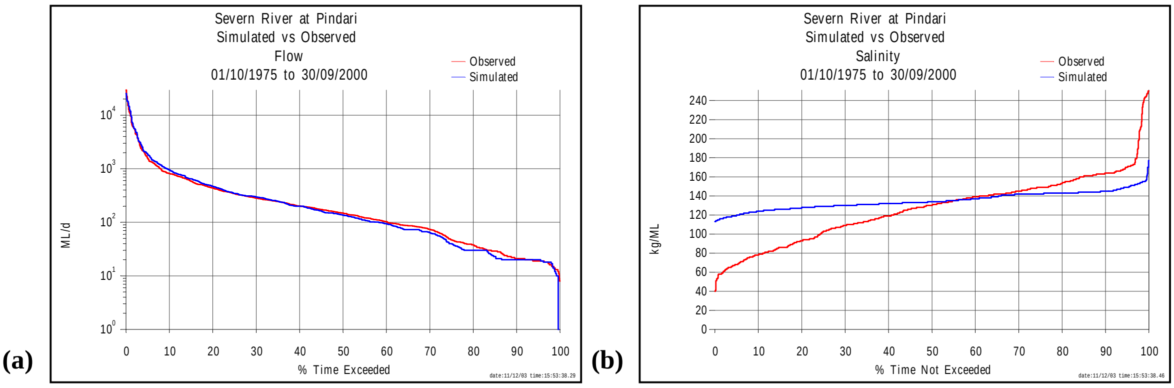


Figure 5.10. Station 416019: Severn River @ Pindari; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.19. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load Station 416019: Severn River @ Pindari

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)						
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*	*Mean error (mg/L)*	R^2	
Low	*Observed*	21	5	8	30	158	36	54	250			3
	Simulated	21	6	1	56	144	7	127	177	24	0.01	3
Medium	*Observed*	155	94	31	380	126	27	53	180			19
	Simulated	154	112	11	661	135	7	118	170	19	0.50	21
High	*Observed*	2,012	3,824	381	29,471	105	36	40	198			195
	Simulated	2,150	3,809	128	25,253	128	9	113	161	31	0.74	265
All	*Observed*	551	1,977	8	29,471	126	35	40	250			56
	Simulated	581	1,995	1	25,253	135	9	113	177	23	0.54	73

5.3.9. Station 416006: Severn River @ Ashford

The gauging station on the Severn River @ Ashford had data collected every 1-2 months up until late 1993, except for gaps in 1976, 1979/80, 1987/88 and 1989/90 (Figure 5.32). The salinity ranges from about 60-405 mg/L, with a median salinity of 129 kg/ML.

The data is representative of all the flow ranges and months (Table 5.20). As at Pindari, sampling within the high flow range (greater than 517 ML/d) was biased towards the higher flows. However, sampling still missed the highest flow events (Table 5.21) as shown by the higher sample mean but lower standard deviation and maximum compared with the complete data se. In the medium and low flow ranges, the data has similar statistical characteristics to those of the complete flow record in those ranges.

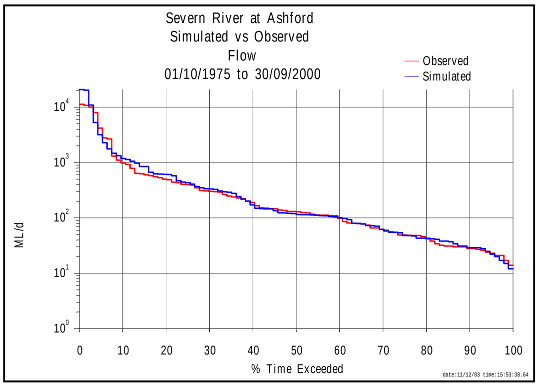
The results for the simulation using Salinity Audit relationships show that flows match the observed flow distribution fairly well although medium and high flows tend to be overestimated (Figure 5.11a). High salinities are still underestimated and medium to low salinities are overestimated (Figure 5.11b and Figure 5.44) whilst salt loads are consistently overestimated (Table 5.22). These results show that the problem which began with the inflow salinities upstream of Pindari Dam, is not only still present at this point, but is being compounded by the same problem with the Frazers Creek inflows.

Table 5.20. Distribution of flow with discrete EC across flow ranges and months for Station 416006: Severn River @ Ashford

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-1993	18	1	0	0	2	4	1	2	1	2	0	3	1
Medium		58	3	5	5	5	4	3	3	5	5	6	6	5
High		18	3	3	0	1	3	1	1	3	1	0	1	0
All		94	6	7	5	8	12	5	6	9	8	6	9	6

Table 5.21. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 416006: Severn River @ Ashford

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	27	9	3	41
	With EC obs	27	6	14	38
Medium	*All*	176	121	42	517
	With EC obs	175	127	42	501
High	*All*	3,085	7,012	518	164,401
	With EC obs	3,241	3,898	532	11,313
ALL	*All*	715	3,320	3	164,401
	With EC obs	734	2,072	14	11,313

(a) 

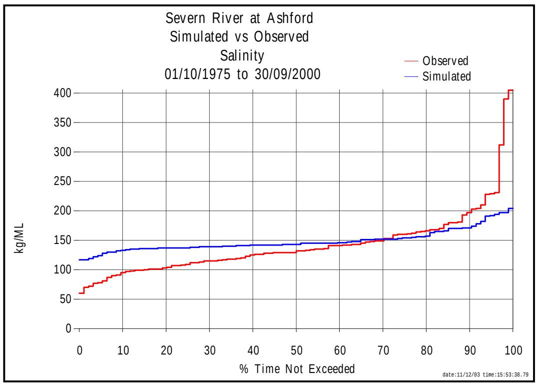
(b) 

Figure 5.11. Station 416006: Severn River @ Ashford; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.22. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load Station 416006: Severn River @ Ashford

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)				Mean error (mg/L)	R^2	
		Mean	S.D	Min	Max	Mean	S.D	Min	Max			
Low	*Observed*	27	6	14	38	159	56	60	312			4
	Simulated	52	76	12	336	162	20	132	194	38	0.07	9
Medium	*Observed*	175	127	42	501	147	58	77	405			24
	Simulated	190	191	29	977	148	16	122	204	31	0.31	28
High	*Observed*	3,241	3,898	532	11,313	107	27	70	168			308
	Simulated	4,152	6,474	578	20,839	137	14	117	174	31	0.58	513
All	*Observed*	733	2,072	14	11,313	142	55	60	405			75
	Simulated	922	3,191	12	20,839	148	18	117	204	32	0.29	117

5.3.10. Station 416012: Macintyre River @ Holdfast

The gauging station on the Macintyre River @ Holdfast has had data collected fairly consistently every 1-2 months over the evaluation period (1975-2000) except for gaps in 1975/76, 1979, 1983, 1987/88 and 1989 (Figure 5.33). The salinity ranges from 63-397 mg/L, with a median of 182 mg/L. The median is about 50 mg/L higher than at Ashford due to the more saline water entering from the upper Macintyre River (median salinity of 302 mg/L) and possibly also from the ungauged catchment upstream of this gauge.

The data is representative of all the flow ranges and months (Table 5.23). In all flow ranges, the data has similar statistical characteristics to those of the complete flow record, although the very highest flows were not sampled (

Table 5.24).

The results for the simulation using Salinity Audit relationships show that flows match the observed flow distribution fairly well although medium and high flows tend to be underestimated and low flows slightly overestimated (Figure 5.12a). The salinity distribution is much closer to the observed distribution at this gauge although both high and low salinities are overestimated by 7% and 21% respectively (Figure 5.12b and Figure 5.45). Salt loads are overestimated in the low to medium flow ranges but the greatly underestimated in the high flow range (Table 5.25). These results show that the salinity contribution from the Macintyre River goes some way towards correcting the salinity distribution mismatch affecting the Severn River contribution.

Table 5.23. Distribution of flow with discrete EC across flow ranges and months for Station 416012: Macintyre River @ Holdfast

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2000	40	3	1	3	6	5	5	3	2	4	1	0	2
Medium		125	5	11	13	5	8	15	8	9	12	9	10	9
High		43	5	8	2	1	1	3	2	3	5	4	2	2
All		208	12	17	17	13	14	20	12	14	18	13	12	13

Table 5.24. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 416012: Macintyre River @ Holdfast

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	44	23	0	79
	With EC obs	43	27	4	79
Medium	*All*	289	189	80	831
	With EC obs	296	194	80	812
High	*All*	4,397	9,107	832	123,000
	With EC obs	4,000	6,226	869	33,153
ALL	*All*	1,042	4,354	0	123,000
	With EC obs	1,013	3,199	4	33,153

(a) (b)

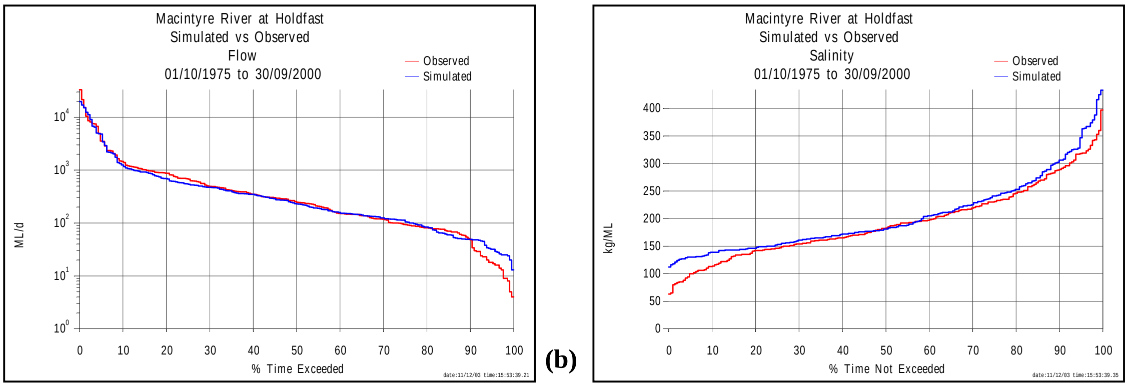


Figure 5.12. Station 416012: Macintyre River @ Holdfast; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.25. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load Station 416012: Macintyre River @ Holdfast

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)				*Mean error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*			
Low	*Observed*	43	27	4	79	219	49	65	318			9
	Simulated	63	51	13	288	232	82	143	433	70	0.00	14
Medium	*Observed*	296	194	80	812	202	67	63	397			56
	Simulated	352	809	51	9,083	215	62	112	388	55	0.17	62
High	*Observed*	4,000	6,226	869	33,153	139	41	80	262			468

	Simulated	3,306	4,730	217	19,817	147	21	116	223	31	0.09	433
All	*Observed*	1,013	3,199	4	33,153	192	65	63	397			132
	Simulated	907	2,540	13	19,817	204	68	112	433	53	0.18	129

5.3.11. Station 416002: Macintyre River @ Boggabilla

The gauging station on the Macintyre @ Boggabilla is the first evaluation point downstream of all three headwater storages. From this point, the model results were evaluated over the period for which all dam releases were forced to observed values: 1/1/1983-29/3/2000.

At Boggabilla, data has been collected fairly consistently every 1-2 months over the evaluation period, except for large gaps in 1987/88 and 1989-90 (Figure 5.34). The salinity ranges from about 70-300 mg/L, with a median salinity of 157 kg/ML. These characteristics reflect the dominant sources of water at this point; the Dumaresq and Macintyre Rivers.

The data is representative of all the flow ranges and months (Table 5.26). However, the medium flow range (235-2,540 ML/d) is over-represented (68% of data points) compared with the exceedance probability range (60% of the time). This occurs at the expense of both the high and low flow ranges which each account for 20% of the time but are represented by only 16% and 15% of the data points respectively. Table 5.27 indicates that data collection was biased towards the higher flows in both the low and medium flow ranges. Conversely, only the lower flows in the high flow range were sampled.

The simulation shows that flows are underestimated by about 20% (Figure 5.13a). However, the simulated salinity distribution matches the observed distribution well, except for the lowest 20% of salinities which are overestimated (Figure 5.13b and Figure 5.46). Salt loads are much too high in the low flow range and are too low in the high flow range (Table 5.28). Overall, the salt loads are too low.

It should be noted that although the salinity results look fairly good at this site, it is only because some of the problems in the upstream branches of the system have effectively cancelled each other out.

Table 5.26. Distribution of flow with discrete EC across flow ranges and months for Station 416002: Macintyre River @ Boggabilla

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1983-2000	29	0	1	2	5	3	5	4	2	2	1	1	0
Medium		120	7	9	10	3	4	3	5	6	5	8	10	10
High		27	3	6	2	0	0	0	0	2	4	1	1	4
All		176	8	12	11	9	7	8	9	10	10	9	10	12

Table 5.27. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 416002: Macintyre River @ Boggabilla

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	106	79	3	235
	With EC obs	115	72	3	225
Medium	*All*	972	604	236	2,540
	With EC obs	1,052	579	260	2,380
High	*All*	14,721	36,133	2,542	757,576
	With EC obs	8,301	8,485	2,572	39,598
ALL	*All*	3,583	17,239	3	757,576
	With EC obs	2,010	4,273	3	39,598

(a) (b)

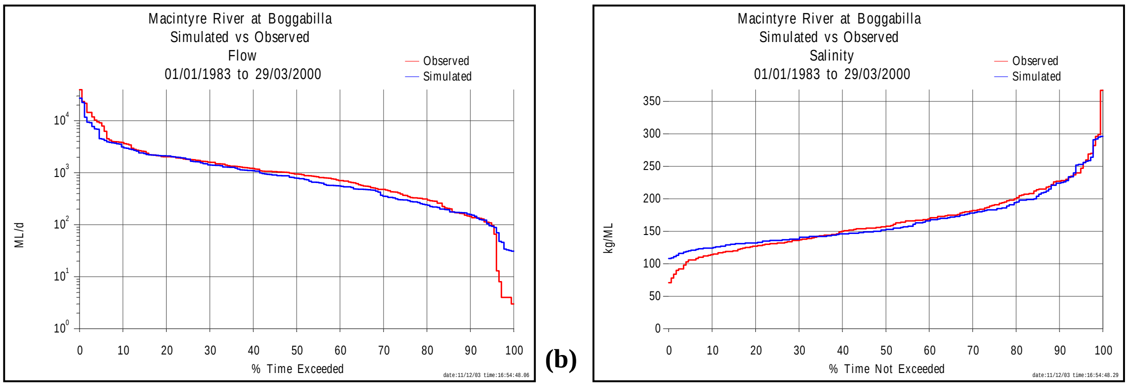


Figure 5.13. Station 416002: Macintyre River @ Boggabilla; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.28. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load Station 416002: Macintyre River @ Boggabilla

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)				*Mean error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*			
Low	*Observed*	115	72	3	225	196	48	84	299			23
	Simulated	197	142	31	599	214	41	152	296	44	0.06	41
Medium	*Observed*	1,052	579	260	2,380	165	42	92	367			164
	Simulated	1,018	809	48	4,524	160	33	113	291	25	0.33	152
High	*Observed*	8,301	8,485	2,572	39,598	133	39	71	260			984
	Simulated	5,714	6,176	965	27,117	134	21	108	191	25	0.13	724
All	*Observed*	2,010	4,273	3	39,598	165	46	71	367			267
	Simulated	1,603	3,047	31	27,117	165	40	108	296	28	0.33	221

5.3.12. Station 416202: Weir River @ Talwood

The gauging station on the Weir River @ Talwood is run by the QDNRM but is evaluated here as it is the last station on the Weir River before it joins with the Macintyre River to form the Barwon River. Like the Macintyre Brook sub-section, the Weir River has already been calibrated; the original Salinity Audit inputs having been replaced with calibrated flow-salinity tables by the QDNRM.

Figure 5.35 shows that there are only 17 data points at this site during the calibration period (1983-2000). The salinity ranges from 54-179 mg/L with a median salinity of 96 mg/L. As the river only flows 59% of the time, there is no low flow range (Table 5.29). The medium (0-119 ML/d) and high flow ranges are both fairly well represented although the highest flow events were not sampled (Figure 5.35).

The results show that flows are greatly underestimated (Figure 5.14a). Low to moderate salinities are significantly overestimated and high salinities are underestimated (Figure 5.14b and Figure 5.47). Salt loads also tend to be underestimated (Table 5.31). However, it is difficult to draw any useful conclusions due to the paucity of data at this site.

Table 5.29. Distribution of flow with discrete EC across flow ranges and months for Station 416202: Weir River @ Talwood

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1983-2000	0	0	0	0	0	0	0	0	0	0	0	0	0
Medium		12	0	0	0	2	0	1	2	1	1	3	1	0
High		5	1	0	1	1	0	0	1	1	0	0	0	0
All		17	1	0	1	3	0	1	4	2	1	3	1	0

Table 5.30. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 416202: Weir River @ Talwood

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	n/a	n/a	n/a	n/a
	With EC obs	n/a	n/a	n/a	n/a
Medium	*All*	27	28	1	119
	With EC obs	32	34	1	103
High	*All*	2,617	4,250	120	30,424
	With EC obs	393	324	142	931
ALL	*All*	592	2,277	0	30,424
	With EC obs	138	236	1	931

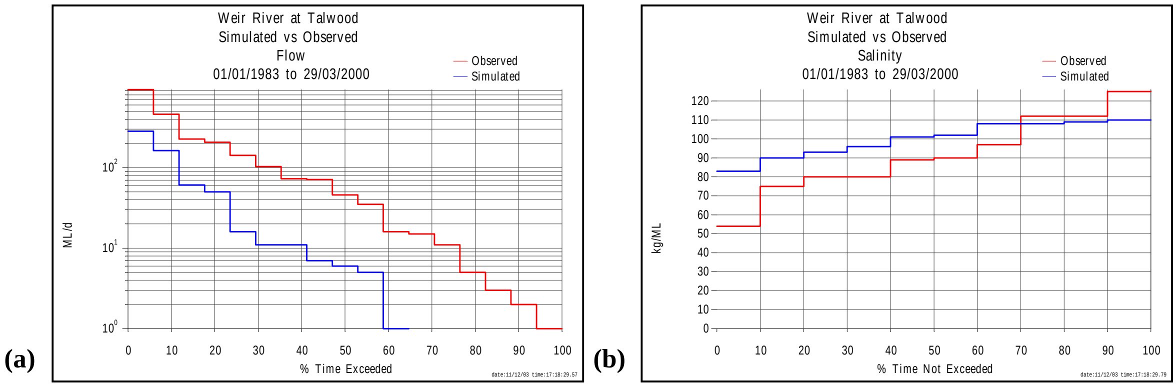


Figure 5.14. Station 416202: Weir River @ Talwood; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.31. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load Station 416202: Weir River @ Talwood

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)				Mean error (mg/L)	R^2	
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*			
Low	*Observed*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Simulated	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a			n/a
Medium	*Observed*	51	37	11	103	91	25	54	125	19	0.60	5
	Simulated	54	112	5	283	103	10	83	110			5
High	*Observed*	377	371	142	931	92	15	80	112	10	0.53	33
	Simulated	73	63	16	163	95	5	90	101			7
All	*Observed*	181	274	11	931	91	21	54	125	15	0.43	16
	Simulated	61	92	5	283	100	9	83	110			5

5.3.13. Station 416001: Barwon River @ Mungindi

The end-of system gauge in the Border Rivers IQQM is on the Barwon River @ Mungindi. Data has been collected consistently every 1-2 months over the evaluation period (1983-2000) with a higher frequency of sampling since 1990. There are only a few small gaps in 1989, 1994 and 1995 (Figure 5.36). The salinity ranges from 38-339 mg/L, with a median of 146 mg/L; slightly lower than at Boggabilla (Table 5.33).

All Queensland inflows between Boggabilla and Mungindi use the same flow-salinity table provided by the QDNRM (Table 5.32). There are no NSW inflows in this part of the model.

Flow data is representative of all flow ranges and months. The low flow range (less than 41 ML/d) is over-represented (26% of data points) compared with the exceedance probability range (20% of the time). Conversely, the high flow range (greater than 2,129 ML/d) is under-represented (14% of the data points). Despite this, the data in all flow ranges has similar statistical characteristics to those of the complete flow record (Table 5.34).

The model slightly underestimates flows over 500 ML/d but lower flows are overestimated by an average of 100% (Figure 5.15a). The simulated salinity distribution is quite close to the observed distribution, although the lowest 30% of salinities are overestimated and the highest 5% are underestimated (Figure 5.15b and Figure 5.48). Again, salt loads are much too high in the low and medium flow ranges but too low in the high flow range and overall (Table 5.35). As already noted with respect to Boggabilla, the salinity results look better than they really are because some of the problems further upstream have cancelled each other out.

Table 5.32. Flow versus salinity Table Q9: used for all Queensland inflows between Boggabilla and Mungindi.

Flow (ML/d)	Concentration (mg/L)
0	120
60	110
100	100
200	90
1,000	80
22,000	67

Table 5.33. Distribution of flow with discrete EC across flow ranges and months for Station 416001: Barwon River @ Mungindi

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1983-2000	83	4	5	3	2	2	2	3	2	2	3	5	2
Medium		192	10	10	13	9	8	5	9	6	5	8	8	11
High		46	2	5	1	2	4	3	1	2	3	1	2	3
All		321	12	15	13	11	13	9	12	10	10	10	10	12

Table 5.34. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 416001: Barwon River @ Mungindi

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	9	12	0	41
	With EC obs	13	12	1	41
Medium	*All*	473	516	42	2,129
	With EC obs	453	525	44	2,115
High	*All*	7,874	8,537	2,131	61,386
	With EC obs	7,324	6,419	2,164	40,666
ALL	*All*	1,774	4,792	0	61,386
	With EC obs	1,324	3,469	1	40,666

(a) (b)

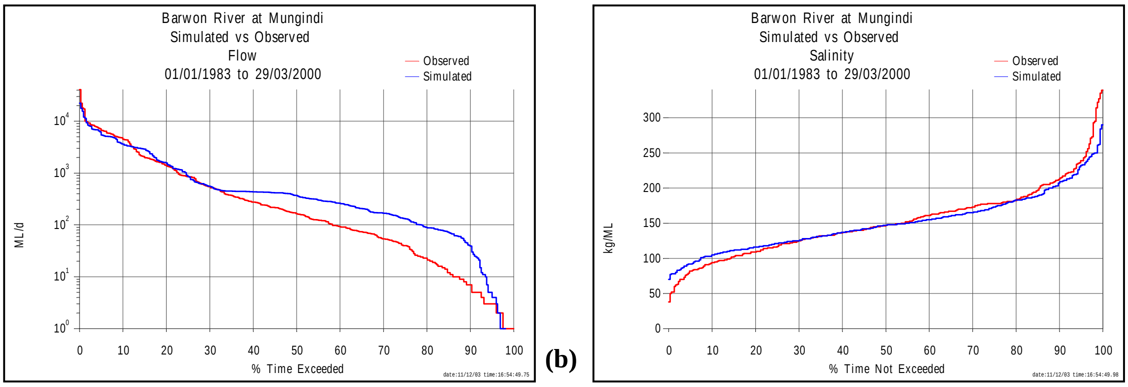


Figure 5.15. Station 416001: Barwon River @ Mungindi; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.35. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load Station 416001: Barwon River @ Mungindi

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)				*Mean error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*			
Low	*Observed*	14	12	1	41	168	57	70	339			2
	Simulated	218	176	1	600	175	35	86	262	49	0.00	34
Medium	*Observed*	457	526	44	2,115	156	45	50	335			64
	Simulated	605	813	2	4,812	151	37	80	290	32	0.19	79
High	*Observed*	7,324	6,419	2,164	40,666	107	30	38	221			750
	Simulated	5,876	4,182	1,228	22,246	106	18	70	159	17	0.29	608
All	*Observed*	1,362	3,512	1	40,666	152	50	38	339			150
	Simulated	1,287	2,572	1	22,246	150	40	70	290	34	0.19	146

5.3.14. Discussion of results from simulation with Salinity Audit relationships

The summary (Appendix B) of simulated salinity distribution for all Audit sites shows that generally they are within 10% of the observed values. However, the average simulated daily salt loads differ from observed loads by 10 to 20%, primarily due to the difference between simulated and observed flows.

5.4. SALINITY MODEL CALIBRATION

5.4.1. Methods (General)

The model calibration re-estimated the salt inflow relationships with the intention of matching the statistical characteristics of the observed data along the mainstream.

5.4.1.1. Headwater catchments

Salt load inflows for headwater catchments were estimated using all available salinity data. Two methods were used to estimate these inflows:

(i) flow versus salt load relationship, using the IID form of the relationship

(ii) flow versus concentration look-up tables (LUT), based on ordinates from exceedance curves

$$SL = e^{\eta} Q^{\lambda} \quad (5.8)$$

The flow versus concentration LUT is based on the assumption that flow is inversely related to concentration (Equation 5.9). This relationship is defined using corresponding pairs of data [(Q_1,C_1), (Q_2,C_2), …(Q_n,C_n)]. These points are taken from corresponding exceedance and non-exceedance ordinates on the ranked plots of data, to form a Table of relationships.

$$C \propto \frac{1}{Q} \quad (5.9)$$

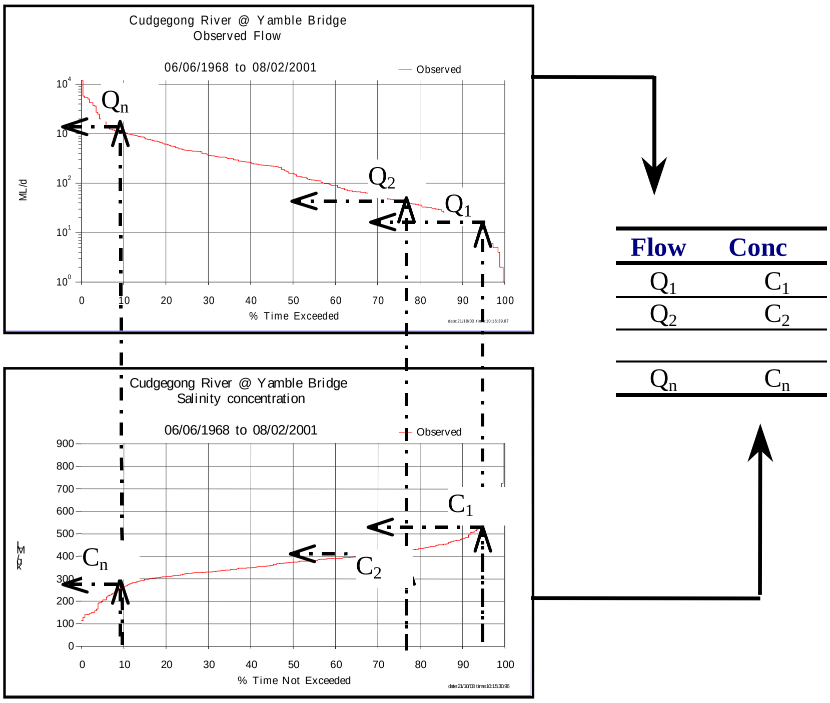


Figure 5.16. Derivation of flow versus concentration LUT from exceedance curves

5.4.1.2. Residual catchments

The salt inflows from residual catchments were calibrated using a procedure as illustrated in Figure 5.17. A target salt load at the calibration point is estimated using the power form of the salt load versus flow relationship (Equation 5.8). The model is run, and the salt load that the residual catchments need to contribute is calculated from the difference between the results of this simulation and the target salt load calculated in Step 1. Using these results and the flow at the residual catchments, an initial estimate of the flow-concentration LUT is made. This LUT is revised methodically to match the 20th, 50th and 80th percentiles of the exceedance curve of salinities at the calibration point.

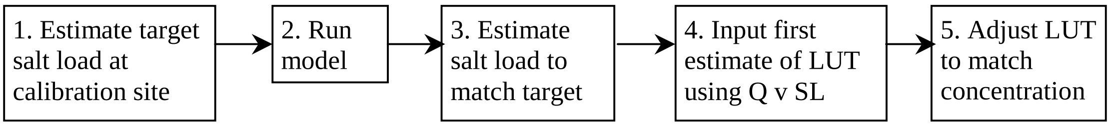


Figure 5.17. Procedure to calibrate salt inflows from residual catchments

5.4.1.3. Queensland catchments

The QDNRM supplied flow-salinity tables for all Queensland inflows in the Border Rivers IQQM (Table 5.3 for those upstream of Boggabilla and Table 5.32 for those downstream). The performance of the model in the Queensland part of the stream network is described in Appendix C. The final gauging stations on Macintyre Brook and the Weir River were also evaluated in more detail in Sections 5.3.6 and 5.3.12 respectively.

No changes were made to any of the Queensland inputs, gauged or ungauged, during the re-calibration process described below (Sections 5.4.2 to 5.4.9).

5.4.2. Station 416011: Dumaresq River @ Roseneath

The model evaluation showed that salinity was consistently underestimated for all but the lowest 5% of values whilst salt loads were slightly overestimated.

