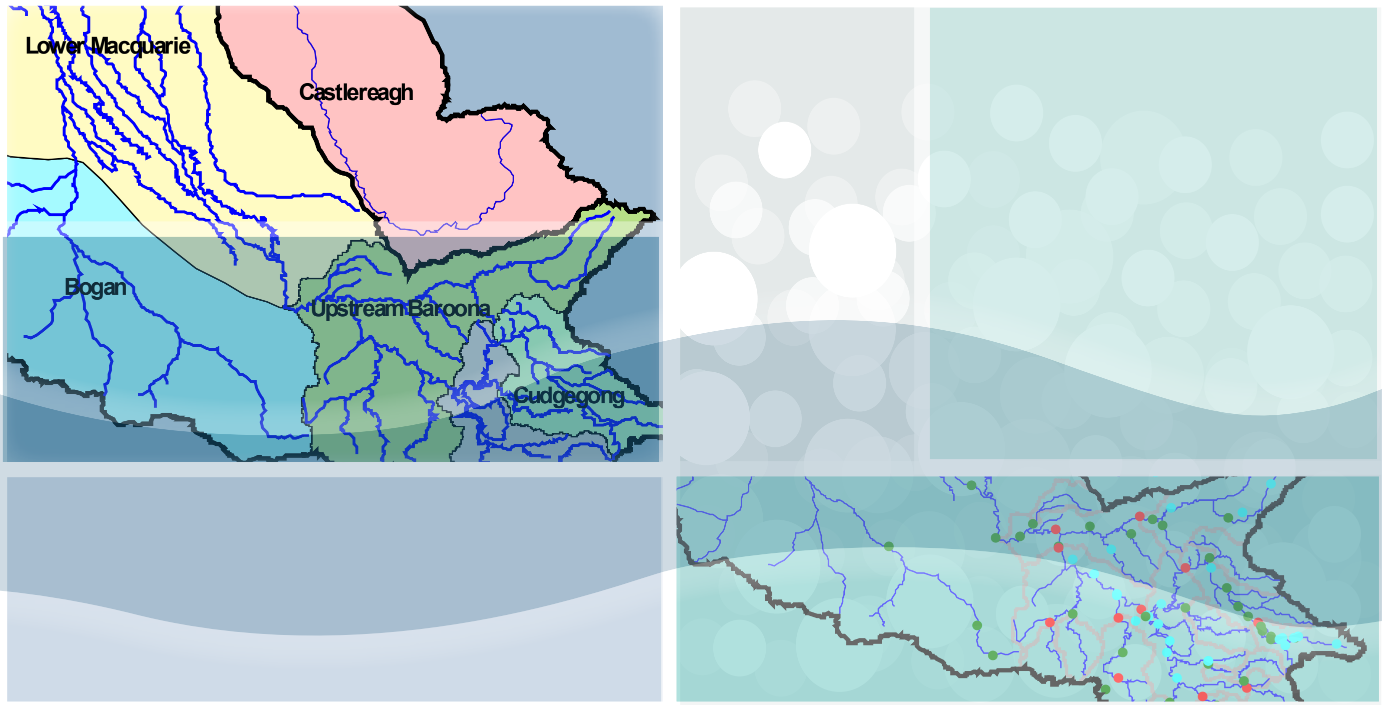
Instream salinity models of NSW tributaries in the Murray-Darling Basin

Volume 4 – Macquarie River Salinity Integrated Quantity and Quality Model



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Instream salinity models of NSW tributaries in the Murray-Darling Basin
Volume 4 – Macquarie River 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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1. Introduction

1.1. PURPOSE OF REPORT

The purpose of this report is to document the results of work carried out to develop a Macquarie River 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 Macquarie River 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 basin wide salinity management, which is discussed in Section 1.2. A number of basin wide and state-wide 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 Macquarie 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 Macquarie 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 the 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, land use, 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 sub catchments 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 basin wide policies developed through the MDBC, and State-wide 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 refer 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.