In addition to the outflow from Glenlyon Dam, four gauged catchments and five residual catchments contribute flow to the Dumaresq River at Roseneath. One gauged catchment and three ungauged catchments are in Queensland so their salinity inputs were not changed (Table 5.3: Table Q8). The Salinity Audit relationships were maintained for Reedy Creek at Dumaresq (416026) and the smaller NSW residual between Mingoola and Roseneath. Flow-salinity tables (Table 5.36) were derived for Tenterfield Creek at Clifton (416003) and Mole River at Donaldson (416032) to match their respective observed salinity duration curves. Another flow-salinity table (Table 5.37) was then derived for the larger NSW residual upstream of Mingoola to achieve the best possible salinity duration curve match at Roseneath.

The calibration slightly improved both the salinity and salt load results in the high flow range and overall but this was achieved at the expense of the results in the low and medium flow ranges (

Figure 5.18 and Figure 5.53).

Table 5.36. Calibrated flow versus salinity relationships for inflows at Station 416003: Tenterfield Creek @ Clifton and Station 416032: Mole River @ Donaldson

Station 416003: Tenterfield Creek @ Clifton		Station 416032: Mole River @ Donaldson	
Flow (ML/d)	Concentration (mg/L)	Concentration (mg/L)	Concentration (mg/L)
1	450	1	270
3	450	4	270
9	252	13	180
13	220	29	152
30	180	50	128
40	164	90	118
59	143	128	112
96	120	183	104
283	100	289	98
591	91	378	88
1,794	59	785	77
		1,625	71
		3,871	50

Table 5.37. Calibrated flow versus salinity relationship for inflows from NSW residual catchment: Dumaresq R. upstream of Mingoola.

Flow (ML/d)	Concentration (mg/L)
1	450
2	450
51	350
196	200
513	100

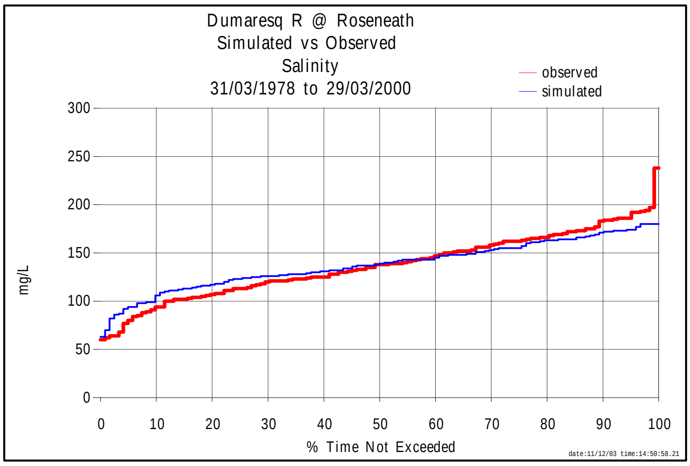


Figure 5.18. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 416011: Dumaresq River @ Roseneath

Table 5.38. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 416011: Dumaresq River @ Roseneath

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	167	25	121	238	31	0.12	7
	Simulated	150	21	98	180			8
Medium	*Observed*	134	30	60	193	17	0.52	51
	Simulated	141	20	92	180			59
High	*Observed*	104	29	62	153	16	0.41	274
	Simulated	102	23	63	143			304
All	*Observed*	137	34	60	238	20	0.39	72
	Simulated	138	25	63	180			81

5.4.3. Station 416007: Dumaresq River @ Bonshaw Weir

The model evaluation showed that both flow and salinity were overestimated at Bonshaw Weir. This indicates that the salinities of the Beardy River at Haystack (416008) and/or the two residual catchments (ie small catchments that enter the Dumaresq River between Roseneath and Bonshaw Weir) were overestimated.

The Queensland residual catchment was not changed but flow-salinity tables were derived for both the Beardy River (Table 5.39) and the NSW residual (Table 5.40). Changes were made to improve the match with the observed and simulated salinity duration curves at Haystack and Bonshaw Weir respectively. However, only small improvements in the results at Bonshaw Weir were possible (

Figure 5.19 and Figure 5.54).

Table 5.39. Calculated flow versus salinity relationship for inflows at Station 416008: Beardy River @ Haystack

Flow (ML/d)	Concentration (mg/L)
1	518
2	225
6	168
8	141
19	129
30	112
60	101
101	96
174	87
471	71
1,343	63

Table 5.40. Calibrated flow versus salinity relationship for inflows from NSW residual catchment: Dumaresq R. between Roseneath and Bonshaw Weir (Salinity Audit catchment R5_NSW)

Flow (ML/d)	Concentration (mg/L)
1	518
16	300
34	250
430	63

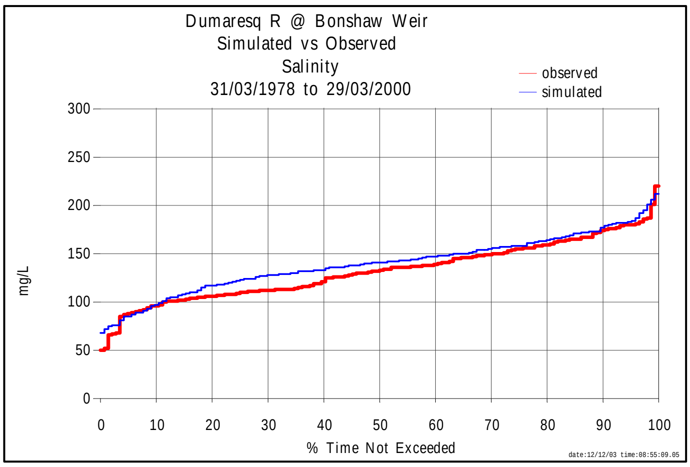


Figure 5.19. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 416007: Dumaresq River @ Bonshaw Weir

Table 5.41. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 416007: Dumaresq River @ Bonshaw Weir

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Mean error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	164	19	132	220	35	0.06	8
	Simulated	160	34	86	212			7
Medium	*Observed*	131	27	50	201			57
	Simulated	139	21	84	183	20	0.31	67
High	*Observed*	103	20	66	136			346
	Simulated	99	18	68	135	15	0.22	362
All	*Observed*	132	31	50	220			96
	Simulated	139	31	68	212	22	0.30	107

5.4.4. Station 416049: Dumaresq River @ Mauro

As at Bonshaw Weir, simulated flows at Mauro tend to be overestimated. However, evaluation of the Audit model showed that the salinity matches the observed distribution fairly well, except for the very low and high salinities which are slightly overestimated.

The Queensland residual between Bonshaw Weir and Mauro was not changed but a flow-salinity table was derived for the NSW residual (Table 5.42). This made little difference as the catchment contributes only a very small proportion of the total flow at Mauro (

Figure 5.20 and Figure 5.55).

Table 5.42. Calibrated flow versus salinity relationship for inflows from NSW residual catchment: Dumaresq R. between Bonshaw Weir and Mauro (part of Salinity Audit residual R6_NSW).

Flow (ML/d)	Concentration (mg/L)
1	518
70	350
100	300
160	200
1,000	63

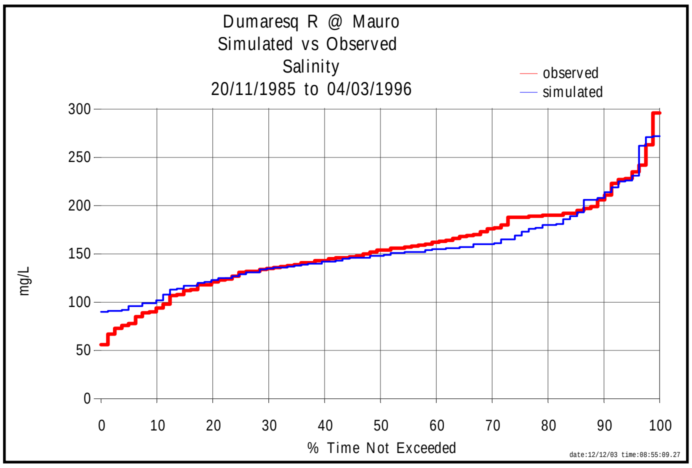


Figure 5.20. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 416049: Dumaresq River @ Mauro

Table 5.43. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 416049: Dumaresq River @ Mauro

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Mean error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	201	39	143	296			4
	Simulated	180	44	92	271	49	0.01	5
Medium	*Observed*	152	34	56	228			50
	Simulated	157	34	91	272	32	0.04	52
High	*Observed*	110	29	67	162			360
	Simulated	115	19	90	146	18	0.21	438
All	*Observed*	154	45	56	296			106
	Simulated	153	41	90	272	33	0.18	123

5.4.5. Pindari Dam

The poor salinity match obtained for Pindari Dam in the initial evaluation was due primarily to the Audit relationship upstream at Severn River at Strathbogie (416039), which greatly underestimates high salinities and overestimates low ones.

The calibration process is complicated by the inflow from a residual catchment and a loss node upstream of the dam as well as the need to force both the dam inflows and releases to observed values. The first step was to derive a flow-salinity table for the Severn River to match the observed salinity duration curve (Table 5.44). Another table was derived for the back-calculated dam inflows to try to match the observed salinity within the dam (Table 5.45). Finally, a third table was derived for the residual catchment inflow between Strathbogie and Pindari Dam to achieve the best possible match with the salinity duration curve for the back-calculated dam inflows (Table 5.46).

The calibration improved the modelled salinity behaviour within Pindari Dam according to all the performance measures except for the R^2 value which was a little lower (Table 5.47). The most dramatic improvements were in the mean and range matches, which dropped from 1.150 and 0.650 to 0.006 and 0.008 respectively. These improvements are most clearly visible in the salinity duration curve for the storage (Figure 5.21 and Figure 5.50) and the salt load results given in Table 5.48 for the downstream gauge Severn River at Pindari Dam (416019).

Table 5.44. Calibrated flow versus salinity relationship used for inflows at Station 416039: Severn River @ Strathbogie

Flow (ML/d)	Concentration (mg/L)
1	305
4	281
10	253
23	220
36	200
60	177
102	157
144	146
205	132
364	119
581	105
844	95
3,232	63
1e37	53

Table 5.45. Calibrated flow versus salinity relationship for Pindari Dam back-calculated inflows

Flow (ML/d)	Concentration (mg/L)
1	330
5	270
50	250
100	190
200	185
300	165
1,000	100
3,000	80
10,000	55
100,000	50

Table 5.46. Calibrated flow versus salinity relationship for inflows from NSW residual catchment: Severn R. between Strathbogie and Pindari Dam (Salinity Audit catchment R1)

Flow (ML/d)	Concentration (mg/L)
1	380
2	380
5	340
13	331
27	330
113	329

311	140
697	95
2931	63
1e37	53

Table 5.47. Results of performance measures for simulated versus observed salinities in Pindari Dam using calibrated relationship

Performance measure	Result
Pattern match	0.355
Mean match	0.006
Average error	0.133
Range match	0.008
R^2	0.580

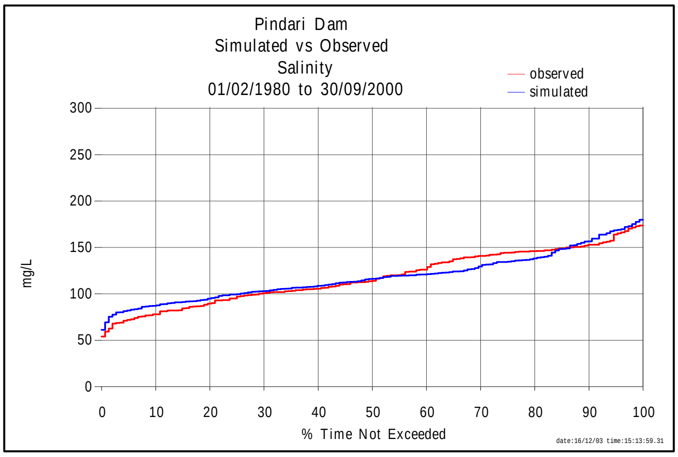


Figure 5.21. Non-exceedance curve for observed versus simulated salinity for calibrated model at Pindari Dam

Table 5.48. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 416019: Severn River @ Pindari

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	158	37	54	274			3
	Simulated	139	21	73	212	34	0.00	3
Medium	*Observed*	126	27	53	180			19
	Simulated	118	20	75	190	17	0.55	20
High	*Observed*	105	36	40	198			195
	Simulated	100	25	61	183	15	0.75	191
All	*Observed*	126	35	40	274			56
	Simulated	117	24	61	212	19	0.51	55

5.4.6. Station 416006: Severn River @ Ashford

Whilst improving the upstream salinity simulation in Pindari Dam should improve the results at Ashford, the model evaluation indicated that a similar problem exists with the Audit relationship for Frazers Creek @ Ashford (416021).

The salinity input for Frazers Creek was revised using a flow-salinity table (Table 5.49) to match the observed salinity duration curve. Flow-salinity tables were then derived for the two residual catchment inflows to achieve the best possible salinity duration curve match at Ashford (Table 5.50). These changes significantly improved the salinity results at Ashford for all but the highest salinities (

Figure 5.22 and Figure 5.51). The salt load results were also greatly improved (Table 5.51).

Table 5.49. Calibrated flow versus salinity relationship used for inflows at Station 416021: Frazers Creek @ Ashford

Flow (ML/d)	Concentration (mg/L)
1	579
2	440
8	378
10	354
13	279
19	234
41	198
66	181
126	172
257	152
586	135
5,389	91

Table 5.50. Calibrated flow versus salinity relationship used for inflows from NSW residual catchments: Severn R. between Pindari Dam and Llanarth and Severn R. between Llanarth and Ashford (part of Salinity Audit catchment R2)

Severn R. between Pindari Dam and Llanarth		Severn R. between Llanarth and Ashford	
Flow (ML/d)	Concentration (mg/L)	Flow (ML/d)	Concentration (mg/L)
1	157	1	210
2	132	2	178
5	119	5	162
16	105	16	142
43	95	43	106
248	63	248	66

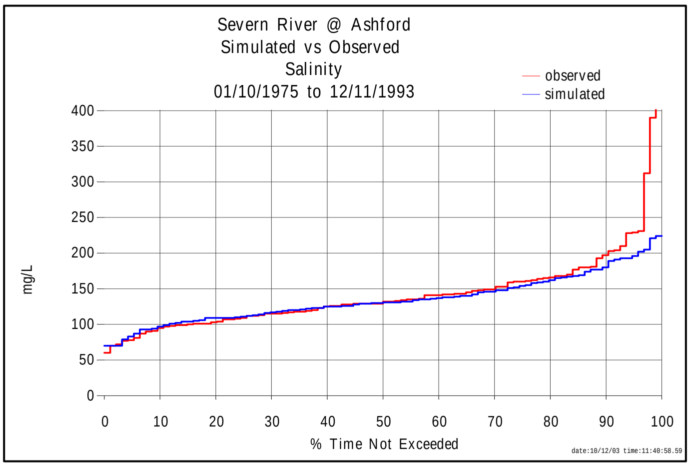


Figure 5.22. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 416006: Severn River @ Ashford.

Table 5.51. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 416006: Severn River @ Ashford

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	159	56	60	312	30	0.20	4
	Simulated	169	36	109	224			8
Medium	*Observed*	147	58	77	405			24
	Simulated	135	23	87	193	29	0.27	24
High	*Observed*	107	27	70	168			308
	Simulated	100	20	70	135	15	0.60	329
All	*Observed*	142	55	60	405			75
	Simulated	135	33	70	224	26	0.31	80

5.4.7. Station 416012: Macintyre River @ Holdfast

The model evaluation showed that both high and low salinities were overestimated at Holdfast. It also showed that the salinity distribution match was better at this station than upstream at Ashford - indicating that the salinity contribution from the Macintyre River was compensating for the salinity mismatch in the Severn River contribution.

The salinity inputs from Macintyre River at Wallangra (416010) were revised using a flow-salinity table (Table 5.52) to better match the observed salinity duration curve. A flow-salinity table was derived for the first of the two residuals using the small amount of data at Macintyre River at dam site (416018). The second residual was calibrated to achieve a good salinity duration match at Holdfast. The flow-salinity tables for these two nodes are shown in Table 5.53.

The calibration further improved the salinity results (Figure 5.23 and Figure 5.52) but salt loads are still underestimated (Table 5.54) because the model underestimates the medium and high flows at this station.

Table 5.52. Calibrated flow versus salinity relationship for inflows at Station 416010: Macintyre River @ Wallangra

Flow (ML/d)	Concentration (mg/L)
1	576
5	468
11	444
31	402
49	389
76	336
92	302
116	287
172	243
274	212
417	181
778	160
5,241	88
1e37	59

Table 5.53. Calibrated flow versus salinity relationship for inflows from NSW residual catchments: Severn and Macintyre Rivers upstream of dam site and Macintyre R. between dam site and Holdfast (part of Salinity Audit catchment R3)

Severn and Macintyre Rs. u/s dam site		Macintyre R. between dam site and Holdfast	
Flow (ML/d)	Concentration (mg/L)	Flow (ML/d)	Concentration (mg/L)
1	576	1	576
44	576	8	212
93	450	40	181
255	300	144	160
571	200	2,159	88
2,404	100	32,036	59
16,373	59		

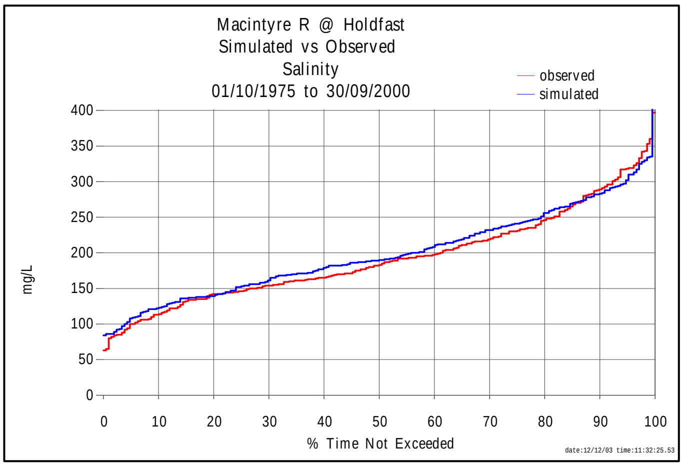


Figure 5.23. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 416012: Macintyre River @ Holdfast

Table 5.54. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 416012: Macintyre River @ Holdfast

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	219	49	65	318			9
	Simulated	222	69	121	405	68	0.02	14
Medium	*Observed*	202	67	63	397			56
	Simulated	209	53	89	328	56	0.12	62
High	*Observed*	139	41	80	262			468
	Simulated	144	42	84	283	31	0.13	368
All	*Observed*	192	65	63	397			132
	Simulated	198	61	84	405	53	0.15	116

5.4.8. Station 416002: Macintyre River @ Boggabilla

The Macintyre River at Boggabilla (416002) is the first gauge in the system that receives regulated flow from all three headwater storages. The model evaluation showed that flows are underestimated by about 20%. It was also noted that although the salinity results looked fairly good, this was only because some of the problems in the upstream branches of the system had effectively cancelled each other out.

During the evaluation period (01/01/1983-29/03/2000), nearly 90% of the flow at Boggabilla comes from the Dumaresq River at Mauro (416049) and the Macintyre River at Holdfast (416012). Salinity has now been satisfactorily calibrated at both of these stations (Sections 5.4.4 and 5.4.7). The third source of flow is via the Macintyre Brook at Booba Sands (416415) which, despite performing poorly for both flow and salinity, was not recalibrated as it is wholly within Queensland. The only significant inputs that could be calibrated are Ottleys Creek and the NSW residual catchment between Holdfast and the Dumaresq River confluence. The remaining six gauged and ungauged inflows were not calibrated as they contribute very little flow and have virtually no available salinity data.

A flow-salinity table (Table 5.55) was derived for Ottleys Creek at Coolatai (416020) to match the observed salinity duration curve. A second table (Table 5.56) was calibrated for the residual catchment between Holdfast and the Dumaresq River confluence to achieve the best possible results at Boggabilla.

The calibration did not significantly alter the salinity or salt load results at Boggabilla (Figure 5.24 and Figure 5.56) but the major sources of flow and salt contributing to this result are more realistic than before.

Table 5.55. Calculated flow versus salinity relationship for inflows at Station 416020: Ottleys Creek @ Coolatai

Flow (ML/d)	Concentration (mg/L)
1	618
2	561
7	444
8	432

Flow (ML/d)	Concentration (mg/L)
9	407
13	390
25	342
41	285
1,244	204

Table 5.56. Calibrated flow versus salinity relationship for inflows from NSW residual catchment: Macintyre R. between Holdfast and the Dumaresq R. confluence (Salinity Audit catchment R4)

Flow (ML/d)	Concentration (mg/L)
10	500
50	342
194	285
1,244	204

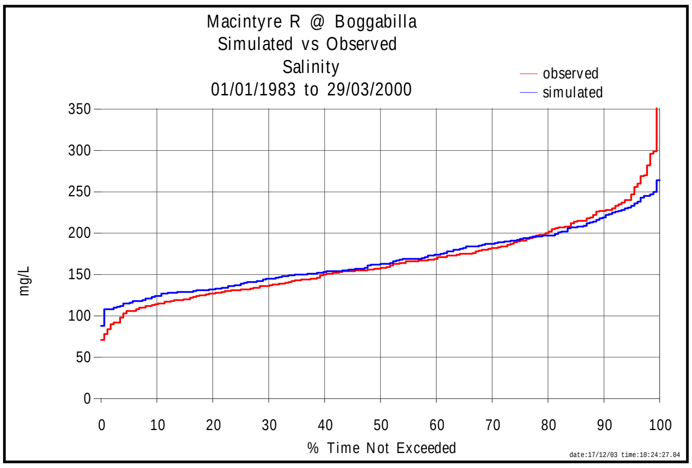


Figure 5.24. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 416002: Macintyre River @ Boggabilla

Table 5.57. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 416002: Macintyre River @ Boggabilla

Flow range	Data set	Distributions: Salinity (mg/L) Mean	S.D	Min	Max	C_o versus C_s: Mean error (mg/L)	R^2	Mean load (t/d)
Low	*Observed*	196	48	84	299	45	0.01	23
	Simulated	206	32	151	264			39
Medium	*Observed*	165	42	92	367	24	0.36	164
	Simulated	164	31	108	243			155
High	*Observed*	133	39	71	260	24	0.17	984
	Simulated	140	26	88	197			719
All	*Observed*	165	46	71	367	27	0.34	267
	Simulated	167	36	88	264			223

5.4.9. Station 416001: Barwon River @ Mungindi

All modelled inflows between Boggabilla and Mungindi are from Queensland so no further calibration was possible. Therefore, the slight improvements in the simulated salinity and salt load at Mungindi (Figure 5.25, Table 5.58 and Figure 5.57) are due entirely to the changes made upstream of Boggabilla.

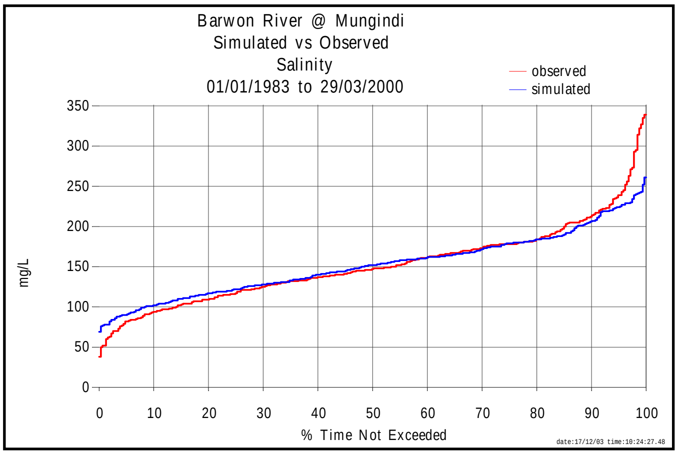


Figure 5.25. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 416001: Barwon River @ Mungindi

Table 5.58. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 416001: Barwon River @ Mungindi

Flow range	Data set	Distributions Salinity (mg/L)				C_o versus C_s		Mean load (t/d)
		Mean	*S.D*	*Min*	*Max*	*Mean error (mg/L)*	R^2	
Low	*Observed*	168	56	70	339	52	0.00	2
	Simulated	175	36	100	261			33
Medium	*Observed*	156	45	50	335	31	0.17	64
	Simulated	154	35	77	252			81
High	*Observed*	107	30	38	221	18	0.29	750
	Simulated	106	21	69	161			596
All	*Observed*	152	50	38	339	34	0.17	150
	Simulated	152	39	69	261			145

5.4.10. Discussion of results from calibration

The initial model used flow-load relationships from the Salinity Audit for all NSW inflows and calibrated flow-salinity relationships for all Queensland inflows. Evaluation of the model showed that this method produced a poor match with the observed salinity distribution at several of the NSW gauged inflow sites. Calibration of the model involved deriving flow-salinity tables to match the observed salinity distribution at each of these stations. NSW residual catchment inputs were calibrated in a similar manner to achieve a match with the observed salinity distribution at the following evaluation point on the main stream.

The comparison of calibrated model results and observed data for both salinity and salt loads is summarised in Table 5.59. The results have been coded according to how close the simulated results match the mean observed concentrations or salt loads in the respective flow ranges.

The mean salinity results are within ±10% of the observed values in each flow range at only five of the ten evaluation sites (Bonshaw Weir, Ashford, Holdfast, Boggabilla and Mungindi). The remaining sites all had an overall match within ±10%. For all sites except the Queensland sites (Booba Sands and Talwood) the worst results were in the low flow range.

The match of simulated and observed salt loads is within ±10% at only one site (Pindari Dam). The results were within ±10% of observed loads for the medium flow range at five sites (Mauro, Booba Sands, Ashford, Boggabilla and Talwood) and for the high flow range at two sites (Bonshaw Weir and Ashford). The worst results were in the low flow range, and to a lesser extent, the high flow range.

In summary, the model appears to simulate the salinity behaviour in the river system reasonably well. Overall the best that could be said is that the model is able to simulate concentrations within the ±10% range and salt loads within the ±20% range. The model is much better at simulating salinity than salt loads. The salt load results tend to be more reliable in the Dumaresq and Severn Rivers than in the Macintyre River with the accuracy reducing further down the main river. The results for the major Queensland inputs, Macintyre Brook at Booba Sands and the Weir River at Talwood, are quite poor but it is hard to draw any firm conclusions here due to the relatively small amount of data available at these sites.

Although the calibration did not significantly alter the salinity or salt load results at the last balance point (Boggabilla) or at the end of system (Mungindi), the major sources of salt contributing to this result are more realistic than in the initial model.

Table 5.59. Summary of comparisons of simulated versus observed salt loads: calibrated model

Target Site		Concentration Match				Salt Load Match			
Number	Name	*Low*	*Medium*	*High*	*All*	*Low*	*Medium*	*High*	*All*
		Legend: 1 < ±10%; 2 < ±20%; 3= > ±20%							
	Glenlyon Dam	*See Appendix C*							
416011	Dumaresq River @ Roseneath	2	1	1	1	2	2	2	2
416007	Dumaresq River @ Bonshaw Weir	1	1	1	1	2	2	1	2
416049	Dumaresq River @ Mauro	2	1	1	1	3	1	3	2
	Coolmunda Dam	*See Appendix C.*							
416415	*Macintyre Brook @ Booba sands*	*1*	*1*	*3*	*1*	*3*	*1*	*3*	*3*
	Pindari Dam	2	1	1	1	1	1	1	1
416006	Severn River @ Ashford	1	1	1	1	3	1	1	1
416012	Macintyre River @ Holdfast	1	1	1	1	3	2	3	2
416002	Macintyre River @ Boggabilla	1	1	1	1	3	1	3	2
416202	*Weir River @ Talwood*	*n/a*	*2*	*1*	*1*	*n/a*	*1*	*3*	*3*
416001	Barwon River @ Mungindi	1	1	1	1	3	3	3	1

Italic font denotes sections wholly within Queensland -these were not altered during the calibration process.

5.5. VALIDATION OF RESULTS

5.5.1. Continuous salinity records

The results for the calibration were further assessed by comparing them with the continuous data at Station 416001: Barwon River at Mungindi shown in Figure 5.37. It is fortunate that this is the end of system gauge as it is the only main stream station in the Border Rivers with continuous salinity data. A full statistical assessment is not possible at this stage, because (i) methods have not been developed yet; (ii) the continuous data record is short therefore not representative of the benchmark climate period; and (iii) there are discrepancies between the discrete and continuous data. Nevertheless, the data is useful to assess that the model is modelling the salinity behaviour correctly. Time series plots of simulated versus observed salinity are shown for the evaluation model (Figure 5.49) and calibrated model (Figure 5.58). The simulated salinity from the calibrated model follows a similar pattern to the observed data although the peaks tend to occur earlier.

5.5.2. Comparison of calibrated salt loads with Salinity Audit salt loads

Table 5.60 shows the mean salt loads for Audit inflow and balance points from (i) the Audit, (ii) the initial IQQM using Audit flow-load relationships (but calibrated flow-salinity tables for Queensland inflows) and (iii) the calibrated IQQM.

Both the initial and calibrated models produced similar salt loads to the Audit for the Dumaresq River at Bonshaw Weir (416007). At both Pindari (416019) and Ashford (416006) on the Severn River, the initial model salt loads were 20-30% higher than the Audit loads, whilst the calibrated model loads were about 5% lower than the Audit loads. The major differences between the initial and calibrated models in this reach are the salt inputs to the Severn River at Strathbogie and Frazers Creek at Ashford.

At Holdfast (416012) on the Macintyre River downstream of the Severn River confluence, the calibrated salt load is 10% lower than both the Audit and initial model loads. As the initial and calibrated inflow loads are similar, the difference is probably due to effects of losses on different salinity distributions. At Boggabilla (416002), both the initial and calibrated model salt loads are about 12% lower than the Audit load due primarily to lower inputs from the residual catchments along the Dumaresq River from Bonshaw Weir to Boggabilla (R6_NSW and R6_Qld).

Table 5.60. Comparison of calibrated average annual salt loads with Salinity Audit, and Audit as modified

Audit inflow / balance point		Mean salt load ('000 T/year)		
Number	**Name**	*Salinity Audit*	*IQQM using Audit inflows*	*Calibrated IQQM*
416011	Dumaresq River @ Roseneath	*36.1*	39.1	41.4
416008	Beardy River @ Haystack	*5.3*	4.4	4.7
R5_NSW	NSW part of ungauged Dumaresq River between Roseneath and Bonshaw	*9.0*	5.4	2.8
R5_Qld	Qld part of ungauged Dumaresq River between Roseneath and Bonshaw	*1.4*	-0.2	-0.1
416007	**Dumaresq River @ Bonshaw Weir**	***46.3***	**47.6**	**47.8**
R6_NSW	NSW part of ungauged Dumaresq River between Bonshaw and the Macintyre River confluence	*8.7*	3.3	2.5

Audit inflow / balance point		Mean salt load ('000 T/year)		
Number	**Name**	*Salinity Audit*	*IQQM using Audit inflows*	*Calibrated IQQM*
R6_Qld	Qld part of ungauged Dumaresq River between Bonshaw and the Macintyre River confluence	*43.8* [a]	32.5	32.7
416039	Severn River @ Strathbogie	*19.8*	18.9	13.1
R1	Ungauged Severn River u/s Pindari	*4.2*	4.3	5.1
416019	**Severn River @ Pindari**	***19.1***	**23.3**	**18.2**
416021	Frazers Creek @ Ashford	*12.7*	12.1	8.1
R2	Ungauged Severn River between Pindari and Ashford	*1.1*	0.7	0.4
416006	**Severn River @ Ashford**	***28.0***	**36.1**	**26.7**
416010	Macintyre River @ Wallangra	*21.3*	18.6	18.5
R3	Ungauged Severn and Macintyre Rivers u/s Holdfast	*11.8*	6.4	10.0
416012	**Macintyre River @ Holdfast**	***61.5***	**60.9**	**55.0**
416020	Ottleys Creek @ Coolatai	*4.0*	3.1	3.6
R4	Ungauged Macintyre River between Holdfast and the Dumaresq River confluence	*1.9*	-3.3	1.0
416002	**Macintyre River @ Boggabilla**	***142.1***	**126.3**	**125.1**

a *R6 flows are not given in the Audit Report, some doubt over equation used to estimate load*

5.6. MODEL SUITABILITY FOR PURPOSE

The salt transport models have two key purposes under the BSMS. The first is to produce a time series of flows, salinities, and salt loads for the Baseline Condition over the Benchmark Climate period. The second is to estimate the in-stream flow and salinity effects of land-based salinity management actions, such as landuse change and crop management, as well as the in-stream flow and salinity effects of changes to water sharing and utilisation, such as that of the Water Sharing Plans.

5.6.1. Baseline

The Border Rivers IQQM is a robust and reliable water balance model of the Border Rivers. Some issues have arisen in the course of the development of the salt transport model about the method used to estimate and calibrate flows from ungauged catchments. Whilst these methods were appropriate for developing a model for water sharing purposes, they created difficulties in calibrating the salt balance.

In general, the model simulates the salinity behaviour in the river system reasonably well (within ±10% of observed values). The results are much poorer for salt loads (generally within ±20% of observed values), particularly in the low and high flow ranges, primarily due to timing differences between the simulated and observed flows.

5.6.2. Land use management scenarios

The CATSALT model is designed to simulate the changes to flow and salt loads resulting from changes to land use and vegetation cover in a catchment. Time series of flow and salinity produced by running scenarios in CATSALT can then be substituted for the existing time series inputs to the Baseline Conditions model. The model would route them through the river system, producing flow, salinity and salt load results which can be compared with the Baseline Condition run to evaluate the impacts of land use change at different locations along the river system.

5.6.3. Water management scenarios

The impacts of various water sharing scenarios on salinity can be simulated with a reserved degree of confidence that must take into consideration the confidence limits of the model.

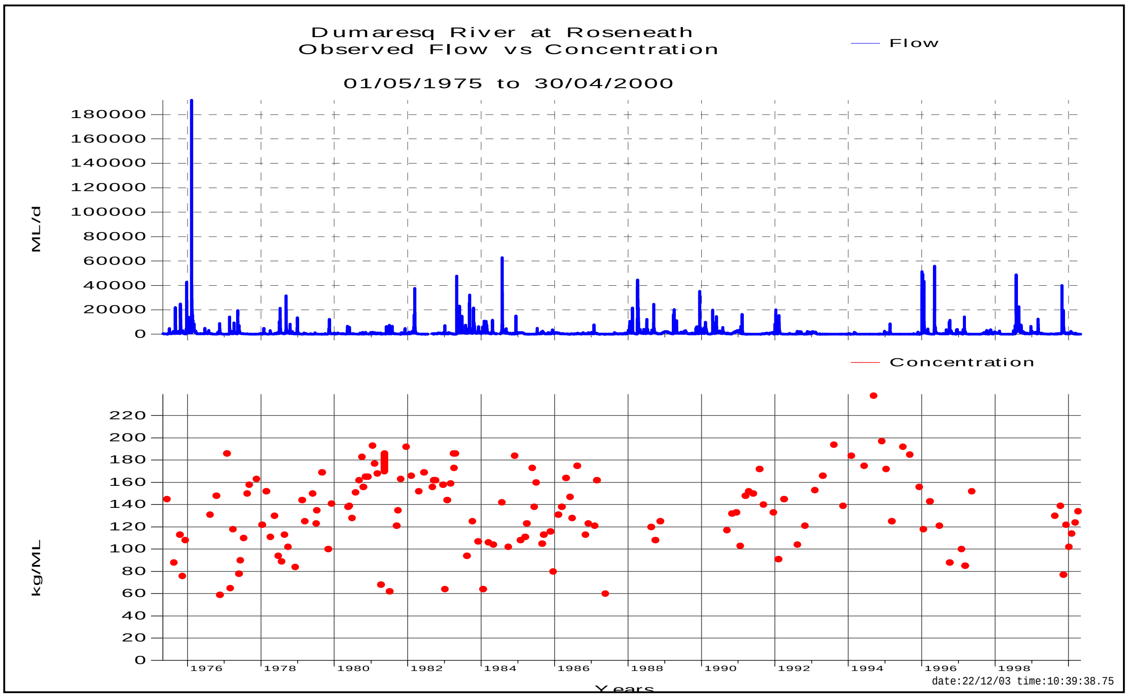


Figure 5.26. Station 416011: Dumaresq River @ Roseneath, observed flow and concentration

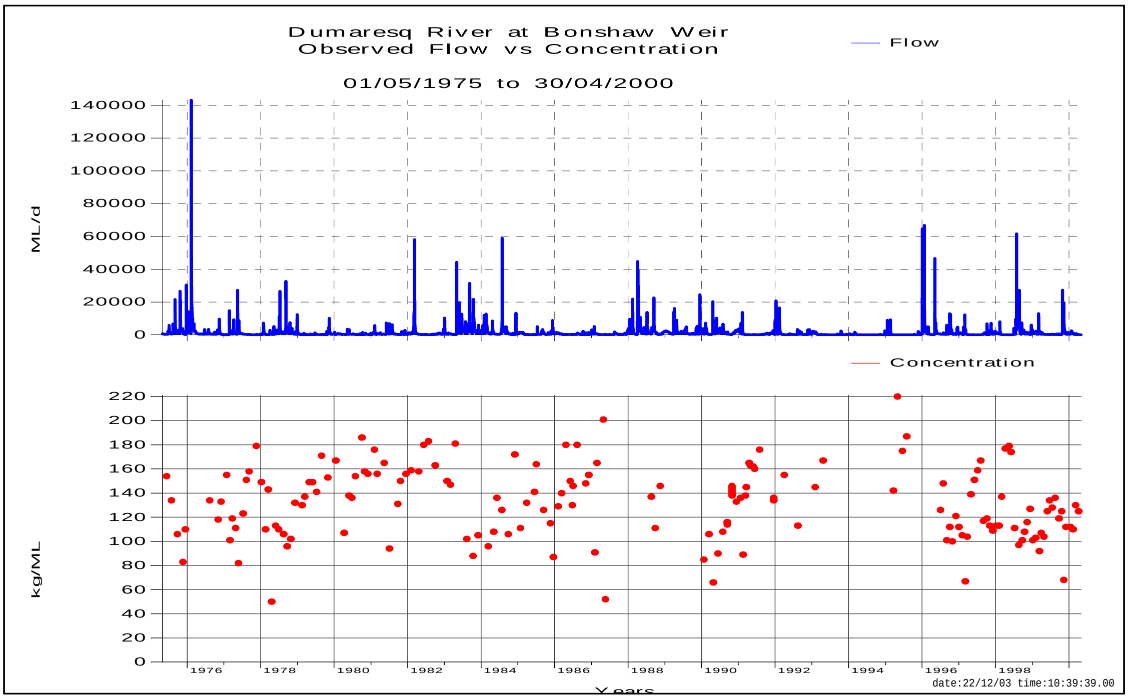


Figure 5.27. Station 416007: Dumaresq River @ Bonshaw Weir, observed flow and concentration

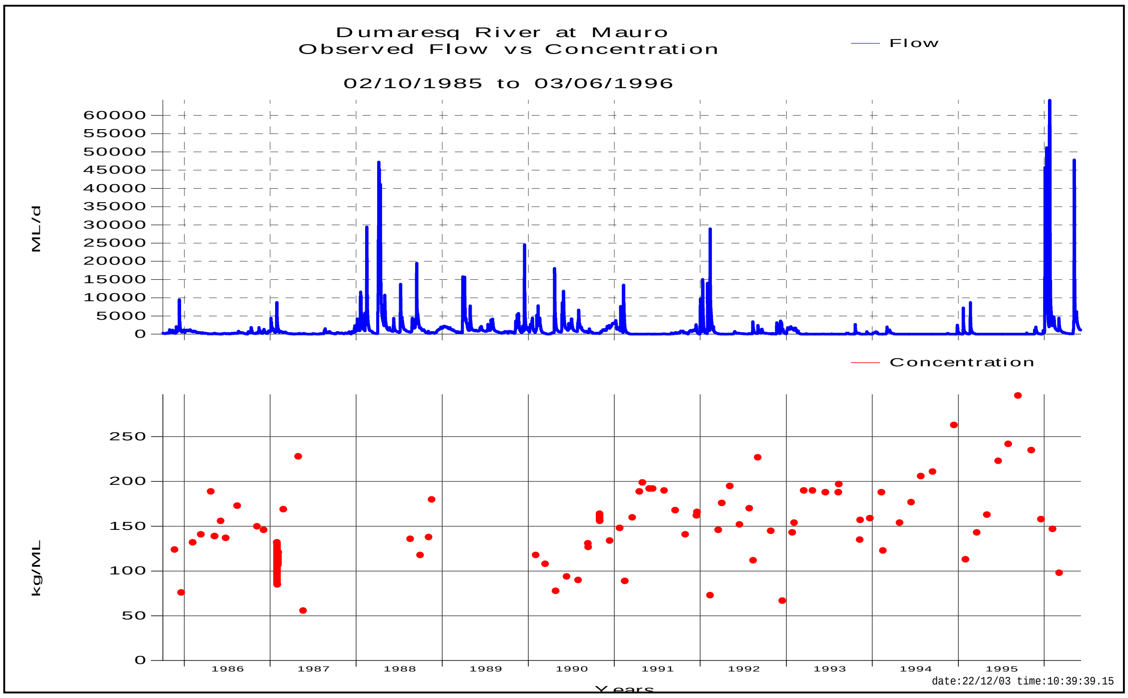


Figure 5.28. Station 416049: Dumaresq River @ Mauro, flow and concentration data

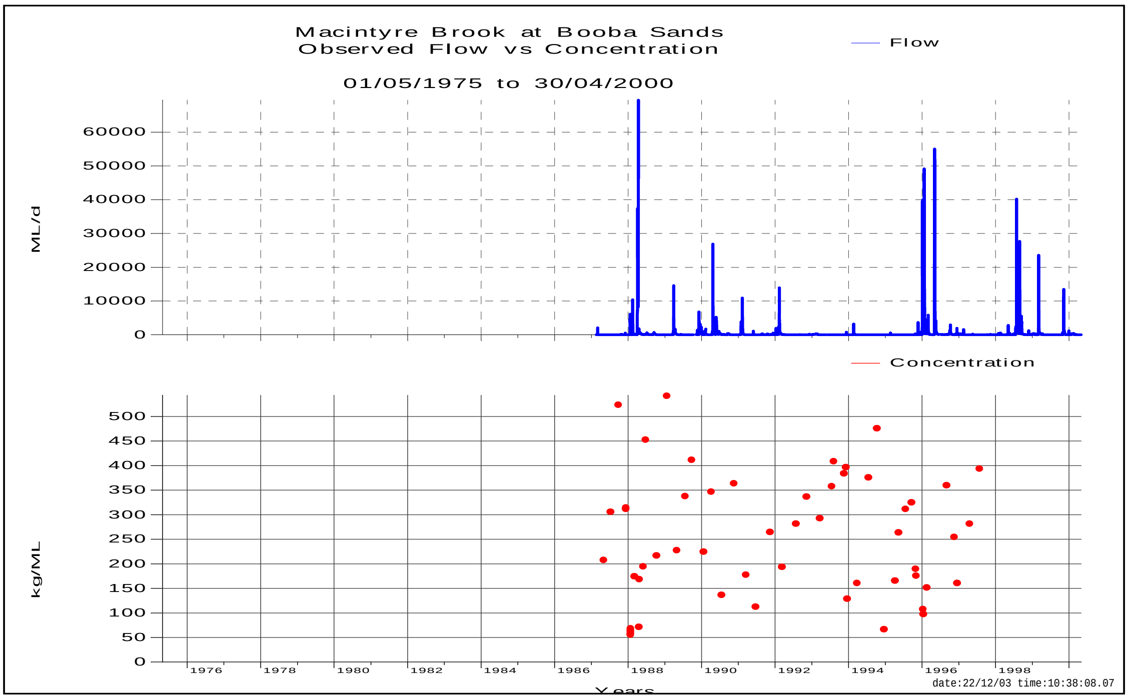


Figure 5.29. Station 416415: Macintyre Brook @ Booba Sands, flow and concentration data

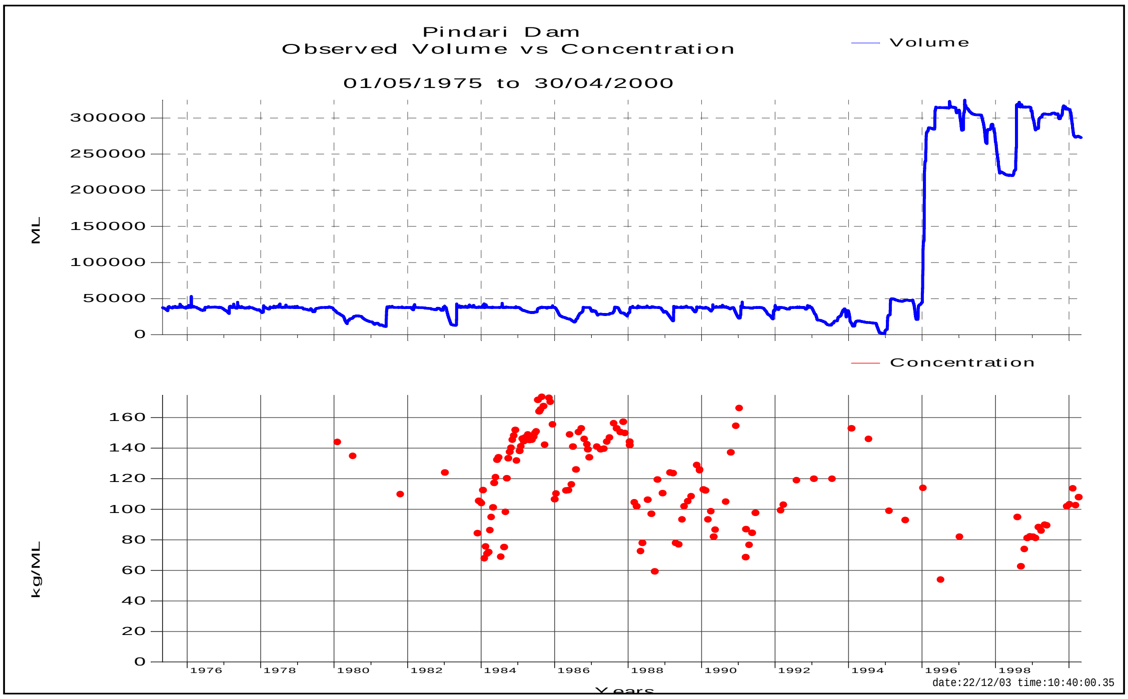


Figure 5.30. Pindari Dam, volume and concentration data

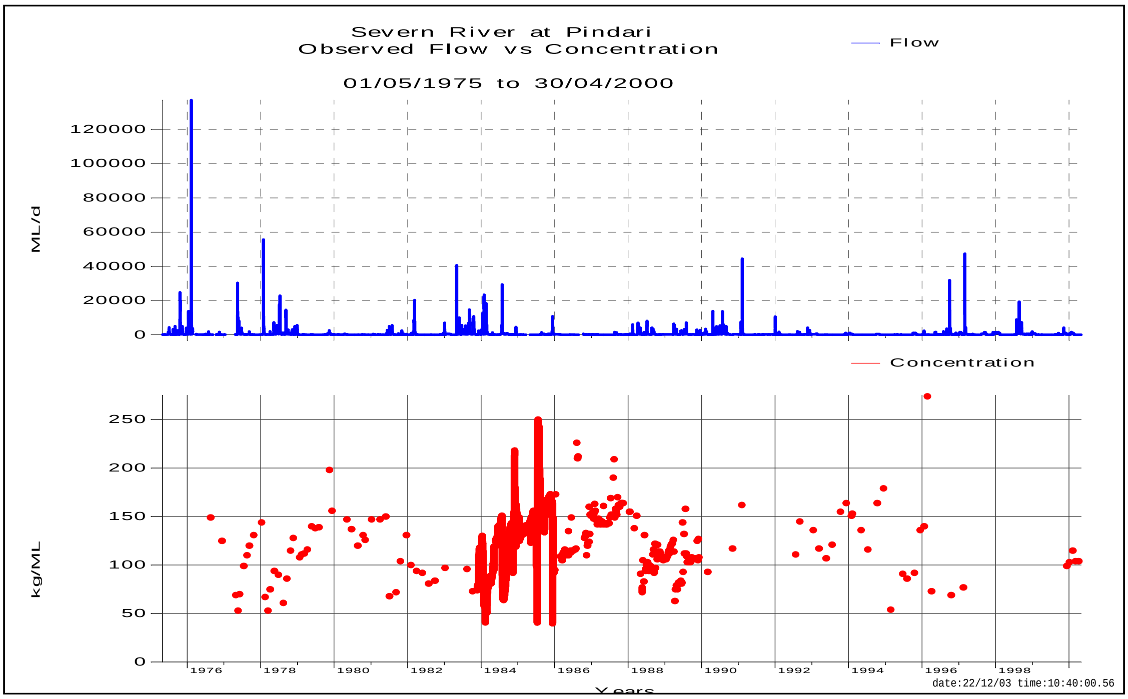


Figure 5.31. Station 416019: Severn River @ Pindari, flow and concentration data

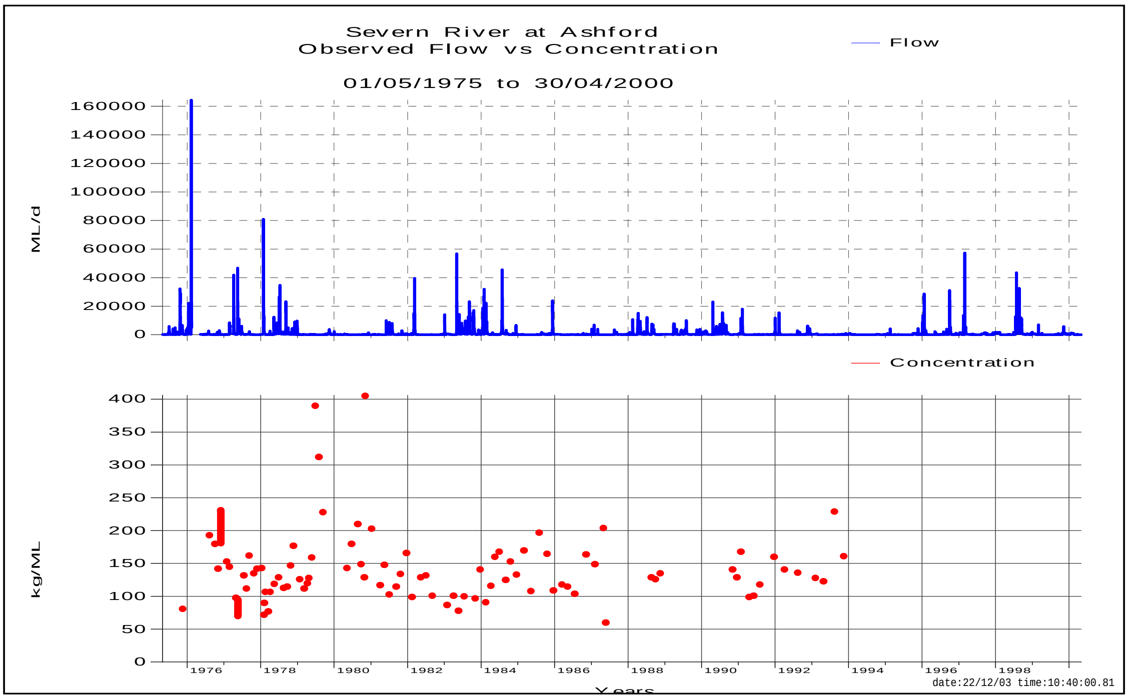


Figure 5.32. Station 416006: Severn River @ Ashford, flow and concentration data

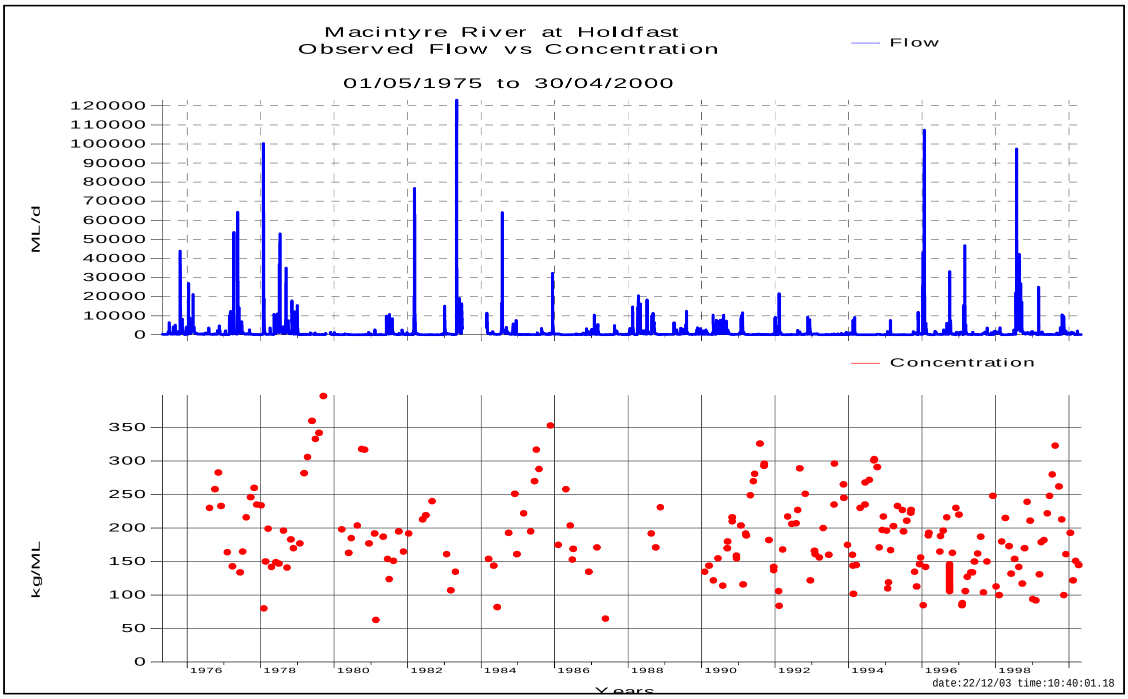


Figure 5.33. Station 416012: Macintyre River @ Holdfast, flow and concentration data

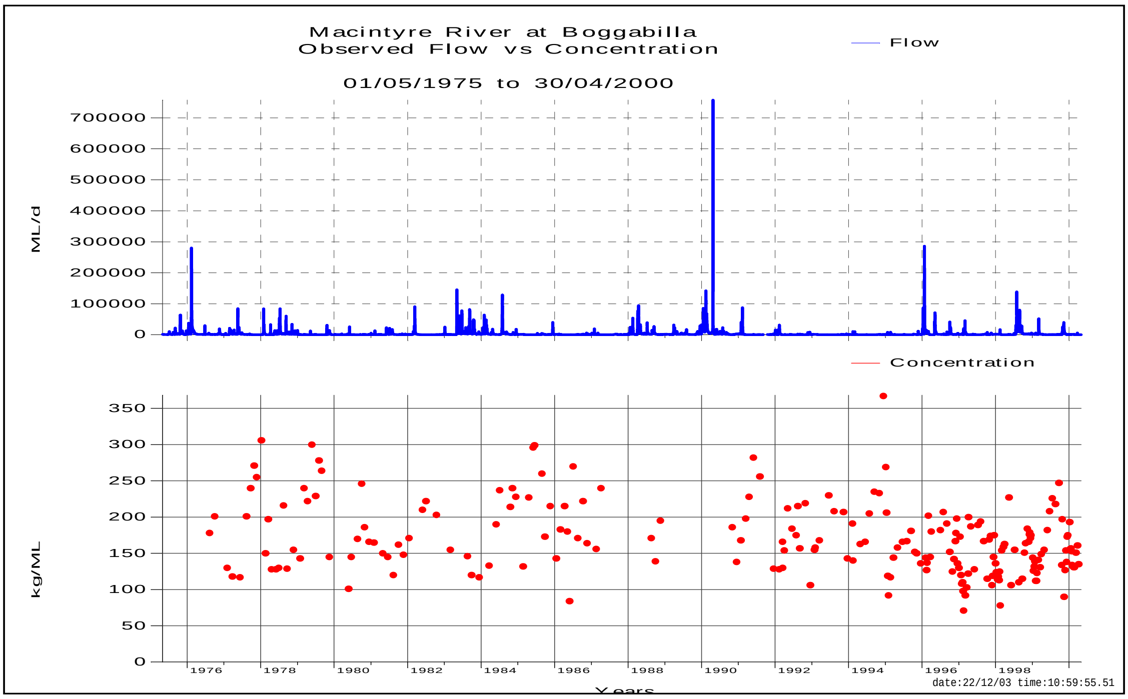


Figure 5.34. Station 416002: Macintyre River @ Boggabilla, flow and concentration data

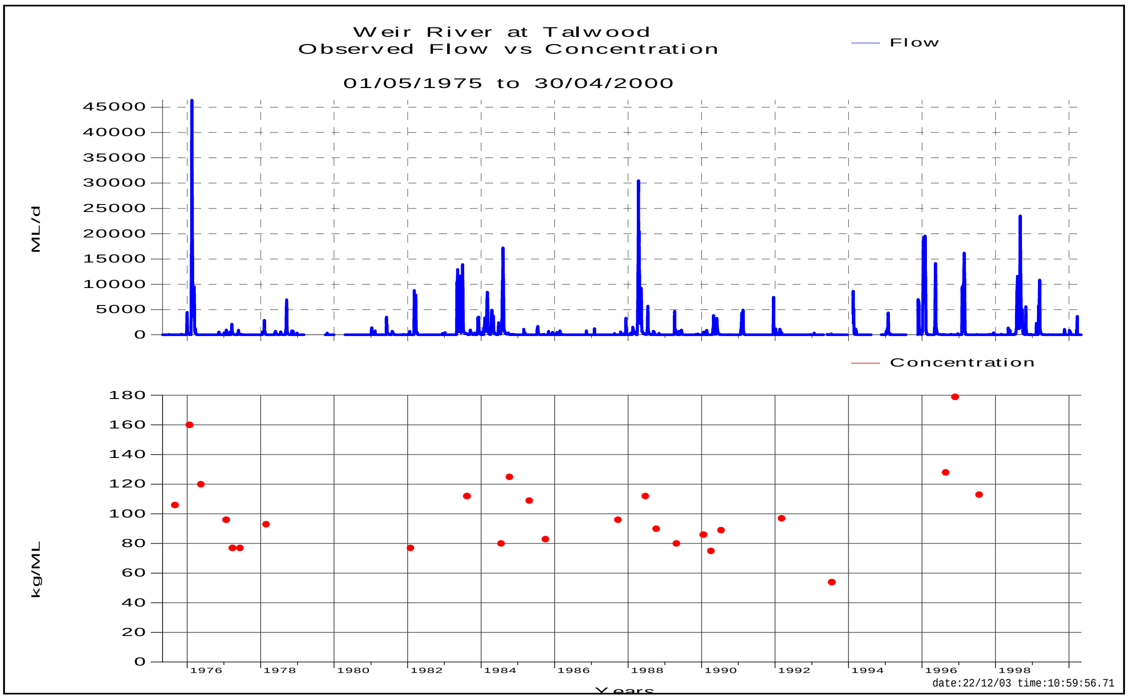


Figure 5.35. Station 416202: Weir River @ Talwood, flow and concentration data

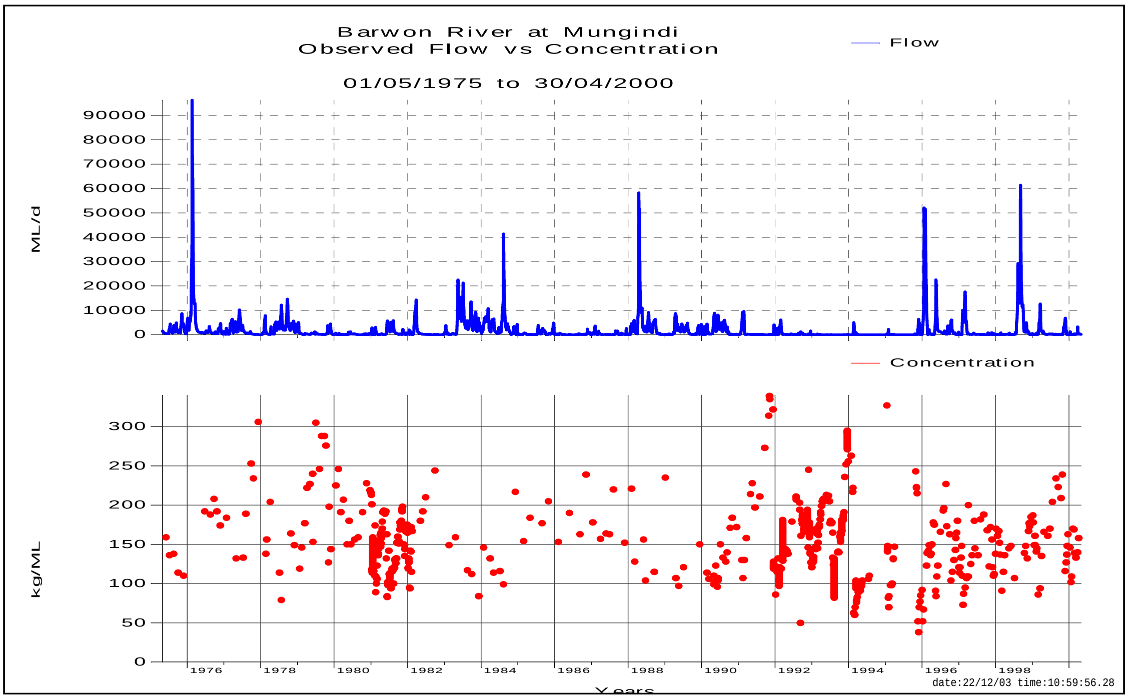


Figure 5.36. Station 416001: Barwon River @ Mungindi, flow and concentration data

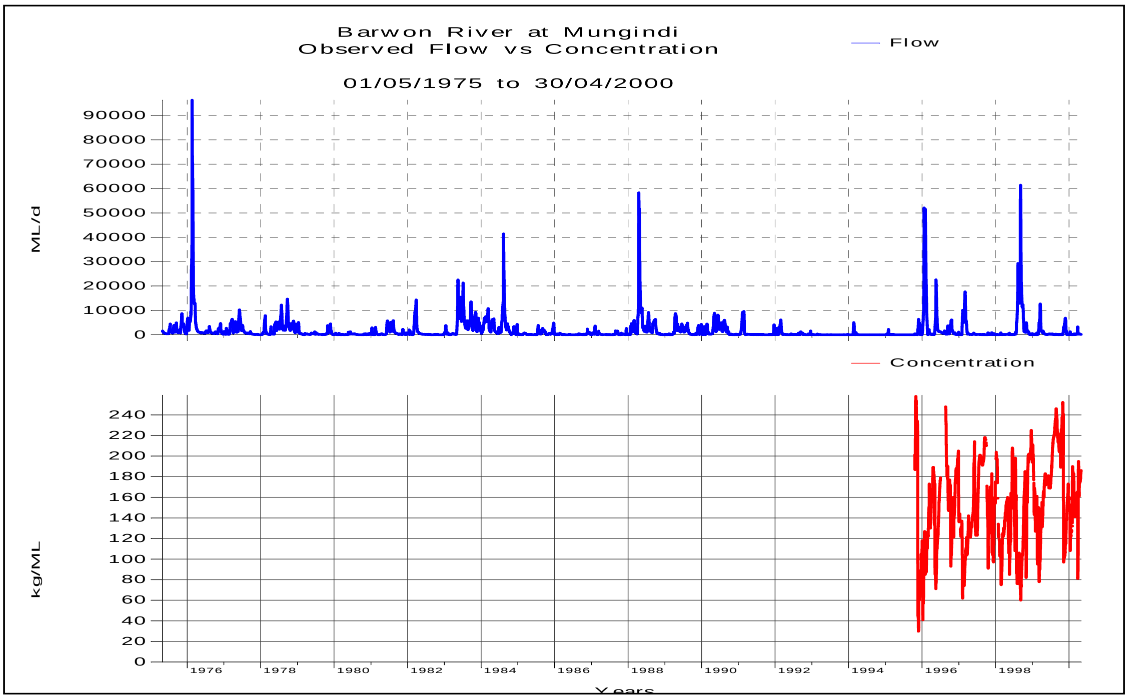


Figure 5.37. Station 416001: Barwon River @ Mungindi, flow and continuous concentration data

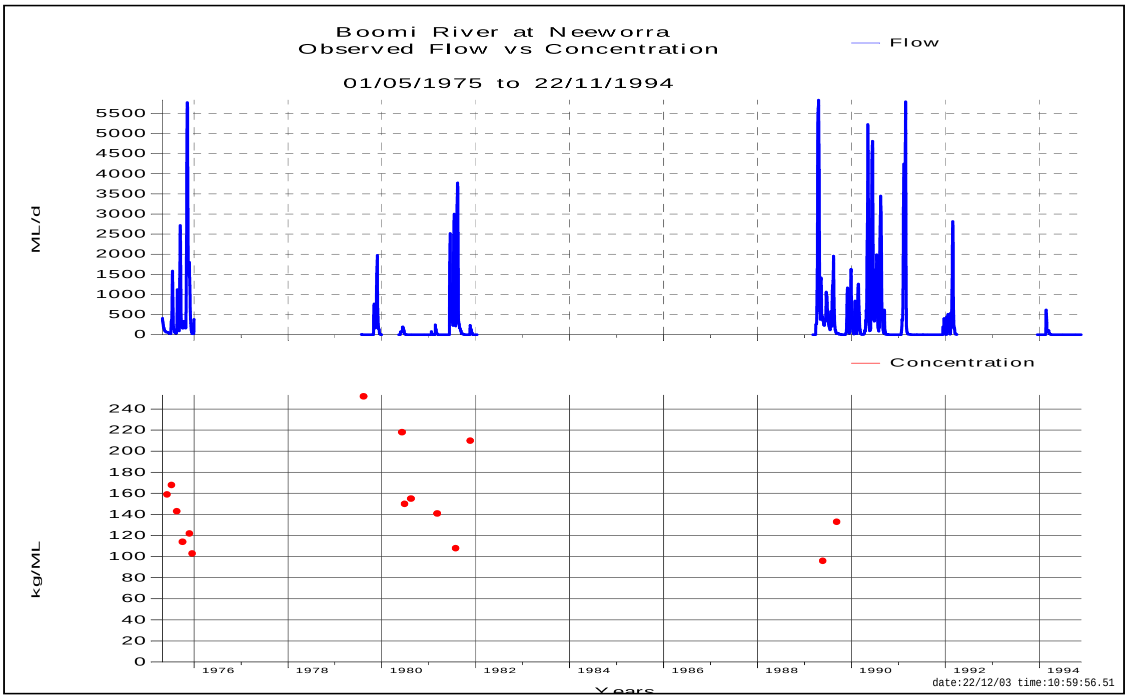


Figure 5.38. Station 416028: Boomi River @ Neeworra, flow and concentration data

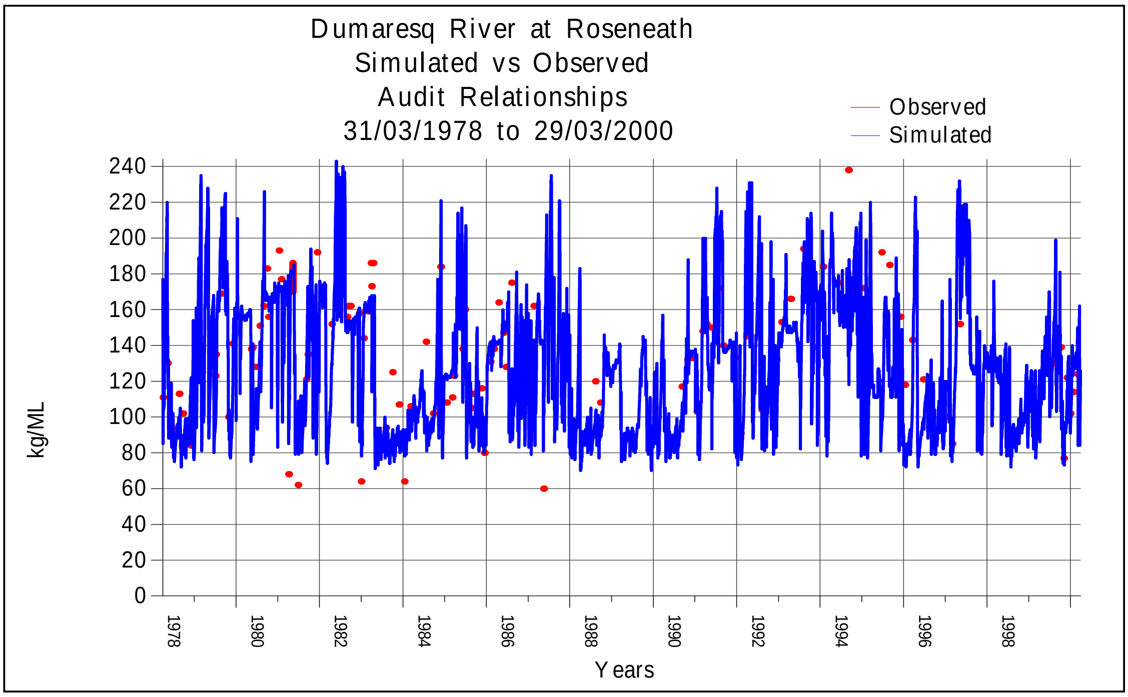


Figure 5.39. Simulated versus observed salinities at Station 416011: Dumaresq River @ Roseneath, using Salinity Audit relationships for NSW inputs and flow salinity tables for Queensland inputs.

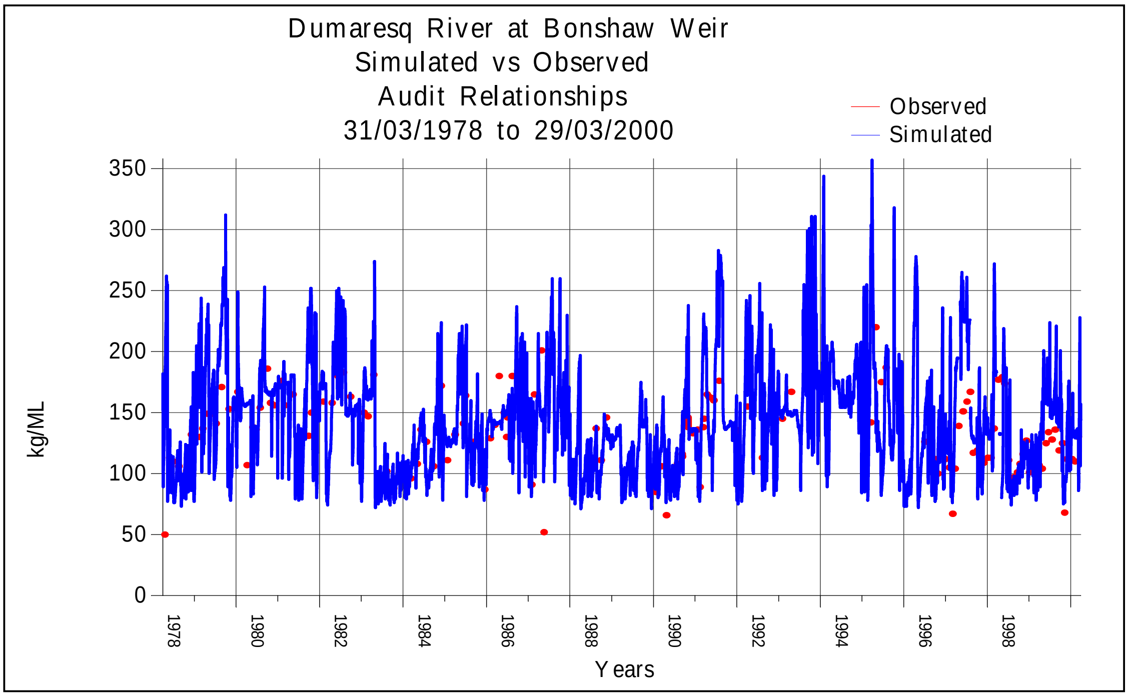


Figure 5.40. Simulated versus observed salinities at Station 416007: Dumaresq River @ Bonshaw Weir, using Salinity Audit relationships for NSW inputs and flow-salinity tables for Queensland inputs.

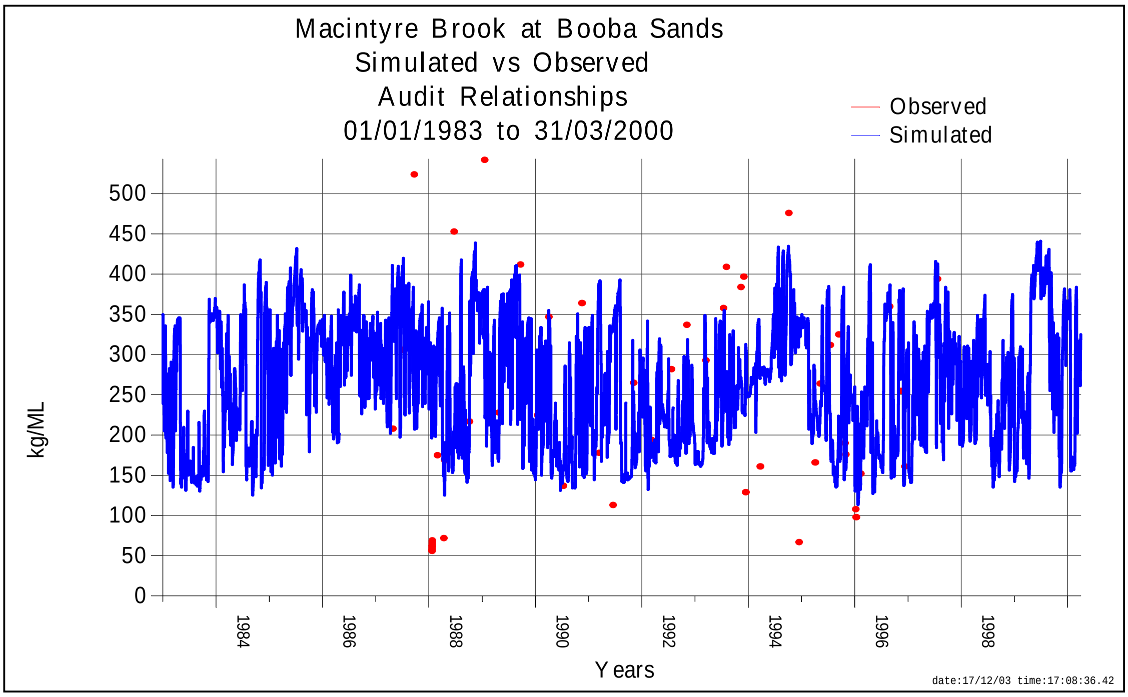


Figure 5.41. Simulated versus observed salinities at Station 416415: Macintyre Brook @ Booba Sands, using flow-salinity tables for Queensland inputs.

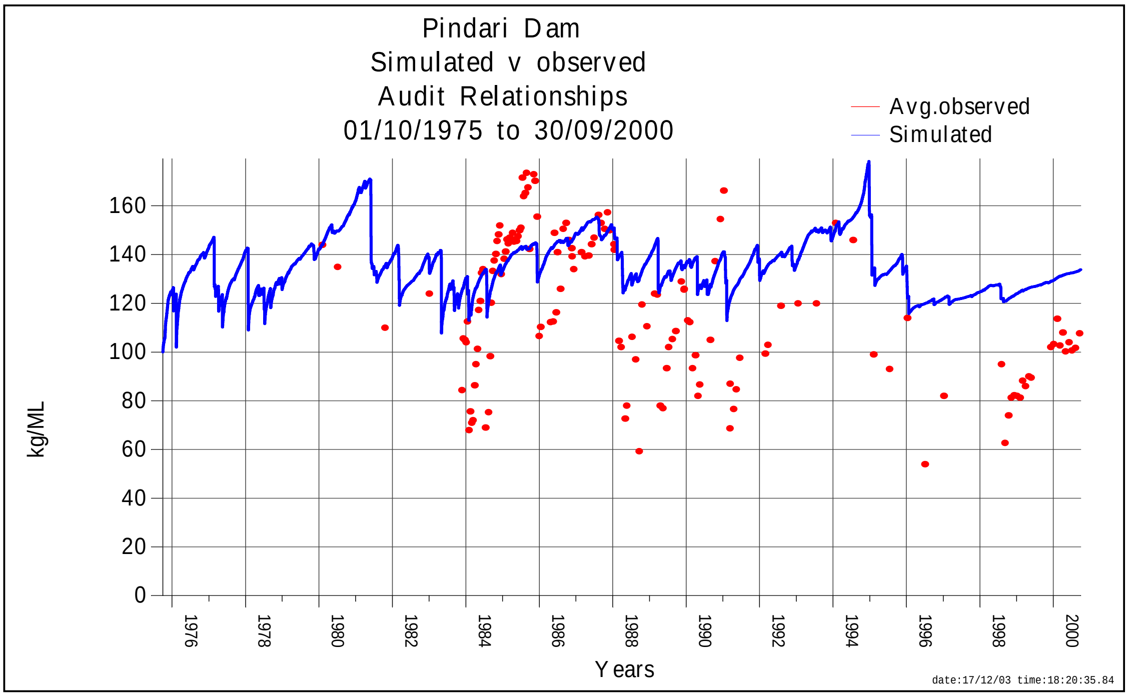


Figure 5.42. Simulated versus observed salinities at Pindari Dam, using Salinity Audit relationships.

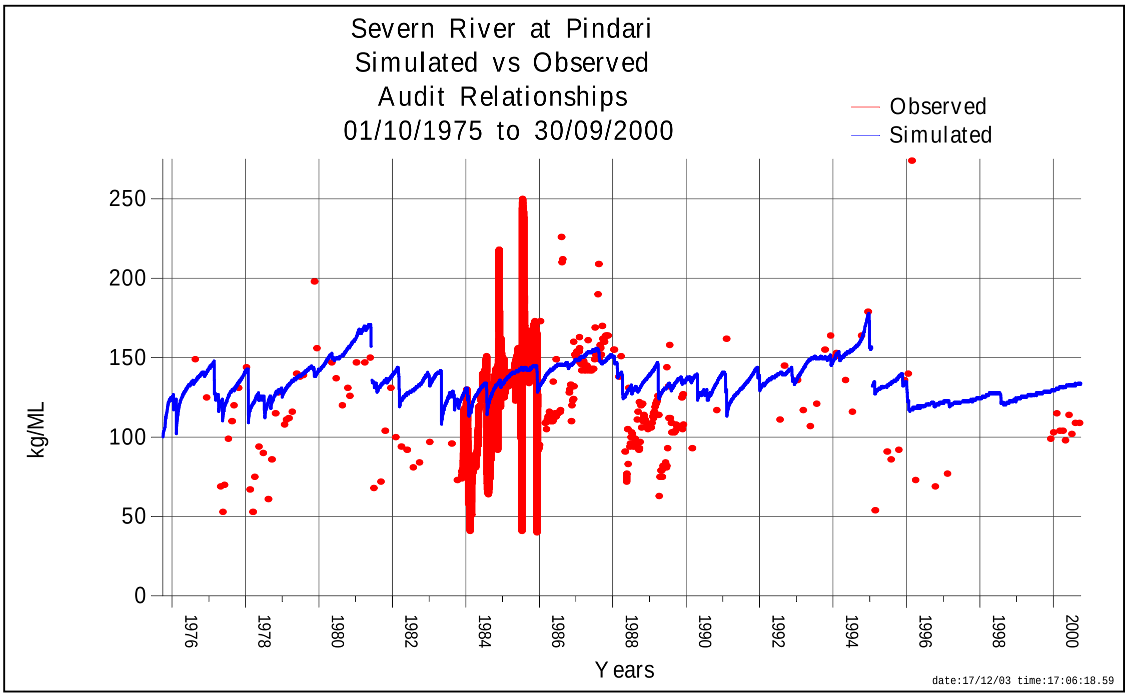


Figure 5.43. Simulated versus observed salinities at Station 416019: Severn River @ Pindari, using Salinity Audit relationships.

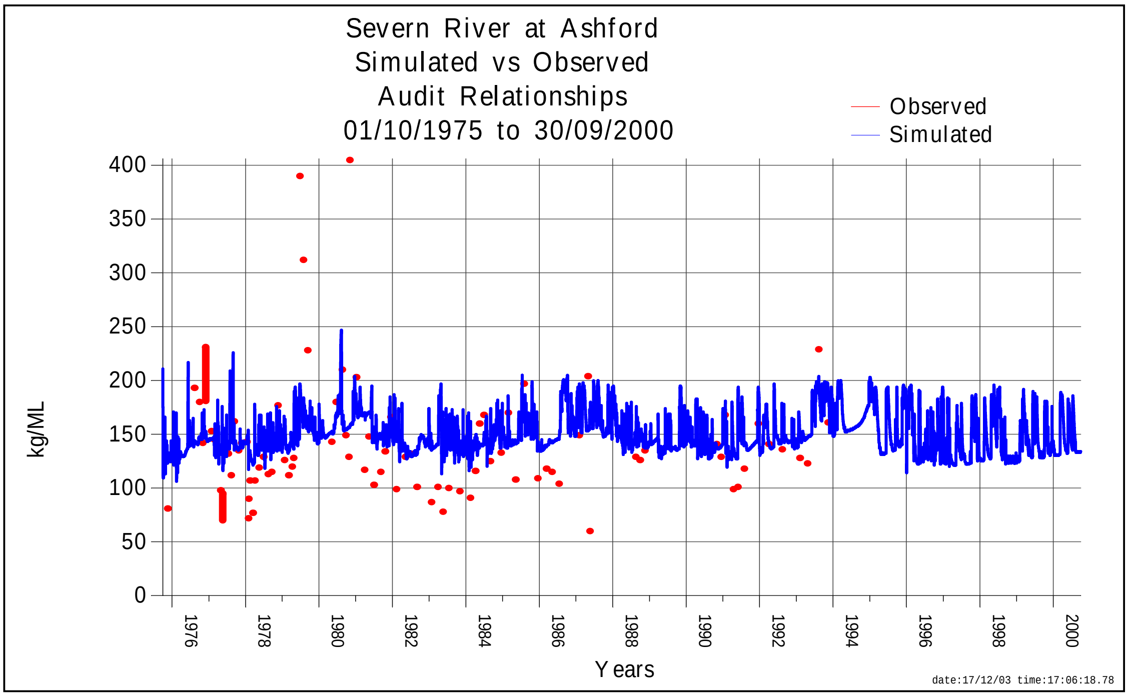


Figure 5.44. Simulated versus observed salinities at Station 416006: Severn River @ Ashford, using Salinity Audit relationships.

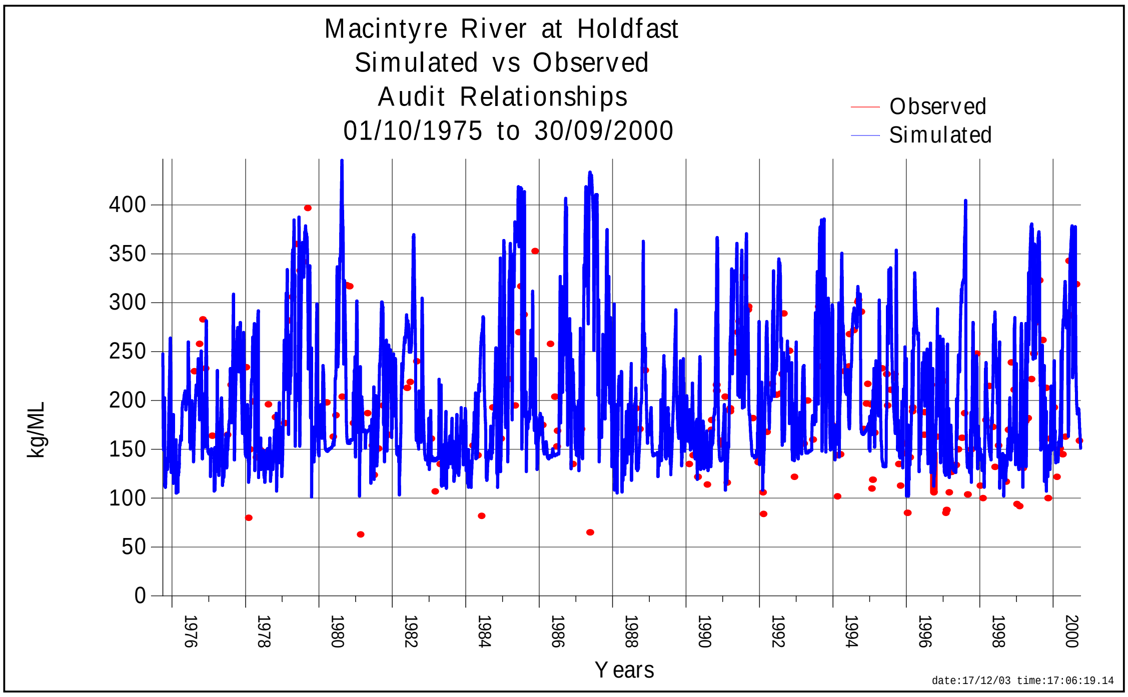


Figure 5.45. Simulated versus observed concentrations at Station 416012: Macintyre River @ Holdfast, using Salinity Audit relationships for NSW inputs.

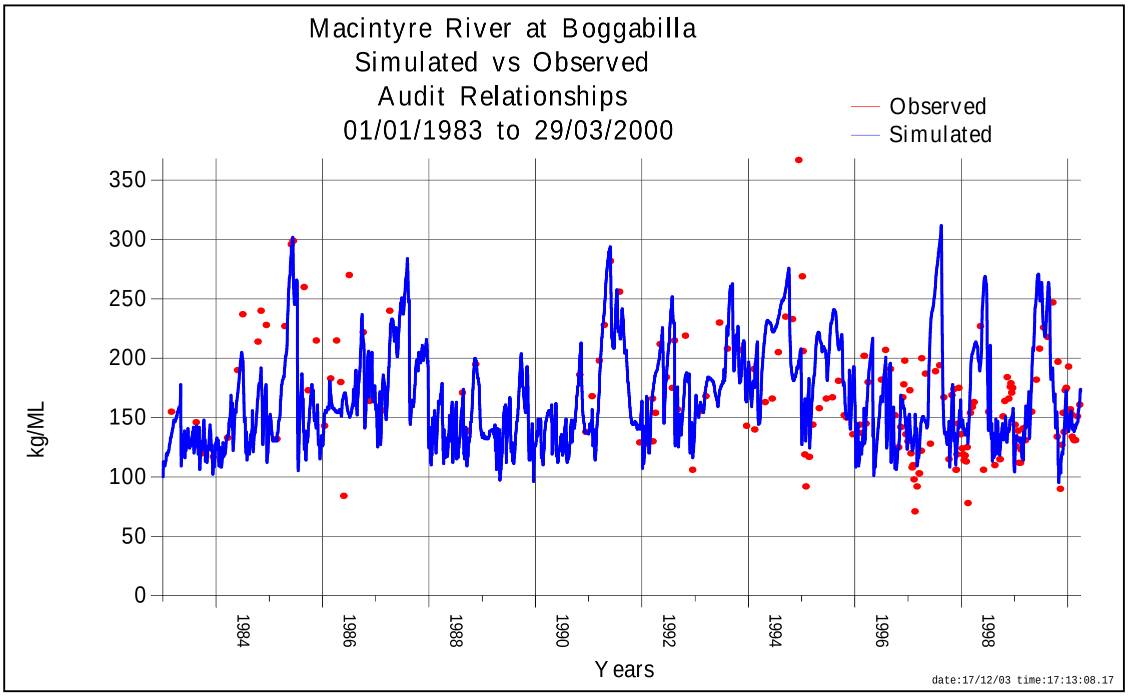


Figure 5.46. Simulated versus observed concentration at Station 416002: Macintyre River @ Boggabilla, using Salinity Audit relationships for NSW inputs and flow-salinity tables for Queensland inputs.

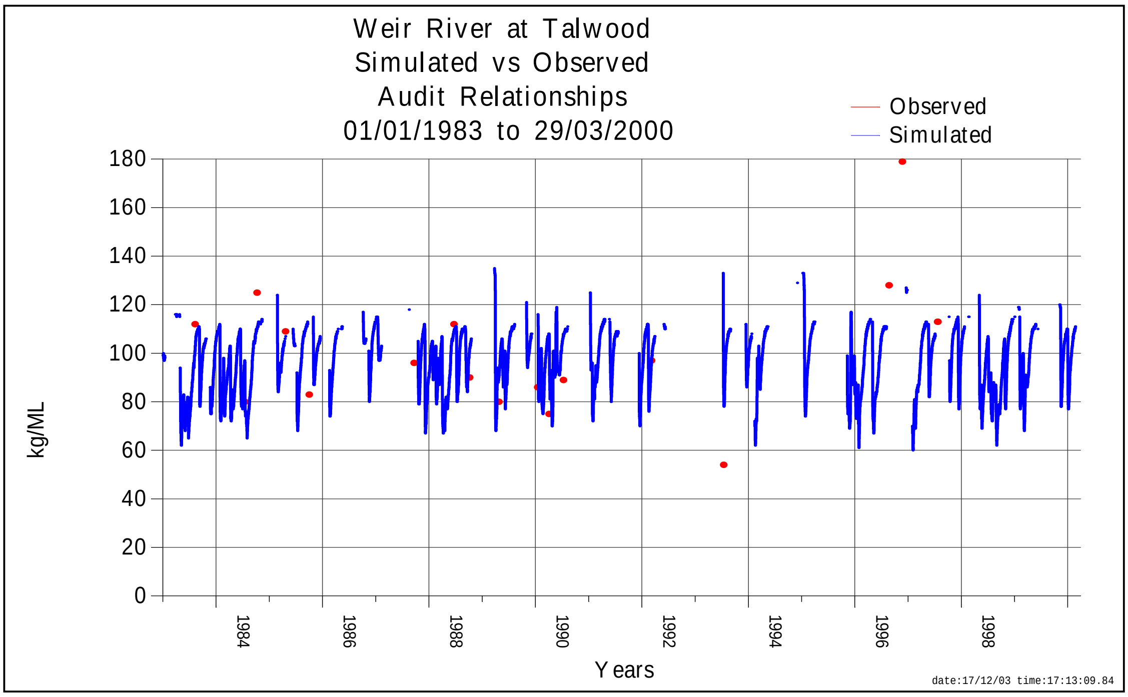


Figure 5.47. Simulated versus observed concentration at Station 416202: Weir River @ Talwood, using flow-salinity tables for Queensland inputs.

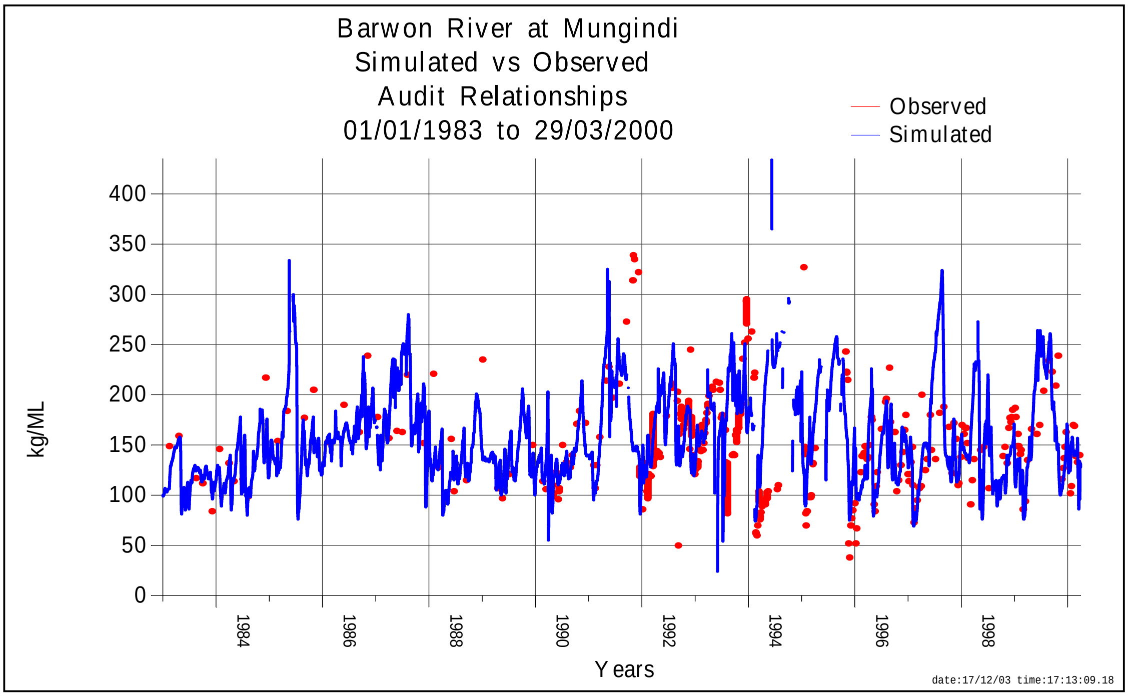


Figure 5.48. Simulated versus observed concentration at Station 416001: Barwon River @ Mungindi, using Salinity Audit relationships for NSW inputs and flow-salinity tables for Queensland inputs.

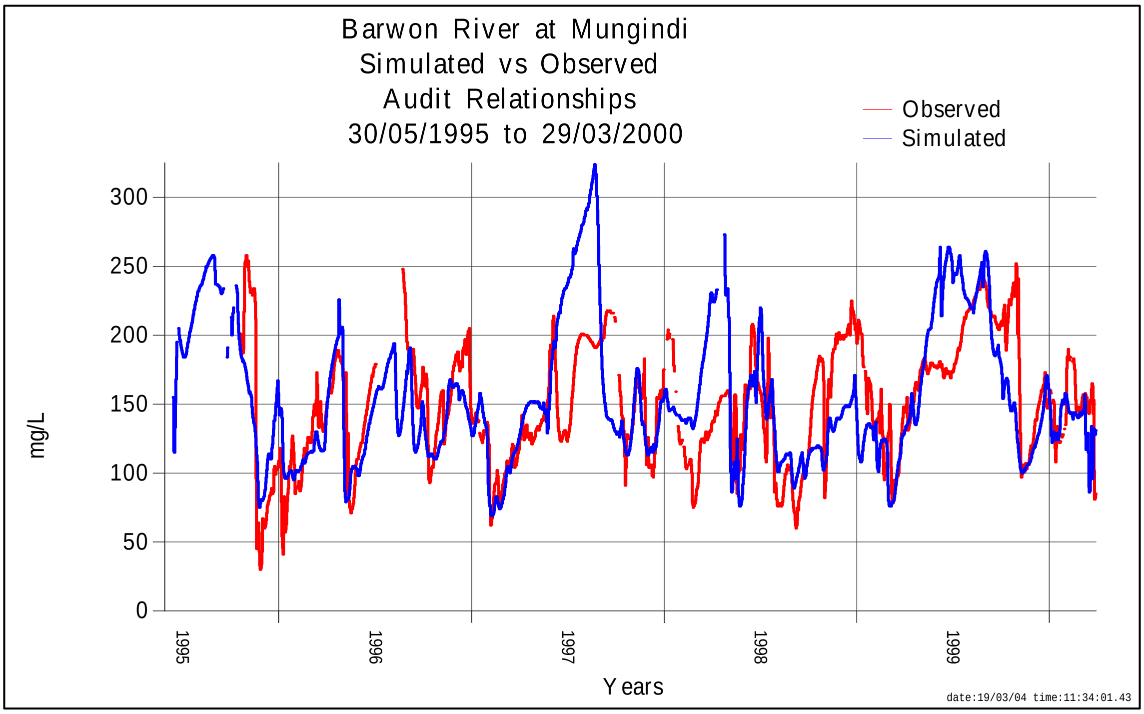


Figure 5.49. Simulated versus observed concentration (continuous data) at Station 416001: Barwon River @ Mungindi, using Salinity Audit relationships for NSW inputs and flow-salinity tables for Queensland inputs.

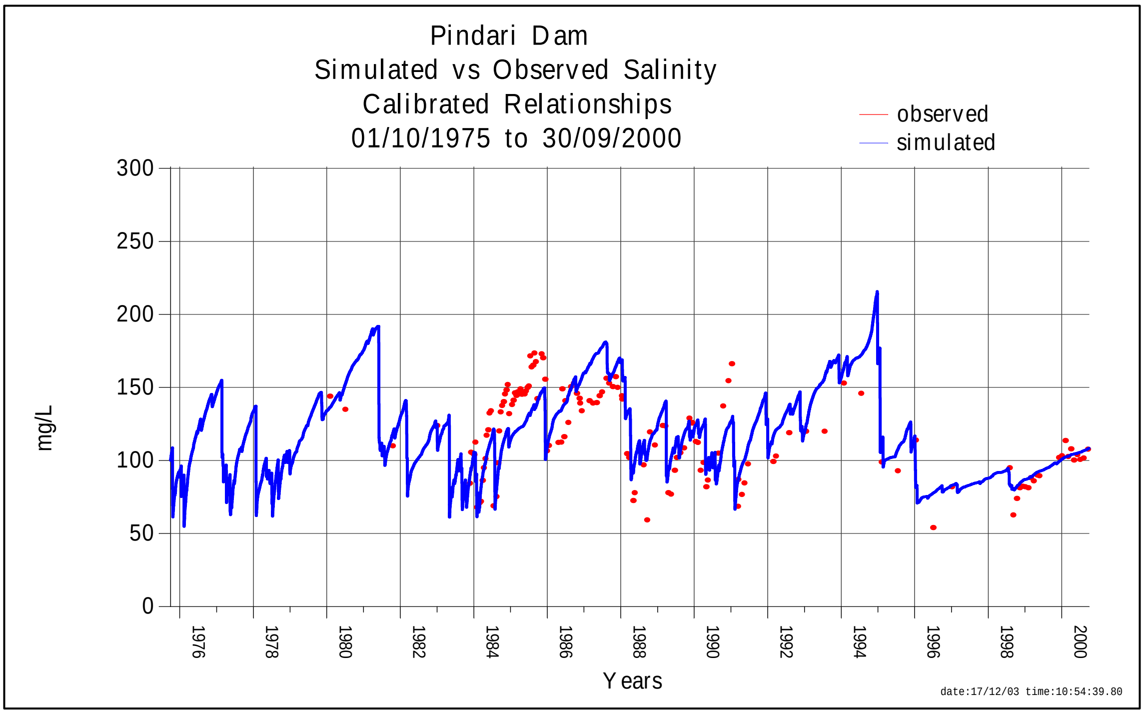


Figure 5.50. Simulated versus observed salinity at Pindari Dam, using calibrated relationship.

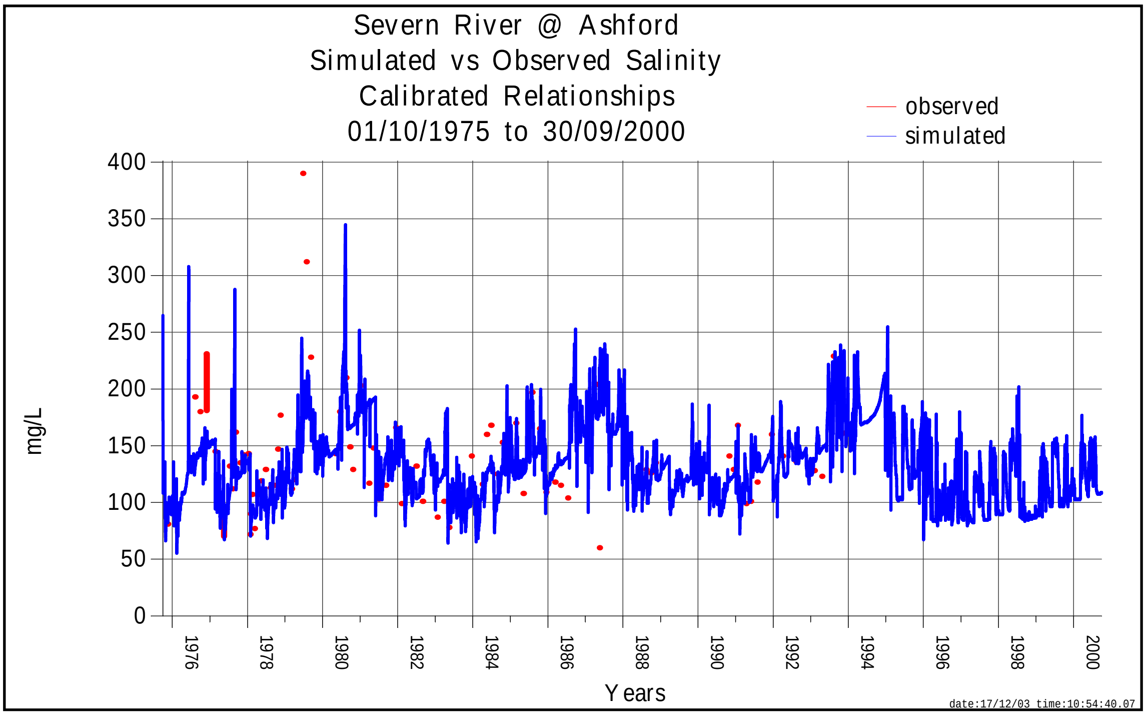


Figure 5.51. Simulated versus observed salinity for Station 416006: Severn River @ Ashford, using calibrated relationships.

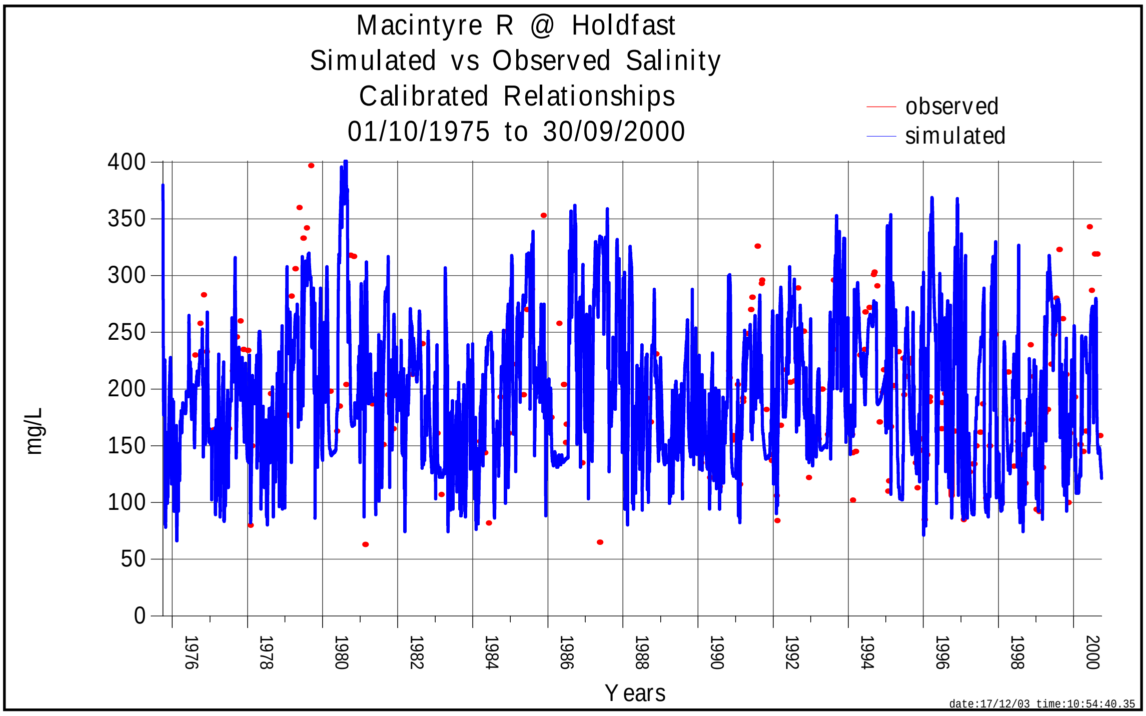


Figure 5.52. Simulated versus observed salinity for Station 416012: Macintyre River @ Holdfast, using calibrated relationship.

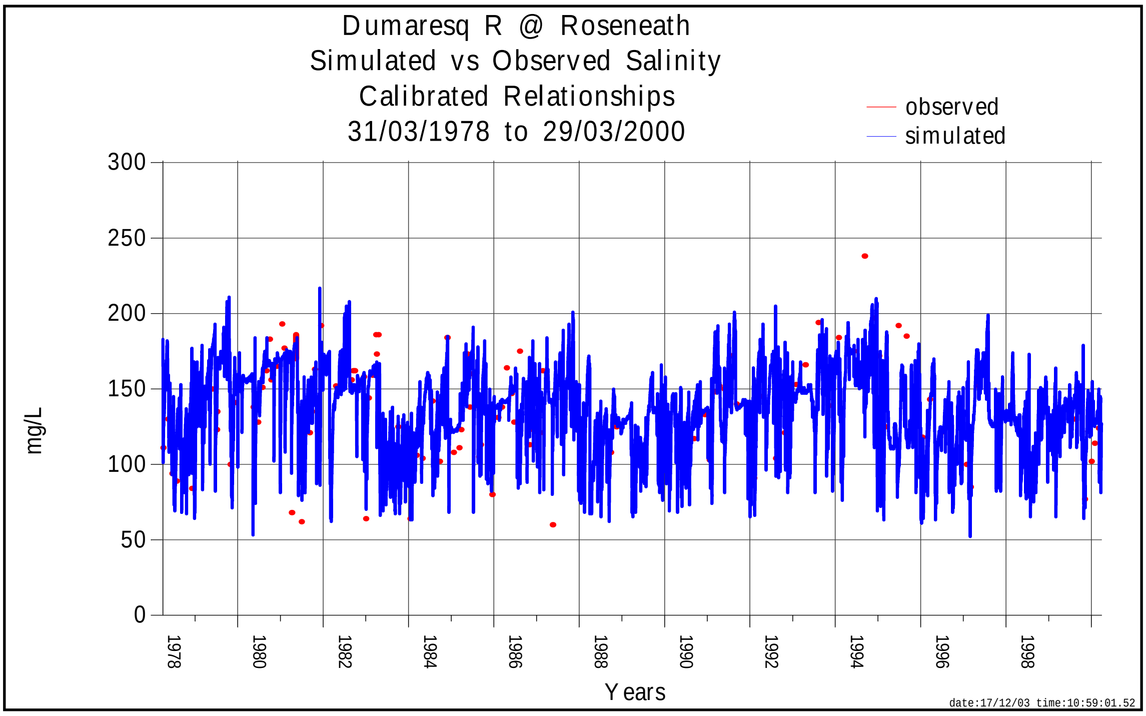


Figure 5.53. Simulated versus observed salinity for Station 416011: Dumaresq River @ Roseneath, using calibrated relationship.

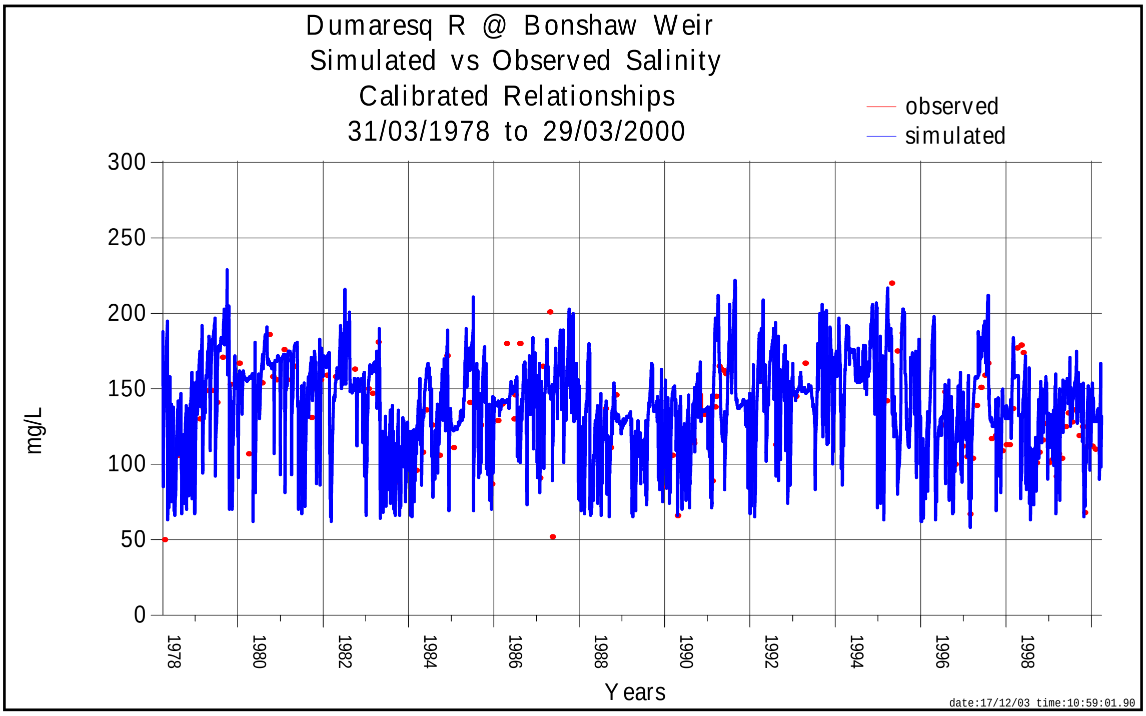


Figure 5.54. Simulated versus observed salinity for Station 416007: Dumaresq River @ Bonshaw Weir, using calibrated relationship.

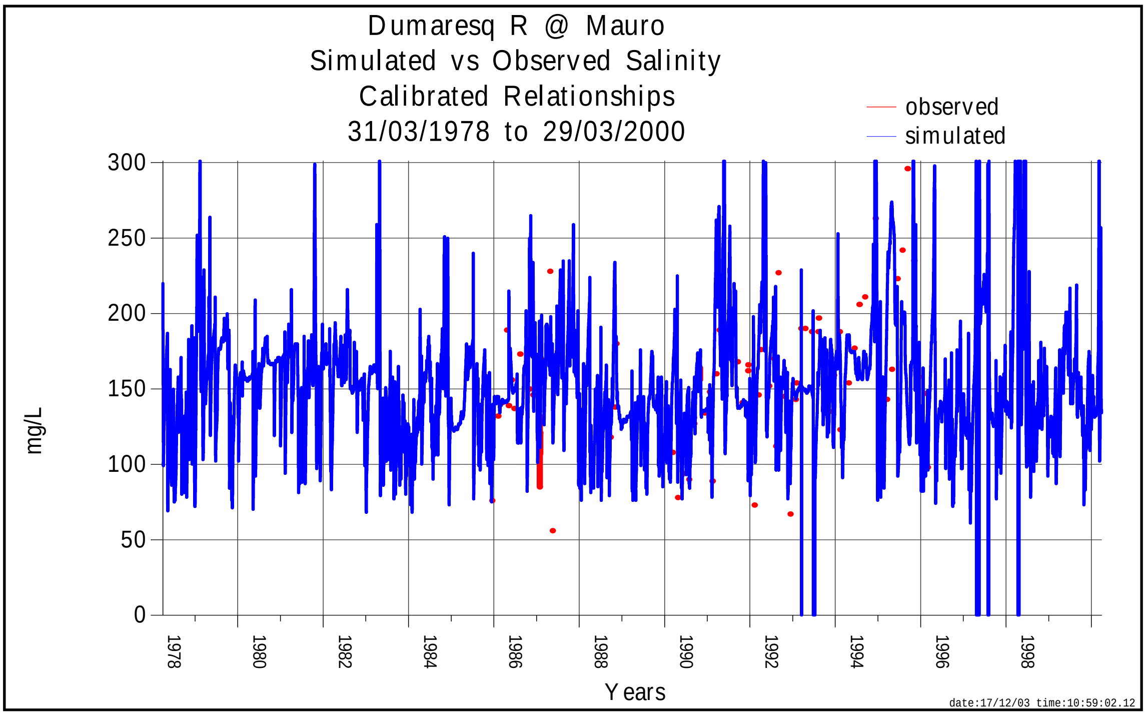


Figure 5.55. Simulated versus observed salinity for Station 416049: Dumaresq River @ Mauro, using calibrated relationship.

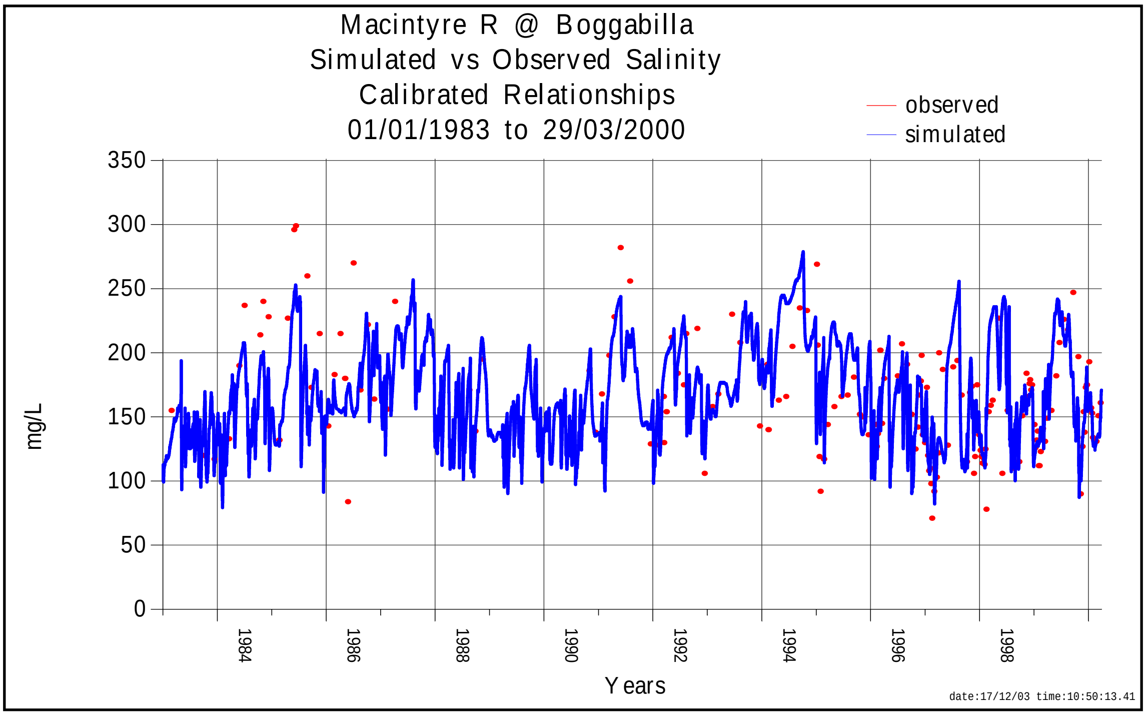


Figure 5.56. Simulated versus observed salinity for Station 416002: Macintyre River @ Boggabilla, using calibrated relationship.

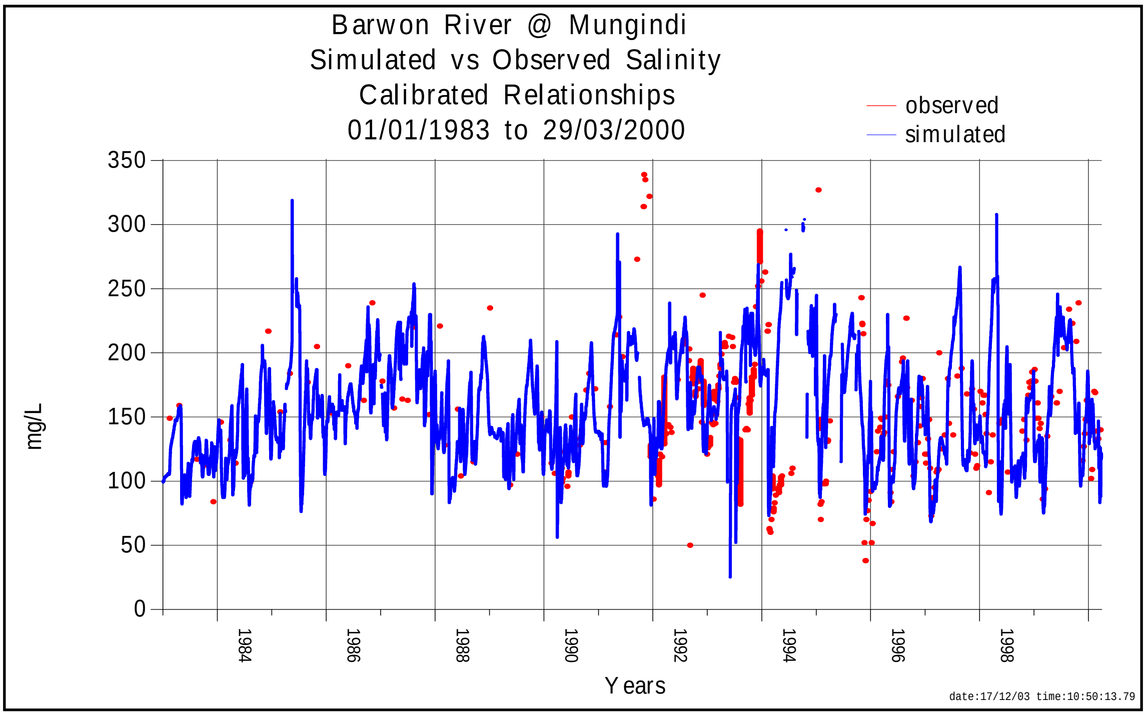


Figure 5.57. Simulated versus observed salinity for Station 416001: Barwon River @ Mungindi, using calibrated relationship.

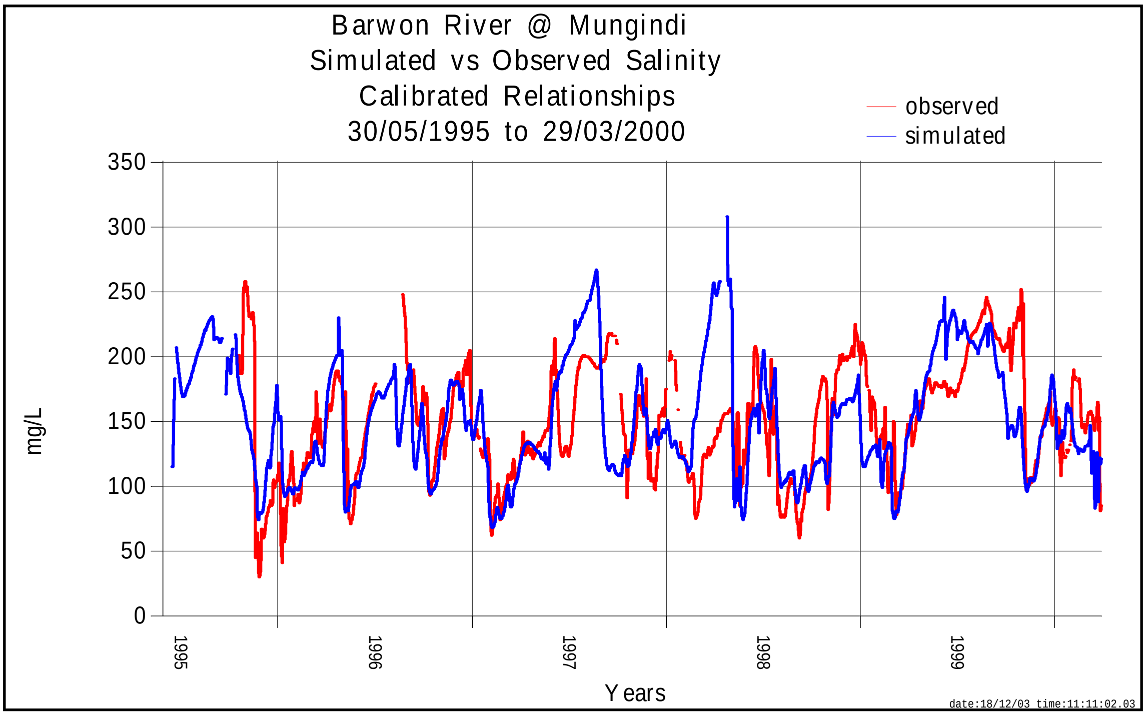


Figure 5.58. Simulated versus observed salinity (continuous) for Station 416001: Barwon River @ Mungindi, using calibrated relationship.

6. Baseline Conditions scenario

6.1. BASELINE CONDITIONS

The BSMS Schedule C requires definition of the following suite of baseline conditions in place within the catchments and rivers on 1 January 2000:

(i) land use;

(ii) water use;

(iii) land and water management policies and practices;

(iv) river operating regimes;

(v) salt interception schemes;

(vi) run-off generation and salt mobilisation processes; and

(vii) groundwater status and condition.

Points (i), (vi) and (vii) will influence the flows and salt inputs to the IQQM, whereas (ii) and (iv) are directly simulated by altering the IQQM configuration and parameterisation. Point (iii) affects both the inputs from the catchments, and includes processes simulated in IQQM. Point (vii) may affect either catchment inflows, or IQQM operation.

Defining the points affecting inputs to the flows and salt inputs to the IQQM is problematic, with difficulties arising from sparse data to describe the important biophysical characteristics, as well as how to reliably estimate the quantitative response of catchments to these characteristics. Salt mobilisation and export from catchments is a dynamic process that changes in time and space. It varies with the spatial organisation of biophysical characteristics of a catchment such as geology, topography and landuse, as well as characteristics that change in time such as climate and groundwater levels. The aggregate response to all these characteristics is measured at the catchment outlet. Unfortunately, these salinity measurements are sparse for tributaries, and cannot currently be used to separate out the effects that change over time. This situation will improve as the catchment modelling studies capture and analyse the catchment data and additional continuous data.

In the absence of suitable data to do otherwise, the flows and salt inflows were based on observations, without any adjustment for changes in catchment characteristics over the period of record.

Information is available to define water use and river operating regimes in the Border Rivers. This information has been collected and developed in the process of setting up the IQQMs over the years. This information is summarised in Table 6.1. Note that in Queensland, the area irrigated has doubled since 1994, whilst in NSW the area increased by more than 20% between 1998 and 2000. (DLWC Border Rivers Calibration Report, 1999).

The results from this simulation are reported in the following section. Note that the daily flows and concentrations were based on large Pindari and development conditions on 1 January 2000, which is quite different from conditions prior to 1995:

Table 6.1. BSMS Baseline (01/01/2000) conditions for water sharing

Water Balance Component	Value	Units
Average annual inflows *(benchmark climatic period)*		
Upper Dumaresq-Macintyre (Glenlyon) system	517	GL/year
Macintyre Brook (Coolmunda) system	67	GL/year
Severn-Macintyre (Pindari) system	319	GL/year
Macintyre-Barwon	423	GL/year
Weir River	28	GL/year
Storages		
Glenlyon		
Active storage	248	GL
Storage reserve	150	GL
Transmission and operation losses	28	GL
Coolmunda		
Active storage	69.0	GL
Storage reserve	45.0	GL
Transmission and operation losses	13.8	GL
Pindari		
Active storage	312	GL
Storage reserve	150	GL
Transmission and operation losses	19	GL
Boggabilla		
Active storage	5.8	GL
Storage reserve	0.0	GL
Transmission and operation losses	0.0	GL
Irrigation		
General security licences		
NSW total	264	GL/year
NSW "A class"	21	GL/year
QLD (including Coolmunda system licences)	91	GL/year
Proportion licences active (*NSW* and *QLD*)	100	%
Maximum allocation (*NSW* and *QLD)*	100	%
Maximum irrigable area		
NSW (regulated pumpers only)	42,516	Ha
QLD		
Regulated Pumpers(including Coolmunda system)	54,662	Ha
Unregulated Pumpers	5,649	Ha
Flood Plain Harvesting/Unregulated Pumpers	900	Ha
Pump capacity		
NSW		
Regulated Streams Pumps	6,290	ML/day
Unregulated Streams Pumps	0	ML/day
Flood Plain Harvesting/2nd lift Pumps	3,687	ML/day
QLD		
Regulated Streams Pumps (includes 2,000 ML/day Pump Capacity in Coolmunda system to model Baseline Condition ordering pattern)	9,523	ML/day
Unregulated Streams Pumps	4,134	ML/day
Flood Plain Harvesting/2nd lift Pumps	7,154	ML/day
On-farm storage capacity		
NSW (regulated pumpers only)	148	GL

Water Balance Component	**Value**	**Units**
QLD		
Regulated Pumpers	243.0	GL
Unregulated Pumpers	39.0	GL
Flood Plain Harvesting/Unregulated Pumpers	6.2	GL
Cotton portion of total planted areas		
NSW (regulated pumpers only)	88	%
QLD		
Regulated Pumpers	82	%
Unregulated Pumpers	99	%
Flood Plain Harvesting/Unregulated Pumpers	100	%
Surplus flow limit		
NSW	120	GL/year
QLD	na	
Town water supply		
Texas	0.3	GL/year
Inglewood	0.5	GL/year
Yelarbon	0.1	GL/year
Ashford	0.2	GL/year
Boggabilla	0.3	GL/year
Goondiwindi	1.8	GL/year
Mungindi	0.3	GL/year
In-stream water supply		
Minimum Flow requirement d/s Coolmunda Dam (max)	0.4	GL/year
DRIP minimum flow requirements (max)	6.4	GL/year
EIS minimum flow requirements (max)	45.8	GL/year
Boomi River replenishment	10.0	GL/year

6.2. RESULTS

The model was run for the Benchmark Climate period with the calibrated salinity inflows and the water usage and policies that existed as at 1 January 2000. The results for the mean and percentile non-exceedances for daily concentration and daily salt load at evaluation points are reported in Table 6.2. The results for the mean and percentile non-exceedance annual salt load at evaluation points are reported in Table 6.3.

The patterns of the concentration results are consistent with observed data, showing high concentrations in the Macintyre River at Holdfast compared with the Dumaresq River at Bonshaw Weir. Salinity increases at Macintyre River at Boggabilla, and then decreases at Mungindi. The concentration results for Mungindi are higher than the mean (166 mg/L versus 154 mg/L) and distribution of observed salinities (Table 6.4)

The results for salt loads showed an increase in salt load from Severn River at Ashford to Macintyre River at Holdfast. The salt load increases at Dumaresq River from Roseneath to Bonshaw Weir. The salt load continues to increase to Boggabilla but decreases at Mungindi as the flows split between a number of effluents (ie. Boomi River and Little Weir River). At Mungindi, the simulated salt load is lower (-3%) than observed which is partly due to lower flow (-31%) than observed (Figure 6.6). The median salt load is higher than observed by 5% (42 versus 40 T/d) and the median flow is lower by 11% (260 versus 291 ML/d). The simulated low flow during the 1975-2000 period (Figure 6.7) under 2000 development condition can be explained by the large increases in irrigation diversions since large Pindari Dam became fully operational in 1996.

Table 6.2. Simulated results of salinity and salt load for MDBMC BSMS Baseline, using calibrated relationships applied to 1/1/2000 conditions model, based on analysis of daily results 01/05/1975-30/04/2000

Target Site		Concentration (kg/ML)				Salt Load (T/day)			
Number	Name	*Mean*	*Percentile non exceedance*			*Mean*	*Percentile non exceedance*		
			20	*50*	*80*		*20*	*50*	*80*
416006	Severn River @ Ashford	166	104	124	208	73	2	14	83
416012	Macintyre River @ Holdfast	230	128	208	334	151	16	55	184
416011	Dumaresq River at Roseneath	135	111	137	157	114	10	41	153
416007	Dumaresq River @ Bonshaw Weir	138	112	140	163	133	10	53	188
416002	Macintyre River @ Boggabilla	173	129	165	214	341	32	128	354
416001	Barwon River @ Mungindi	166	119	153	207	138	4	42	182

- Note: In Bewsher (2004) it has been recommended that the Border Rivers model be classified as Class 3. This means there is low confidence in statistical variability of baseline conditions from this model. However, there should be some confidence that mean salt loads are of the right order. Predictions of changes in salinity are likely to be more accurate by comparing results from model runs. The Class of the model may be improved if more upstream sites (where flow prediction tends to be more reliable) are chosen for salinity prediction.

Table 6.3. Simulated results of salt loads for MDBMC BSMS Baseline, using calibrated relationships applied to 1/1/2000 conditions model, based on analysis of annual results 01/05/1975-30/04/2000

Target Site		Salt load (x 1000 T/year)			
Number	Name	*Mean*	*Percentile non exceedance*		
			20	*50*	*80*
416006	Severn River @ Ashford	27	13	22	39
416012	Macintyre River @ Holdfast	55	29	49	79
416011	Dumaresq River at Roseneath	42	20	37	57
416007	Dumaresq River @ Bonshaw Weir	48	21	50	69
416002	Macintyre River @ Boggabilla	125	53	117	207
416001	Barwon River @ Mungindi	50	12	41	83

- Note: In Bewsher (2004) it has been recommended that the Border Rivers model be classified as Class 3. This means there is low confidence in statistical variability of baseline conditions from this model. However, there should be some confidence that mean salt loads are of the right order. Predictions of changes in salinity are likely to be more accurate by comparing results from model runs. The Class of the model may be improved if more upstream sites (where flow prediction tends to be more reliable) are chosen for salinity prediction.

Table 6.4. Statistics of observed data for flow, salinity, and salt load (1975-2000) at Barwon River @ Mungindi

Parameter	Units	Mean	Percent non-exceedance		
			20	50	80
Flow	(ML/d)	1804	41	291	2129
Salinity	(mg/L)	154	114	149	189
Salt load	(tonnes/d)	142	8	40	194

The following figures (Figure 6.1 to Figure 6.10) show the Baseline Condition model results compared with observed data at Station 416001: Barwon River at Mungindi.

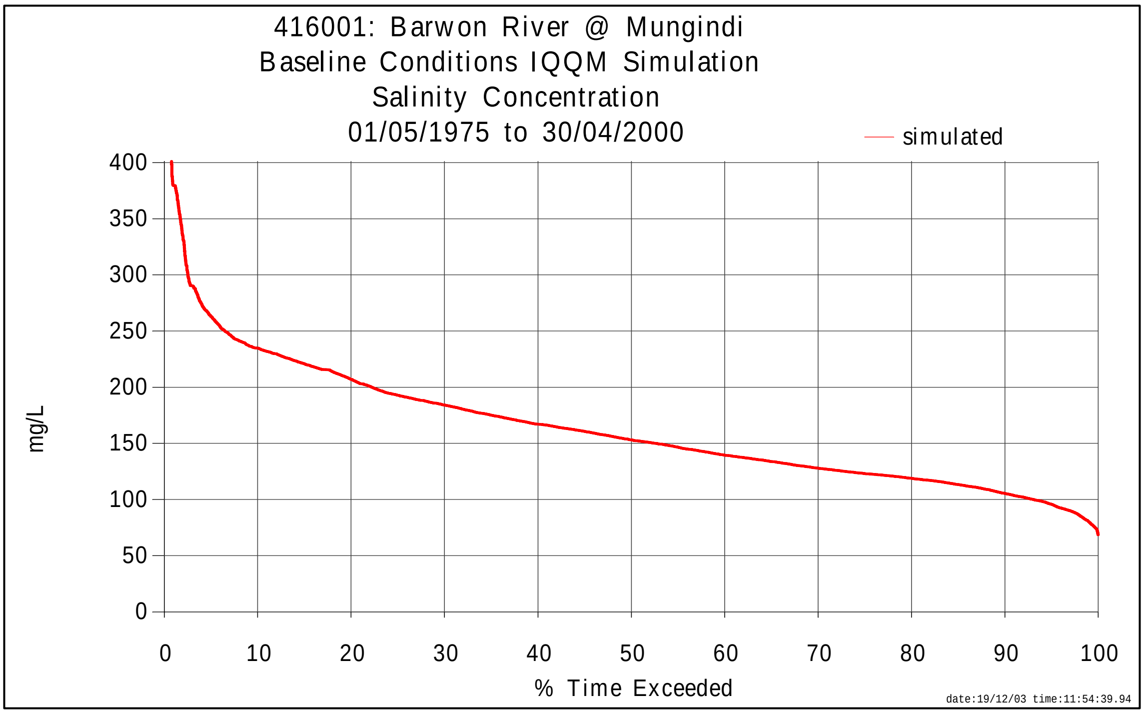


Figure 6.1. Frequency of exceedance of simulated salinity for Baseline Conditions scenario (1/5/1975-30/4/2000) for Barwon River @ Mungindi.

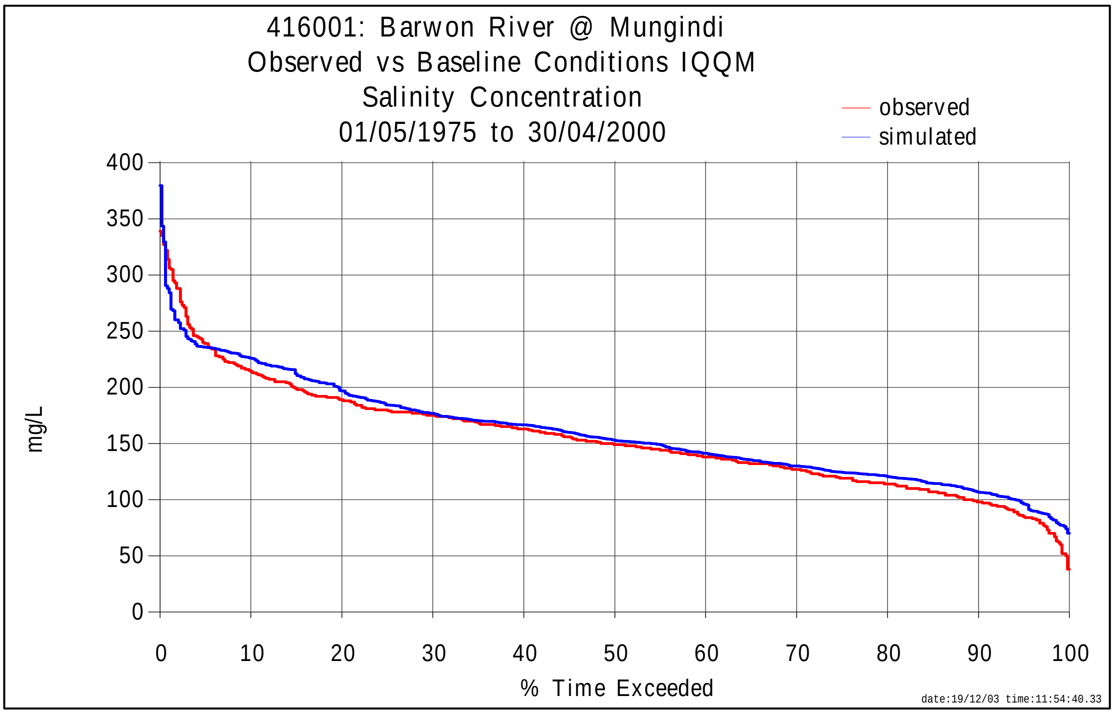


Figure 6.2. Frequency of exceedance of simulated salinity for Baseline Conditions scenario on days with salinity observations (1/5/1975-30/4/2000), compared with salinity observations for Barwon River @ Mungindi.

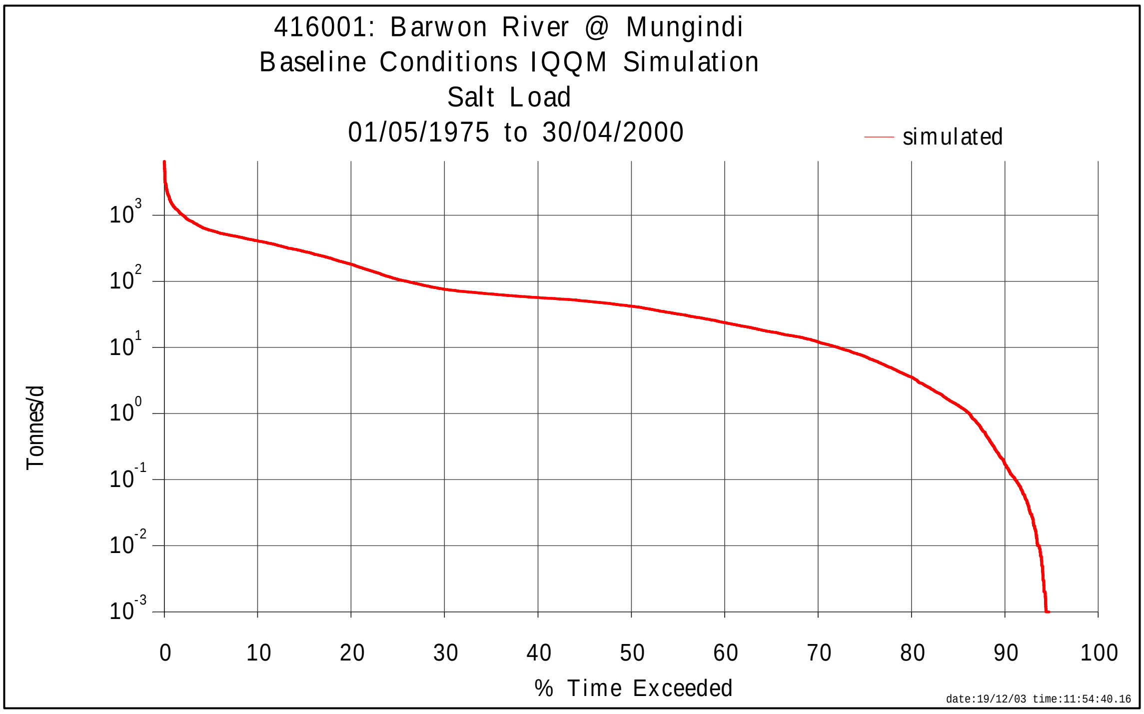


Figure 6.3. Frequency of exceedance of simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Barwon River @ Mungindi.

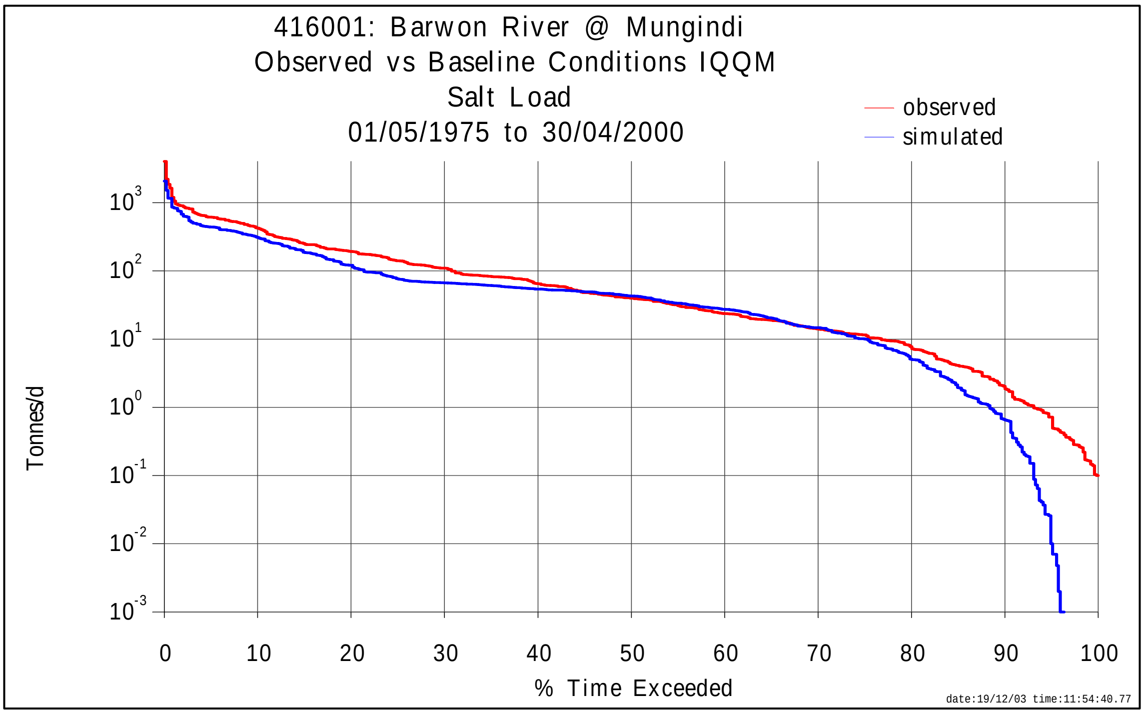


Figure 6.4. Frequency of exceedance of simulated salt load for Baseline Conditions scenario on days with salinity and flow observations (1/5/1975-30/4/2000), compared with salinity observations for Barwon River @ Mungindi

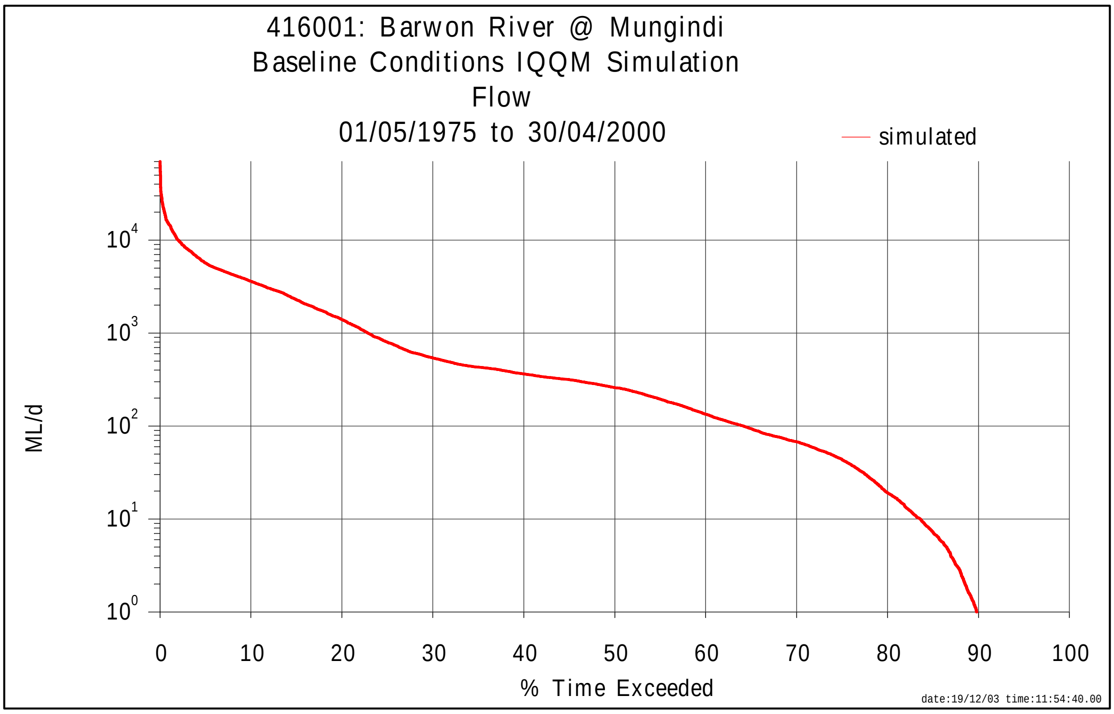


Figure 6.5. Frequency of exceedance of simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Barwon River @ Mungindi

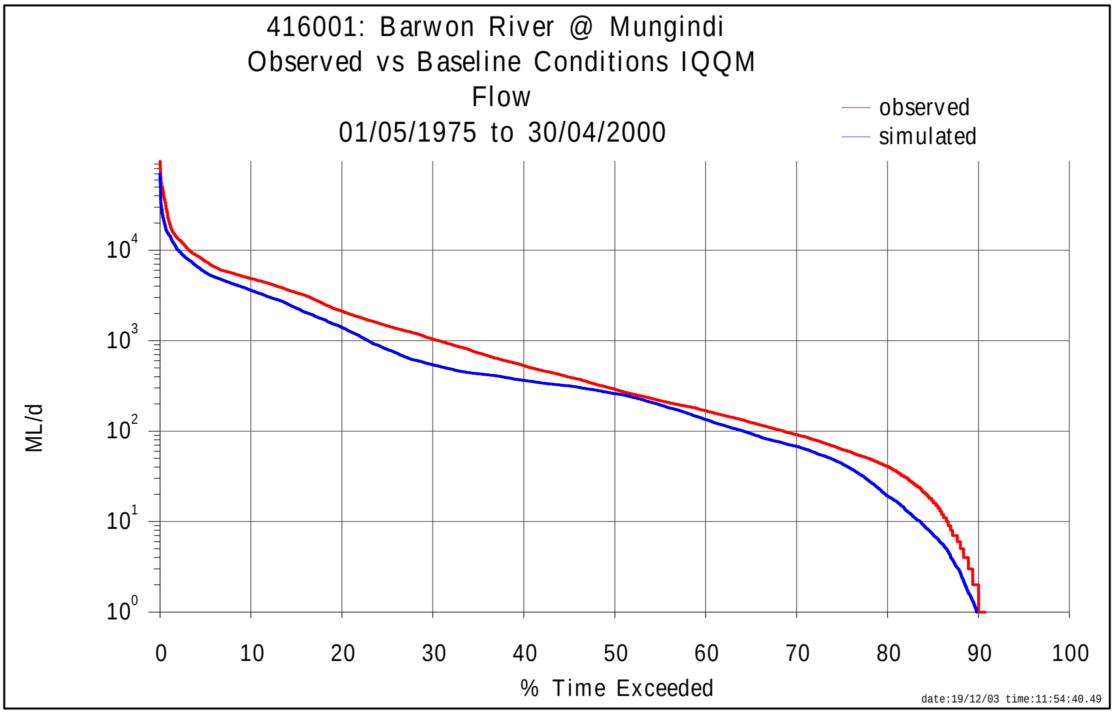


Figure 6.6. Frequency of exceedance of simulated flow for Baseline Conditions scenario on days with flow observations (1/5/1975-30/4/2000), compared with observed flow for Barwon River @ Mungindi

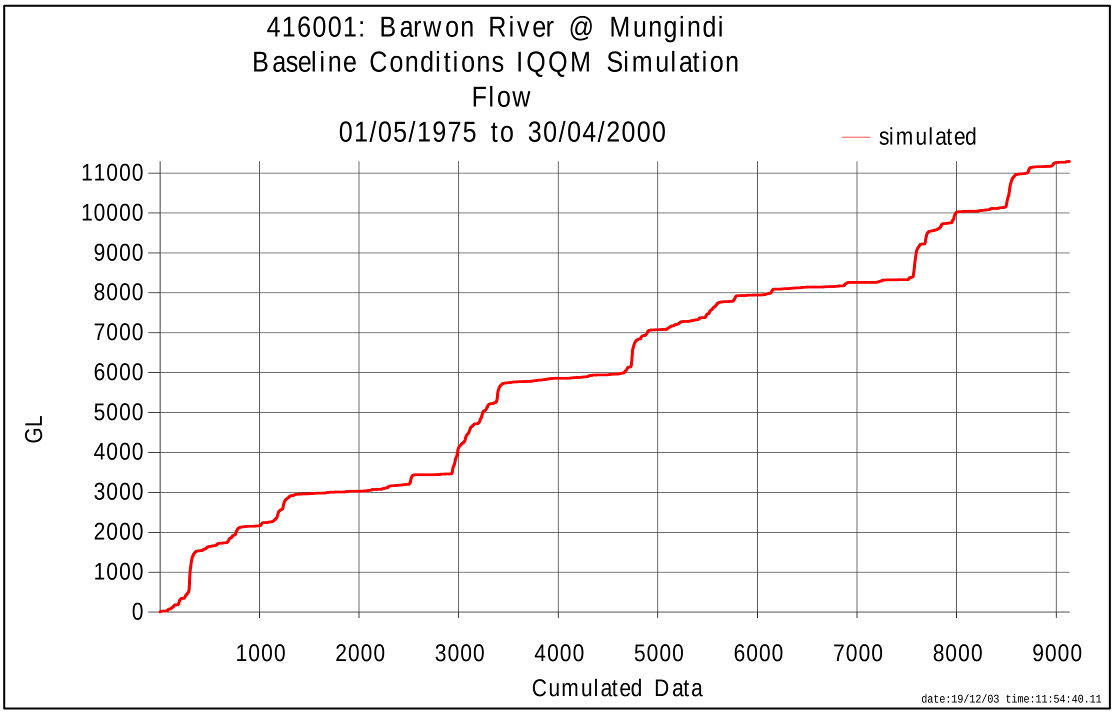


Figure 6.7. Cumulative simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Barwon River @ Mungindi

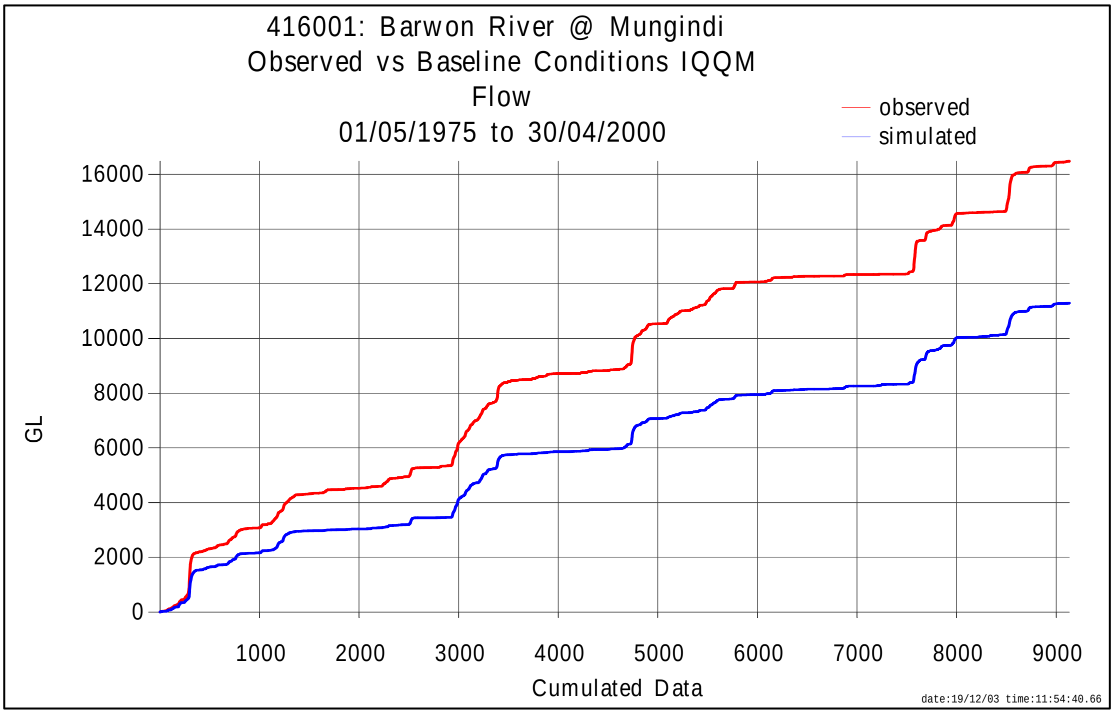


Figure 6.8. Cumulative simulated flow for Baseline Conditions scenario on days with observed flow (1/5/1975-30/4/2000) for Barwon River @ Mungindi

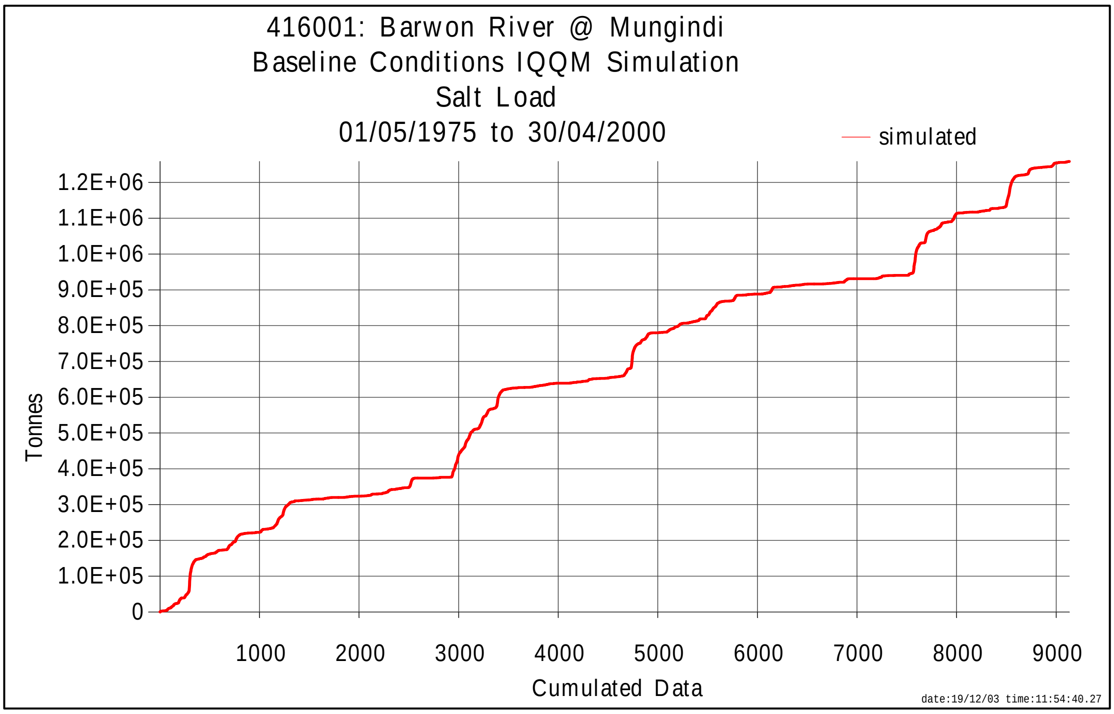


Figure 6.9. Cumulative simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Barwon River @ Mungindi

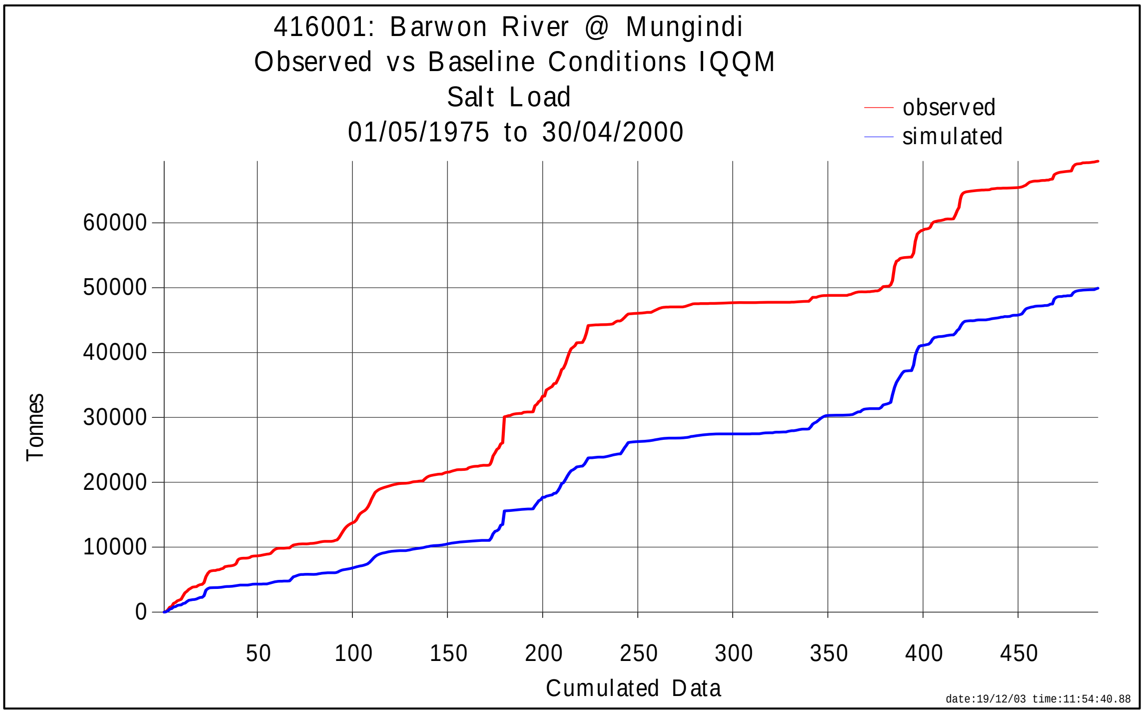


Figure 6.10. Cumulative simulated salt load for Baseline Conditions scenario on days with salinity and flow observations (1/5/1975-30/4/2000) for Barwon River @ Mungindi

7. Conclusion and recommendations

7.1. CONCLUSION

The calibrated Border Rivers IQQM produced simulated concentrations within 10% of the observed concentrations for all flow ranges at a majority of evaluation points. However, the simulated salinity peaks tended to occur earlier than the observed peaks. This may be due to routing problems as there was insufficient continuous salinity data to test the suitability of the routing parameters used along the main rivers in the model. The salt loads tended to be lower than observed, especially in the high flow range, largely due to the underestimation of high flow volumes.

The Baseline Conditions model (with development levels as at 1 January 2000) was run over the Benchmark Climatic Period (1 May 1975 to 30 April 2000). Under these conditions, flows at the end of system are lower than observed, especially in the low to medium flow range. This is to be expected due to the expansion in irrigation since Pindari Dam was enlarged in 1994.

The Border Rivers IQQM is capable of estimating the flow and salinity impacts of water sharing policies. However, because of current model limitations there are difficulties in getting the correct distribution of flows especially in the Macintyre-Barwon river system. These flow limitations will result in limitations on the model’s ability to predict salinity changes.

7.2. RECOMMENDATIONS ON MODEL IMPROVEMENTS

Review of the available salinity data and development of this valley model to simulate Baseline Conditions have highlighted a number of areas where the model could be improved. The timetable for these improvements will depend on additional data becoming available, other projects underway to meet NSW salinity strategy and priority of modelling work within the Department. The Department is committed to developing the salinity models, however, the timetable for the model improvements will be part of future work planning. The following points outline the areas of model.

- Improvements could be made to the methods used to estimate salt loads under Baseline Conditions. The flow versus salt load and flow versus concentration relationships, alone, are not capable of reproducing the variability in the observed data. This is particularly true in the Severn and Macintyre River systems where there is evidence of significant groundwater interaction. Catchment process-based modelling (especially if it can be calibrated against continuous data) would improve salt export estimates.

- There is significant groundwater interaction in both the Severn and Macintyre River systems. The flow and salinity data should be reviewed to try to enhance salinity modelling.

- There is a need to re-calibrate the residual inputs along the border in conjunction with the Queensland DNRM. At present, the salinity in some of the NSW residual inflows had to be made unrealistically high (to compensate for the low salinty of some Queensland inflows) in order to achieve a reasonable match at the next evaluation station on the main river.

- The estimation of inflows to Pindari Dam and other tributaries should be reviewed. This will increase confidence in the ability of the model to estimate the effects of land use changes on flow, salinity and salt load at the end of the river system.

- The effects of rainfall and evaporation on model reaches with significant surface areas should be checked to make sure the results are sensible.

- Salinity processes should be taken into consideration in a review of transmission losses, especially in the lower reaches of the model. This could improve the estimation of salt exports from the catchment.

7.3. RECOMMENDED FUTURE DATA COLLECTION

Catchment process-based models like CATSALT are capable of predicting the effects of antecedent soil moisture conditions, changes in groundwater level and the impacts of land use changes on salt exports from the tributary catchments in the Border Rivers. However, for salt inputs from ungauged catchments and from groundwater interaction with the river, more data is required to identify the sources of salt and to gain an understanding of the processes affecting salinity in the main streams of the catchment.

- Continuous EC data at all major gauging stations would allow improvements in the estimated salt balance over various flow regimes, wet and dry periods, and different seasons. For example (in NSW):
    - data at the major main river stations including Roseneath (416011), Mauro (416049), Boggabilla (416002) and either Boomi Weir (416043) or Kanowna (416048) would improve the calibration of residual catchment inputs as well as losses and effluents;
    - data for the Severn River @ Strathbogie (416039) and Frazers Creek @ Ashford (416021) could help identify the processes contributing salt to these upland streams and lead to the development of better modelled inputs (from CATSALT, or other models);
    - data for the Severn River at Ashford (416006), the Macintyre River at Wallangra (416010) and the Macintyre River at ‘dam site’ (416018) could explain the large increase in salinity (residual catchment or groundwater interaction?) between Ashford and the ‘dam site’;
    - data for the Macintyre River at Holdfast (416012) and Boonal (416038) as well as Ottleys Creek at Coolatai (416020) would be useful in working out the total contribution from Ottleys Creek (possibly the most saline tributary in the catchment) and the whole of the Severn-Macintyre region within NSW. Flow data would also be needed at Boonal as the gauge has been discontinued.
    - there is currently no data at all for Whalan Creek and very little for the Boomi River, which creates uncertainty with respect to the total salt load exported from the Border Rivers.

- Observed daily diversion data could improve the calibration of low flows by enabling diversions to be separated from transmission losses when analysing water balance between gauging stations. It is important to get the low flows right as salinities tend to be higher and tributaries can have a greater impact at these times.

- River cross-section, surface water level, groundwater level near the river, aquifer storage data and riverbed leakage properties could be used to model river-aquifer interaction (Figure 2.10 shows the locations where there is hydraulic connection between rivers and groundwater). This would enable the losses in the IQQM to be fine-tuned and give a better indication of salt entering the river from the groundwater.

- Measurements of soil salinity and groundwater salinity near the river will assist in identifying possible sources of salinity, from floodplain or directly from groundwater. This is important in the upstream catchments especially in the Severn-Macintyre rivers.

- Table of flow versus floodplain area could be incorporated in the lower reaches of the IQQM to model the increase in salinity due to evaporation from flooded areas during summer floods.

- Continuous EC data at storage inflow and at outflows will assist in modelling salinity behaviour in storages. Knowledge on changes in salinity due to changes in inflows and outflows will assist water resources managers in formulating the storage release rules.

- Estimate of inflows and salt loads from residual and ungauged catchments could be reviewed to consider local conditions like land use, soil properties and groundwater levels. Accuracy in the estimation of residual inflows reduces the uncertainty in estimating the losses and groundwater inflow within the river reach.

- Continuous flow and EC data from Queensland catchments contributing to the Macintyre and Dumaresq Rivers will provide information in estimating salt loads from NSW residuals.

7.4. MODEL UNCERTAINTY AND RECOMMENDED USE OF MODEL RESULTS

The issues of model uncertainty and how the model results might be used is important to understand. Whilst the models were derived using the best available information and modelling techniques having regard to financial and resource constraints, they nevertheless contain considerable uncertainties.

Uncertainty in the baseline conditions arises from two sources. Firstly, the model inputs, and secondly, the internal modelling processes which translate the model inputs into the model outputs. Whilst there is presently no clear indication of the uncertainty introduced by this latter mechanism, it is clear that there is very large uncertainty introduced into the model outputs by the model inputs.

In using the model results the following key issues should be considered:

- *absolute accuracy of the model results has not been quantified* — the model should be used cautiously because the uncertainty in results hasn't been quantified.

- *complexity of natural systems* — the natural systems being modelled are very complex and the salinity and to a lesser extent, the flow processes, are not fully understood. This makes modelling difficult.

- *lack of data, data quality & data accuracy* — in some locations there is a lack of comprehensive flow and salinity data. This makes calibration and verification of models difficult, and increases the uncertainty in the model results.

- *using models to predict the impacts of changes* — these types of models are most often used to measure the impact of changed operation or inputs. To do this, the difference between two model runs is determined. The 'relative accuracy' of the model used in this manner is usually higher than the 'absolute accuracy' obtained if the results of a single model run are compared with the real world.

- *flow ~ salinity relationships* — in nearly all cases the salinity inputs to the models have been derived from empirical relationships between salinity and flow. These relationships are approximate and whilst calibrated to the available data (i.e. to reproduce longer term salt loads), often confidence in the relationships is poor. However in the absence of further data collection and further scientific research, the relationships are probably the best available.

- *inappropriate use of model results* — models should not be used to 'predict' or back-calculate salinities (and to a lesser extent, flows), on any given day or longer time period. Rather, when viewed over the whole of the benchmark period, the model results provide a reasonable indication of the probabilities of obtaining flows of given magnitudes, and average salt loads, at key locations.

The above text was substantially taken from Bewsher (2004).

8. References

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Appendix A. Salinity data

Table A.8.1. NSW EC data in the Border Rivers valley

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
416001	Barwon River @ Mungindi	28.967	148.983	Continuous	1995-2001	2318
416001	Barwon River @ Mungindi	28.967	148.983	Discrete	1968-2002	654
416002	Macintyre River @ Boggabilla	28.600	150.367	Discrete	1976-2002	253
416003	Tenterfield Creek @ Clifton	29.033	151.717	Discrete	1970-2001	216
416005	Macintyre River @ Yetman	28.900	150.767	Discrete	1976-1988	70
416006	Severn River @ Ashford	29.300	151.117	Discrete	1970-1993	128
416007	Dumaresq River @ Bonshaw Weir	29.000	151.283	Discrete	1964-2002	264
416008	Beardy River @ Haystack	29.233	151.383	Discrete	1970-2001	205
416010	Macintyre River @ Wallangra	29.267	150.900	Discrete	1976-1993	79
416011	Dumaresq River @ Roseneath	29.133	151.450	Discrete	1964-2001	237
416012	Macintyre River @ Holdfast (Yelarbon Crossing)	28.800	150.733	Discrete	1976-2001	229
416014	Dumaresq River @ Mingoola	29.033	151.500	Discrete	1969-1981	77
416015	Severn River @ Llanarth	29.367	151.150	Discrete	1965-1988	129
416016	Macintyre River @ Inverell (Middle Creek)	29.800	151.133	Discrete	1976-1990	64
416018	Macintyre River @ dam site	29.067	150.917	Discrete	1976-1989	64
416019	Severn River @ Pindari	29.400	151.233	Discrete	1976-2001	1049
416020	Ottleys Creek @ Coolatai	29.233	150.759	Discrete	1970-1990	95
416021	Frazers Creek @ Ashford	29.350	151.100	Discrete	1964-1988	135
416022	Severn River @ Fladbury	29.517	151.700	Discrete	1970-1994	178
416023	Deepwater River @ Bolivia	29.300	151.933	Discrete	1970-1990	112
416024	Swan Brook @ Campbell	29.733	151.217	Discrete	1976-1988	70
416025	Beardy River @ Dakabin	29.367	151.617	Discrete	1969-1988	86
416026	Reedy Creek @ Dumaresq	29.067	151.517	Discrete	1976-1988	72
416028	Boomi River @ Neeworra	29.017	149.067	Discrete	1969-1989	73
416029	Boomi River @ Kanowna	28.700	149.367	Discrete	1969-1995	76
416030	Severn River @ Pindari Dam-Storage Gauge	29.400	151.250	Discrete	1976-1977	2
416031	Macintyre River @ Ridgelands	29.067	150.900	Discrete	1976-1981	40
416032	Mole River @ Donaldson	29.017	151.600	Discrete	1973-2001	195
416033	Beardy Waters @ Glen Legh Road	29.783	151.767	Discrete	1972-1991	100
416034	Croppa Creek @ Tulloona Bore	28.933	150.117	Discrete	1976-2000	13
416035	Macintyre River @ Elsmore	29.817	151.283	Discrete	1976-1987	62
416036	Campbells Creek near Beebo	28.717	150.883	Discrete	1976-1991	28

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
416037	Boomi River @ offtake	28.633	149.667	Discrete	1973-1989	67
416038	Macintyre River @ Boonal	28.717	150.533	Discrete	1976-1981	41
416039	Severn River @ Strathbogie	29.450	151.467	Continuous	1993-1998	1766
416039	Severn River @ Strathbogie	29.450	151.467	Discrete	1976-2001	202
416040	Dumaresq River d/s Glenarbon Weir	28.667	150.850	Discrete	1973-1978	12
416043	Macintyre River @ Boomi Weir	28.628	149.671	Discrete	1976-2001	157
416046	Macintyre River @ Boonanga Bridge	28.577	149.562	Discrete	1981-1984	7
416047	Macintyre River @ Terrewah	28.609	149.874	Discrete	1985-2002	58
416048	Macintyre River @ Kanowna	28.697	149.387	Discrete	1985-2002	95
416049	Dumaresq River @ Mauro	28.717	150.933	Discrete	1985-2002	152
416050	Barwon River @ Presbury Weir	29.124	148.802	Discrete	1989-1989	1
416051	Macintyre River @ Yarrowee	28.805	149.178	Discrete	1989-1989	1
41610001	Pindari Dam (Dam Wall) Station 1	29.388	151.246	Discrete	1980-2001	155
41610002	Pindari Dam (Dead Trees) Station 2	29.386	151.264	Discrete	1983-1995	108
41610003	Pindari Dam (Rockface) Station 3	29.399	151.277	Discrete	1983-2001	148
41610004	Pindari Dam (Inflow) Station 4	29.391	151.300	Discrete	1983-1992	212
41610005	Pindari Dam (Outflow) Station 5	29.400	151.250	Discrete	1994-2001	37
41610038	Dumaresq River @ Texas (Low Level Bridge)	28.873	151.163	Discrete	2000-2001	8
41610049	Macintyre River below Severn	29.102	150.951	Discrete	1997-1997	1
41610053	Severn River d/s Pindari @ road bridge	29.399	151.193	Discrete	2001-2001	5

Table A.8.2. QLD EC data in the Border Rivers valley

Station number	Station name	Lat. (S)	Long. (E)	Data type	Period collected	Number of data days
416303C	Pike Creek @ Glenlyon	28.850	151.467	Discrete	1960-1987	94
416305B	Brush Creek @ Beebo	28.683	150.983	Discrete	1963-1990	22
416306A	Pike Creek @ Pikedale	28.633	151.617	Discrete	1963-1992	6
416310A	Dumaresq River @ Farnbro	28.917	151.583	Discrete	1958-2001	243
416312A	Oaky Creek @ Texas	28.800	151.150	Discrete	1959-2002	133
416404C	Bracker Creek @ Terraine	28.483	151.267	Discrete	1961-1992	85
416407A	Canning Creek @ Woodspring	28.350	151.133	Discrete	1962-1993	16
416410A	Macintyre Brook @ Barongarook	28.433	151.450	Discrete	1963-2000	126
4163016	Pike Creek @ Glenlyon Dam 0.5km u/s	28.850	151.467	Discrete	1977-1997	56
4163017	Pike Creek @ Glenlyon Dam d/s of outlet	28.967	151.467	Discrete	1977-1986	14
4164053	Macintyre Brook @ Barongarook MRHI site	28.433	151.450	Discrete	1984-1988	4
416201B	Macintyre River @ Goondiwindi	28.533	150.300	Discrete	1958-1995	237
416202A	Weir River @ Talwood	28.483	150.250	Discrete	1967-1996	135
416303C	Pike Creek @ Glenlyon	28.850	151.467	Discrete	1960-1987	94
416307A	Dumaresq River @ Bonshaw Weir	28.983	151.267	Discrete	1965-1997	73
416402C	Macintyre Brook @ Inglewood	28.400	151.083	Discrete	1960-1999	300
416409A	Macintyre Brook @ Coolmunda Dam H/W	28.433	151.217	Discrete	1976-2000	180
416415A	Macintyre Brook @ Booba Sands	28.567	150.833	Discrete	1983-1995	138
4164042	Macintyre Brook @ Coolmunda Dam	28.433	151.217	Discrete	1963-1998	378
4164051	Macintyre Brook @ Inglewood Weir	28.400	151.083	Discrete	1972-1989	146

Appendix B. Salinity Audit comparison

B.1. COMPARISON OF FLOWS AND SALT LOADS WITH AUDIT RESULTS

The flow and salt load results from the 'first cut' model are tested for consistency with the Salinity Audit results by comparing these results to those published in Table 5.1 of the Salinity Audit. This test for consistency is necessary for confidence in the Border Rivers System IQQM, that it can reliably reproduce the peer reviewed and published results from the Salinity Audit, that have been used to develop Salinity Targets (NSWG, 2000a, 2000b).

In addition to the straight comparison, the effect of the modifications described in Section 5 were also compared. This was so the effect of these modifications could be quantified, and any differences explained in the event that Salinity Targets are revised as a result of these modifications.

The flow and salt load results from the model were extracted for all the nodes listed in Table 5.1 and Table 5.2, as well as for all gauge nodes corresponding to the balance points used for the Salinity Audit. Prior to the comparison, reporting some results had to be combined. In cases where more than one inflow node represented a Salinity Audit catchment (eg. Dumaresq River @ Roseneath (416011) and several of the residual catchments), the results were added. For all the residual catchments the results of flow and salt loads removed at the calibration nodes (shown at Figure 4.4-Figure 4.7), were subtracted to produce net flow and salt load for that catchment.

These results are summarised in Table B.8.3. The shaded rows in the Table B.8.3 represent Salinity Audit balance points, and the other rows represent inflow points.

Table B.8.3. Salt transport model results compared with Audit results

Audit inflow / balance point		Mean flow (GL/year)			Mean salt load ('000 t/year)				
Number	**Name**	*Audit*	*1*	*2*	*Audit*	*1*	*2*	*3*	*4*
416011	Dumaresq River @ Roseneath	*376.0*	426.2	420.5	*36.1*	42.7	42.0	39.3	39.1
416008	Beardy River @ Haystack	*66.7*	65.7	65.7	*5.3*	5.3	5.3	5.0	4.4
R5_NSW	NSW part of ungauged Dumaresq River between Roseneath and Bonshaw	*n/a*	22.5	22.4	*9.0*	7.3	7.4	6.9	5.4
R5_Qld	Qld part of ungauged Dumaresq River between Roseneath and Bonshaw	*n/a*	-3.0	-3.1	*1.4*	-0.2	-0.2	-0.2	-0.2
416007	**Dumaresq River @ Bonshaw Weir**	***436.8***	**504.3**	**498.4**	***46.3***	**53.6**	**53.0**	**49.7**	**47.6**
R6_NSW	NSW part of ungauged Dumaresq River between Bonshaw and the Macintyre River confluence	*n/a*	2.9	7.1	*8.7*	4.8	5.7	5.3	3.3
R6_Qld	Qld part of ungauged Dumaresq River between Bonshaw and the Macintyre River confluence	*n/a*	142.5	166.0	*43.8*[d]	30.2	34.5	32.4	32.5
416039	Severn River @ Strathbogie	*148.6*	147.6	151.3	*19.8*	19.7	20.2	18.9	18.9
R1	Ungauged Severn River u/s Pindari	*63.9*	41.0	40.8	*4.2*	4.6	4.6	4.3	4.3
416019	**Severn River @ Pindari**	***181.1***	**194.7**	**186.9**	***19.1***	**26.0**	**24.8**	**23.3**	**23.3**
416021	Frazers Creek @ Ashford	*65.1*	65.5	66.8	*12.7*	12.6	12.9	12.1	12.1
R2	Ungauged Severn River between Pindari and Ashford	*290.5*[a]	5.4	5.4	*1.1*	0.8	0.8	0.7	0.7
416006	**Severn River @ Ashford**	***267.9***	**265.4**	**259.0**	***28.0***	**39.4**	**38.5**	**36.1**	**36.1**
416010	Macintyre River @ Wallangra	*54.5*[b]	126.3	130.2	*21.3*	21.3	21.9	20.5	18.6
R3	Ungauged Severn and Macintyre Rivers u/s Holdfast	*205.2*	56.3	59.2	*11.8*	6.3	6.6	6.2	6.4
416012	**Macintyre River @ Holdfast**	***451.6***	**447.1**	**447.4**	***61.5***	**66.8**	**66.8**	**62.6**	**60.9**
416020	Ottleys Creek @ Coolatai	*12.9*	13.1	14.1	*4.0*	2.9	3.1	3.1	3.1
R4	Ungauged Macintyre River between Holdfast and the Dumaresq River confluence	*68.8*[c]	-29.7	-26.1	*1.9*	-4.1	-3.7	-3.5	-3.3
R_002 **	Losses between the Dumaresq-Macintyre River confluence and Boggabilla	*n/a*	-33.2	-35.6	*n/a*	-4.3	-4.7	-4.4	-4.3
416002	**Macintyre River @ Boggabilla**	***1017.0***	**950.9**	**976.1**	***142.1***	**134.5**	**139.3**	**130.6**	**126.3**

Notes:

(1). Direct comparison, same climate period, same conversion factor, and no concentration limit

(2). Different comparison period, same conversion factor, no concentration limit

(3). Different comparison period, lower conversion factor, no concentration limit

(4). Different comparison period, lower conversion factor, concentration limit

R1 = Inflows (304, 045) – Losses (308, 046)

R2 = Inflows (049) – Losses (174, 053)

R3 = Inflows (055, 062) – Losses (176, 060, 115)

*R4 = Inflows (070) – Losses (179,106)***

R5_NSW = Inflows (125) – Losses (half of 015)

R5_Qld = Inflows (126) – Losses (half of 015)

*R6_NSW = Inflows (020, 128, 026, 142) – Losses (half of 022, 029, 044)***

*R6_Qld = Inflows (188, 127, 189, 129, 226, 227, 229, 245, 131, 247, 238, 248, 136) – Losses (230, 246, 239, 242, half of 022, 029, 044)***

*** Part of R4, R6_NSW and R6_Qld = Inflows (nil) – Losses (184) – Effluent (067 Whalan Ck.)*

a *R2 mean flow of 290.5 GL/year is based on an erroneous run-off figure*

b *416010 mean flow of 54.5 GL/year is based on a possibly erroneous run-off figure*

c *R4 mean flow of 68.8 GL/year doesn't match that given in the Audit spreadsheet (the latter matches the IQQM flow)*

d *R6 flows are not given in the Audit Report, some doubt over equation used to estimate load*

B.1.1. Flow

B.1.1.1. Direct comparison

The direct comparison of the flows reported in the Salinity Audit and those used in IQQM shows that there are differences in many of the inflow balance points. Of the fourteen inflow points, four of the gauged inflows are within 2% of the reported Salinity Audit results, one gauged inflow is within 20%, and one gauged and four residual catchment inflows are over 20%. No results were given for the remaining four residual catchment inflows in the Audit. The IQQM results significantly underestimate the comparable Salinity Audit results for all the residual inflows, especially R4 where the IQQM net residual inflow is negative.

These results are not what were expected, as the flows should have been the same. The reasons for discrepancies for the gauged inflows are not apparent. Possible explanations include:

(i) Observed flows for 416011 Dumaresq River at Roseneath were used in the Salinity Audit, whereas modelled flows are reported here (a significant part of the catchment above Roseneath is modelled in IQQM).

(ii) Rounding errors when converting to mean annual runoff, and then back to volume.

(iii) Reporting in the Audit using only observed flow data, without gaps filled. (There is not sufficient detail in the report to assess if this is the case).

(iv) Changes to inflows used in IQQM as better data became available in HYDSYS, as may happen when rating tables are upgraded.

(v) Typographic error in the runoff figure for the case of 416010 Macintyre River @ Wallangra.

Possible explanations for differences in the residual inflows include:

(vi) Residual catchment inflows may have been revised since the model version used for the Salinity Audit was produced - the major difference being a change in the way losses from residual catchment inflows are treated in IQQM.

(vii) Typographic errors in the runoff figures for the case of R2 and possibly R4.

The results at the balance points are also slightly different between IQQM and the Salinity Audit. The differences in this case could be partially attributable to the former using observed data and the latter using modelled results based on the 1993/4 MDBMC Cap scenario.

B.1.1.2. Climatic period

The mean annual flows for the BSMS climatic period (01/05/1975-30/04/2000) are higher for ten of the fourteen inflow points than the mean annual flows for the Salinity Audit climatic period (01/01/1975-31/12/1995). This indicates that the additional period used for the BSMS is wetter on average than the preceding twenty-one years, a conclusion supported by the higher than average rainfall in the latter years at Boggabilla (Figure 2.7). The three inflows that were slightly lower on average were from residual catchments in the upper reaches of the Dumaresq and Severn Rivers. The catchments downstream of Bonshaw Weir and Pindari Dam appear to have had the biggest percentage increases. At Boggabilla, the BSMS benchmark period produced an average annual flow lower than that in the Audit by 4%.

B.1.2. Salt loads

B.1.2.1. Direct comparison

The direct comparison of the salt loads reported in the Salinity Audit and those calculated in IQQM shows that there are differences for most of the inflows and balance points, many of them quite significant. Of the fourteen IQQM inflow points, only four of the gauged inflows are within 2% of the reported Salinity Audit results and one gauged inflow and two residual inflows are within 20%. The remaining inflows, one gauged and six residual, differ by more than 20% whilst the net inflow loads for R4 and R5_Qld are actually negative.

The seven salt load inflow points which differ by more than 20% are all residual catchments, with the exception of 416020 Ottleys Creek @ Coolatai. The 27% difference in this case is puzzling as the annual flow volume is almost exactly the same as that given in the Audit report for this stream. It may be that the flow time series at this site is significantly different. The differences for the residual catchments are all quite high, ranging from 20-70%, and this magnitude difference could not be explained only by the revision in flow estimates for the IQQMs since 1999.

The probable reason for these differences is that the Salinity Audit relationships are applied to different time series. The basic equation for Model IIC calculates salt load using a linear relationship with flow (Equation B.1). Referring to Figure B.1, the Salinity Audit relationship would have been applied to the net residual inflows, ie. after flows removed by the calibration node were subtracted (Equation B.2). However, in IQQM the salt loads are calculated by applying the Salinity Audit relationship before flows removed by the calibration node are subtracted, and then salt loads removed by the calibration node are subtracted (Equation B.3). The salt load removed at the calibration node is not just the salt load from the residual catchment, but includes salt load from upstream. These differences in structure between the Salinity Audit and IQQM make it difficult to directly compare salt load inflows for residual catchments.

$$SL = \eta + \lambda Q \qquad \text{(B.1)}$$

$$SL_{resid} = \eta + \lambda(Q_{resid} - Q_{cal}) \qquad \text{(B.2)}$$

$$SL_{resid} = \eta + \lambda Q_{resid} - SL_{cal} \qquad \text{(B.3)}$$

Where: η, λ are salt load relationship parameters

*SL*__, *Q*__ are shown in Figure B.1.

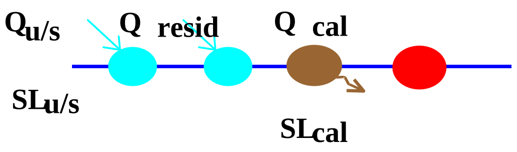

Figure B.1. Schematic for calculating net salt load inflow from residual catchments in IQQM

B.1.2.2. Climatic period

The mean salt loads for the BSMS climatic period (1975-2000) are about the same as that in the Salinity Audit (1975-1995). The extension of the climate period increased the salt load at Boggabilla by about 3%.

B.1.2.3. Conversion factor

Applying a lower EC→salinity conversion factor has a predictable effect, with the results shown in Column 3 of Table B.8.3 a constant ratio of 0.9375 (or 0.60/0.64) lower than those in Column 2 of Table B.8.3.

B.1.2.4. Concentration cap

Capping the salinity inflow concentration reduced the salt load inflows of some catchments. The results shown in Column 4 of Table B.8.3 reduced the mean salt load at Boggabilla by about 3%.

B.2. CONCLUSION

The direct comparison (same climate period) of mean annual <u>flow</u> results reported in the Salinity Audit and those from IQQM show huge differences at ungauged inflow points. However, the net difference at Macintyre at Boggabilla is approximately -6%.

The direct comparison same climate period, same EC→Salinity conversion factor, and no concentration cap) of mean annual <u>salt loads</u> reported in the Salinity Audit and those from IQQM showed some differences. The net difference at Macintyre at Boggabilla is approximately -5%. Some probable reasons for this were put forward. Some of this difference is because of differences in flows, as well as differences in the configuration of the residual catchments and the calibration nodes.

The net mean annual flows Macintyre at Boggabilla for the BSMS Benchmark climate period was 4% higher than that used in the Salinity Audit. The mean annual salt load was 2% lower than that used in the Salinity Audit.

These mean annual salt loads were then reduced by 6% using the lower EC→ Salinity conversion factor and a further 3% by adopting a realistic maximum concentration for the salinity inflows.

The net difference in mean annual salt loads (with all the modifications) is -11% (Macintyre at Boggabilla) compared with the Salinity Audit.

Appendix C. Method and results for Queensland part of Border Rivers

The parts of the Border Rivers catchment totally within Queensland were calibrated independently using different methods, and were also reported differently. This Appendix contains the work of Queensland Department of Natural Resources and Mines. Apart from some formatting changes, the text in this Appendix is unchanged.

C.1. RELIABILITY OF AVAILABLE DATA

The suitability of available data at each site was determined through the method developed in McNeil et.al. (2000), by considering the data and its distribution over time and ranges of flow (Figure C.1.1) and Table C.1.1.

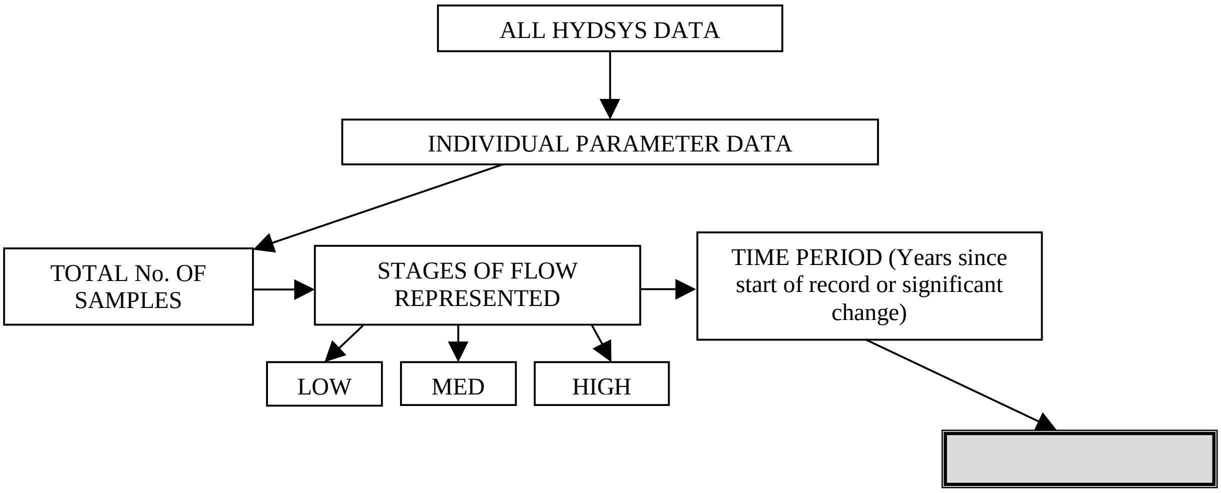

Figure C.1.1. Flow diagram for assessing site data reliability

Table C.1.1: Reliability of site assessment

Parameter type	Total no of samples	Stages of flow represented			Time period (*years since start of record or significant change*)	Reliability rating
		LOW	MEDIUM	HIGH		
ROBUST (eg. Salinity & Major Ions)	> 100	> 20	> 30	> 30	> 30 no major gaps	Excellent
	> 70	> 10	> 20	> 20	> 20 no major gaps	Good
	> 40	> 5	> 10	> 6	> 20	Moderate
	≤ 40	< 4	< 9	< 5	≤ 20	Poor
	<10			< 3	<5	Unrateable

C.2. MODELLING METHOD

The modelling methodology has been detailed in the following sections.

C.2.1. Flow Salinity Relationship Derivations

Plots of EC versus flow tend to show a great deal of scatter, because at most sites, there are multiple sources of variability so that the choice of an algorithm must be made subjectively on the basis of expected relationships. The corresponding processes are both natural and anthropogenic, and may vary over time. If major changes to drainage patterns have taken place during the sampling period, not only the parameters of the model may have changed, but the original algorithm used to create the model may also no longer be appropriate. Figure C.2.1 summarises some of the processes. In unregulated streams, change in concentration associated with discharge is usually the dominant time process, but other factors may play a strong role at particular sites, and if this is the case, a simple EC/Flow relationship may produce a poorly correlated model.

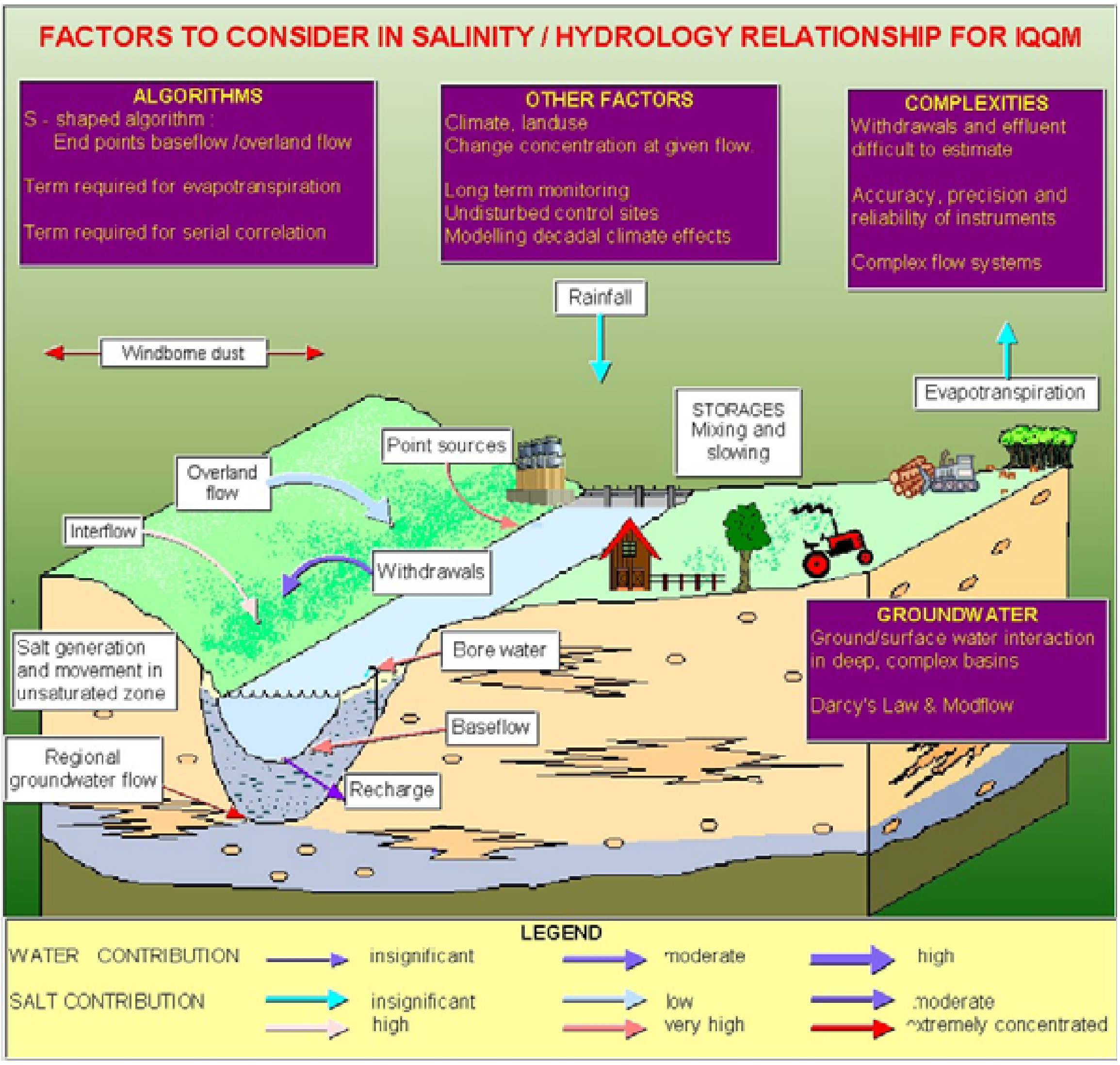

Figure C.2.1. Factors to Consider in Salinity/Hydrology Relationship for IQQM

There are a number of algorithms commonly used to model EC/Instantaneous Flow, depending on the processes assumed to be controlling the relationship. Most of these processes are nonlinear, and so cannot be satisfactorily modelled by simple regression. A dilution driven system indicates that an exponential algorithm can be used (Harned et al. 1981, Hirsch et al. 1982). Alternatively, a quadratic relationship based on log of flow and parameter concentration has been demonstrated by Yu and Neil (1993). This relationship produces a maximum salinity at intermediate rather than minimum flows, which allows for a more complex pattern of sources than merely dilution. Hirsch et al. (1982) also recommend a quadratic function where constituent loads increase dramatically with an increase in discharge during storm runoff. Other approaches involve smoothing using a robust algorithm such as LOWESS (Cleveland 1979), removal of flow weighted means, or including the flow as a regression term in parametric analyses.

However, Thorburn et al. (1992) proposed an algorithm (Equation C.2.1), which is suitable for streams running through alluvial valleys where ground and surface water interact. It is the model adopted for the analyses in this report as it accounts for baseflow and overland flow representing different sources of salt, with baseflow inevitably more saline, due to prolonged soil and mineral contact. Normal streamflow represents a mixture between the two. The algorithm produces a Z-shaped curve that is asymptotic to assumed baseflow as flow approaches zero, and approaches the salinity of overland flow at high flow exceedences.

$$EC = \frac{K1 - K2}{1 + K3Q^{K4}} + K2 \qquad \text{(Equation C.2.1)}$$

where K1 is the maximum EC under lowest flow conditions, K2 is the lowest EC in runoff, Q is the discharge, and K3 and K4 are constants relating to curvature.

However the EC/Flow relationship is estimated, it seldom accounts for the majority of the EC variability, especially in large and complex catchments. In particular, it cannot account for dynamic changes during periods of no flow. Such factors as serial correlation (Morton, 1997), and antecedent weather conditions discussed in a study of the autosensor data from Whyenbah and Chinchilla in the Condamine Balonne Report could be expected to be strong factors in determining the Border EC. At the Whyenbah site, the model was significantly improved by the incorporation of regression factors for monthly and annual flow volumes. Whilst these cannot be estimated with the present technology and dataset, they must be considered in reliability estimates, and suggest that an EC/Hydrology algorithm should be used, which can incorporate more than one process.

The relationships derived were input into IQQM. At the time of the writing, IQQM did not have the ability to enter flow/EC relationships using the Thorburn algorithm. The response of the Thorburn algorithm was simulated using a flow/EC relationship (see Chapter 5, Table 5.1 to Table 5.3).

With the EC relationships entered into the IQQM, it was possible to route the salt through the IQQM and compare the modelled salt concentrations with the recorded concentrations from discrete readings. In the IQQM, the salt in the stream was assumed to the perfectly mixed in solution both in streamflow and in storages.

When the concentrations in the model were compared with the recorded concentrations, it was poor. This poor comparison was due to the model taking account of dynamic changes in the streamflow already accounted for in the EC/flow relationship. This included processes such as periods of no flow, effect of waterholes and antecedent weather conditions. The effect on the salinity in the model was exaggerated by representing the effects in the salinity relationship and the model. .

The EC/flow relationships were modified to remove the effect of the processes that were represented in the model. This was carried out throughout the Border Rivers catchment between all gauging stations with recorded salinity readings. The EC/flow relationships at all of the tributaries in the model were modified if the fit with the recorded data was poor. In headwater catchments, generally the modification was minimal or not necessary due to the simplicity of the model in the reach. As the flow was routed further down the catchment, greater modification was necessary to the model to account for more observed drivers of salinity such as waterholes, evaporation, storage routing and periods of no flow.

C.2.2. TDI/EC Relationship Derivations

Once the EC/Hydrology relationship is established, the simulated EC time series must be converted to a salt concentration in order to calculate loads. As discussed in Webb (2002) and McNeil and Cox (2000), the relationship between EC and TDI or TDS depends on the concentration, valence and rate of movement of each ionic species. Reduction in mobility with increasing concentration means that the rate at which EC rises with flow will not be linear. Colloidal and suspended matter may also contribute to measured values of EC. Appropriate conversion factors should ideally be established for individual sites, but as this was not possible for the majority of the QMDB, the basin was divided into the 8 zones shown on Table C.2.1 based on climate, geology, and observed water chemistry as shown of Figure C.2.3, which also spatially defines the 8 zones.

There are several ways to define the relationship between EC and TDI. The linear regression approach, shown in Figure C.2.2 indicates good correlation overall, but there is a leverage effect caused by two distinct populations of widely differing salinity. Non linear approaches would also be affected to some extent by this dichotomy. It was therefore decided to base the relationship on the percentiles of TDI/EC ratios for individual samples, as shown in Table C.2.1. This excludes outliers, but allows for a broadbased ratio with an uncertainty factor.

All complete analyses with EC were used to estimate the TDI/EC relationship for the Border Rivers Catchment, as long as they passed data quality control checks. These included chemical balance in equivalents (CBE), using the Equation C.2.2 recommended by Freeze and Cherry (1979).

$$\%CBE = \frac{100 * \left(\sum z * m_c - \sum z * m_a\right)}{\sum z * m_c + \sum z * m_a} \qquad \text{(Equation C.2.2)}$$

where z = ionic charge (absolute value), mc = molalities of cation, and ma = molalities of anions.

The result was considered satisfactory if the %CBE was within 5 %, however for a variety of reasons, a large number of poor balances occur in the lower salinity ranges, particularly in samples where the TDI is less than 200 mgL$^-$1 (Fritz et al. 1990, McNeil 2002). Therefore, a tolerance of 10% was permitted within this range.

In addition, both TDS and TDI were recalculated, providing a useful check for transcription errors, and the EC distribution was plotted (Figure C.2.2) to detect any outliers, particularly among measurements unsupported by laboratory analyses. Despite the fact that there were two distinct populations, the higher salinity samples representing an ephemeral lake, the regression trend of the resulting set of paired TDI and EC records were considered to be of sufficient quality to be included with the corresponding data from throughout the QMDB for division into zones for the establishment of local TDI/EC relationships.

Table C.2.1. Summary of stream chemistry Zones to Define TDI/EC Ratios in Qld MDBC

Name	No of Samps	Percentiles EC/TDI			Median EC	Dominant Chemistry	Geology	Rainfall (mm)
		20	50	80				
1. Condamine US of Warwick, and northern tribs to and including Kings Ck	647	0.67	0.73	0.80	310	Na & Mg HCO3	Basalts and underlying sandstones	700 - 1100
2. Condamine from Warwick DS, all southern tribs of Condamine, Leslie Dam, and northern tribs west of Kings Ck	1650	0.61	0.66	0.72	419	NaCl	Basalts, sandstones & coal measures, granites & metas in SE, old & recent alluvium	600 -800
3. Upper Balonne to Beardmore Dam, including all tribs and Maranoa	332	0.69	0.76	0.82	170	HCO3, no dominant cation	Older alluvium, sandstones with duricrust	500 - 750

Name	No of Samps	Percentiles EC/TDI			Median EC	Dominant Chemistry	Geology	Rainfall (mm)
		20	50	80				
4. Beardmore Dam and Balonne/Culgoa River system DS	192	0.70	0.74	0.79	197	Similar to Zone 3, but more Cl	Recent alluvium, bordered and underlain by older alluvium	250 - 500
5. Warrego	187	0.75	0.79	0.82	200	Mixed, high SO4 in upper reaches	Recent alluvium, bordered by older alluvium & sandstone	300 - 700
6. Paroo	141	0.61	0.71	0.81	137	Similar to Zone 5, but SO4 more widespread	Sandstone with duricrust, some alluvials	200 - 400
7. Moonie	54	0.77	0.81	0.87	140	$NaHCO_3$ Relatively high SO4	Mainly weathered sandstones	450 - 650
8. Border Rivers	2495	0.64	0.68	0.73		Highly Variable	Mainly weathered sandstones downstream and granites upstream	

Figure 3.1 Relationship of TDI and TDS to EC in Paroo Catchment

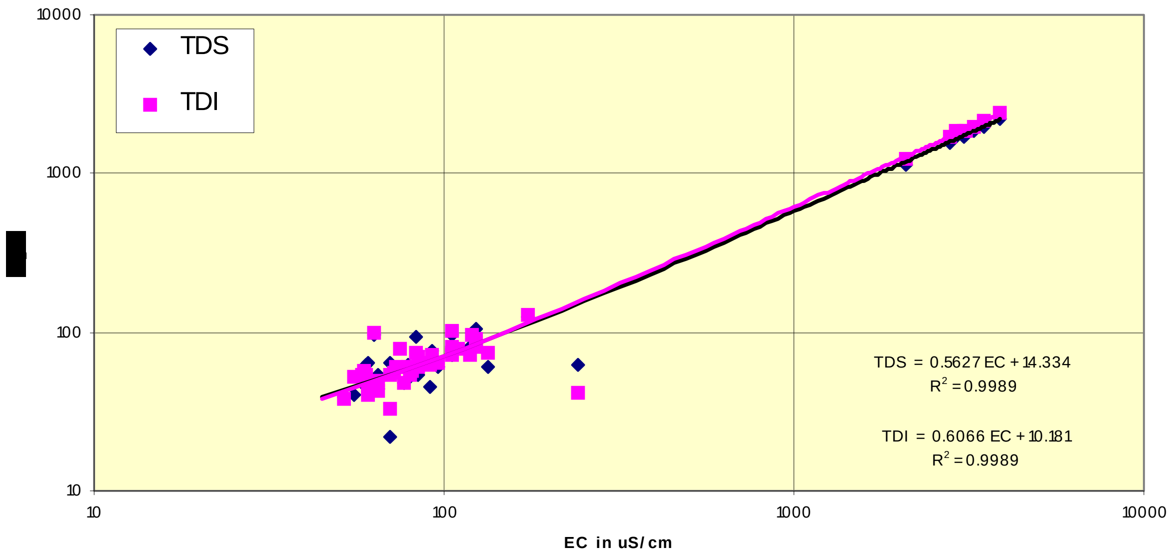

Figure C.2.2. Relationship of TDI and TDS to EC in Border Rivers Catchment