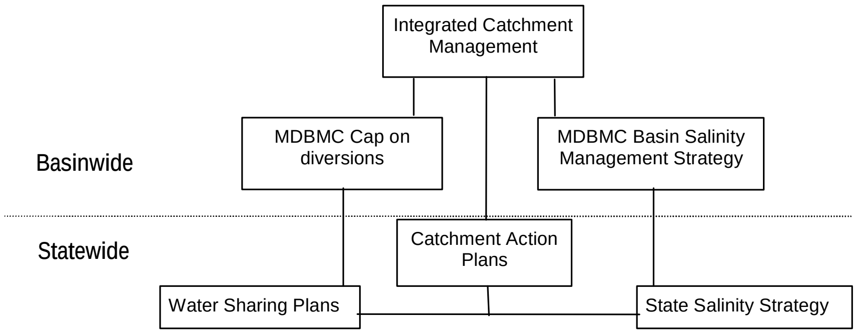


Figure 1.1. Relationship of Basinwide and Statewide policies and plans

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 linkage 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

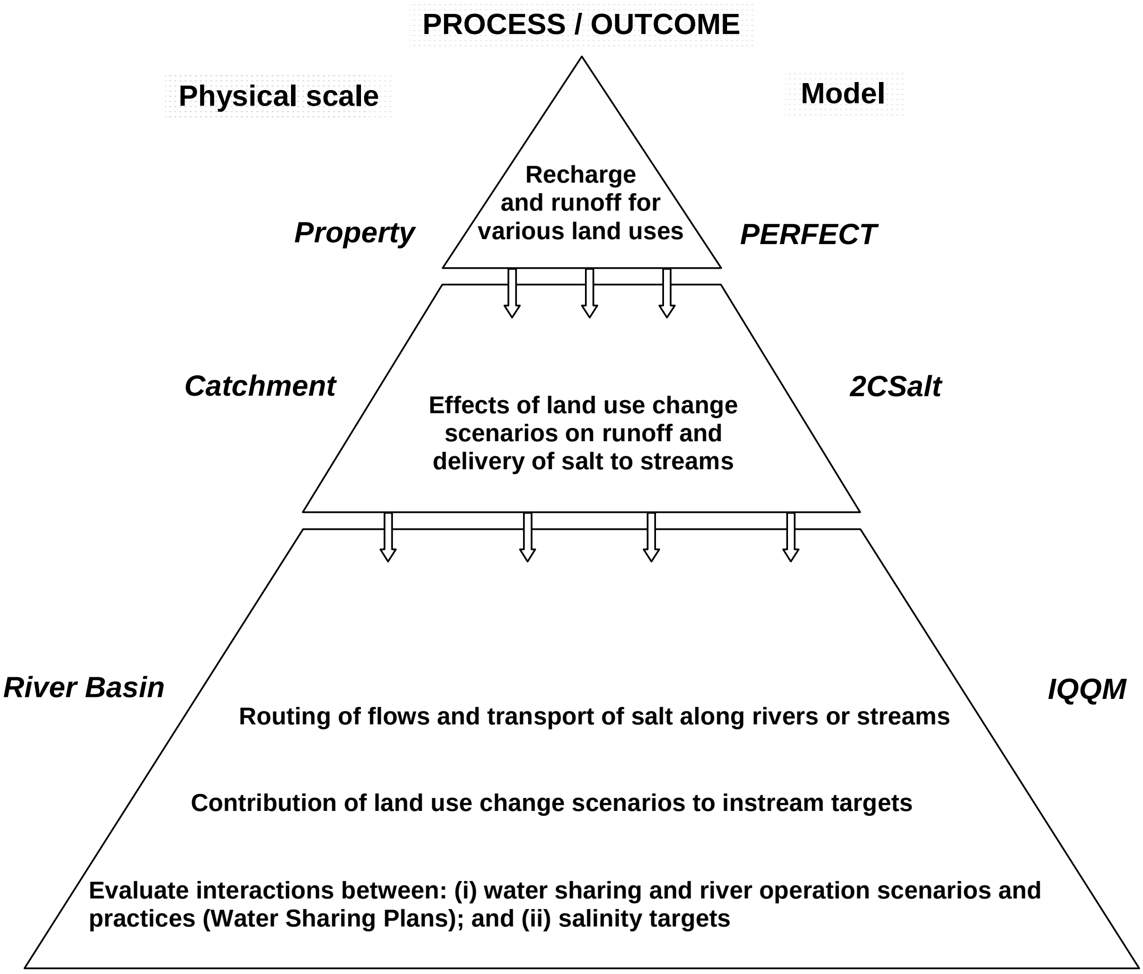


Figure 1.2. Applications and linkages of DECC and DWE models at different scales

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.

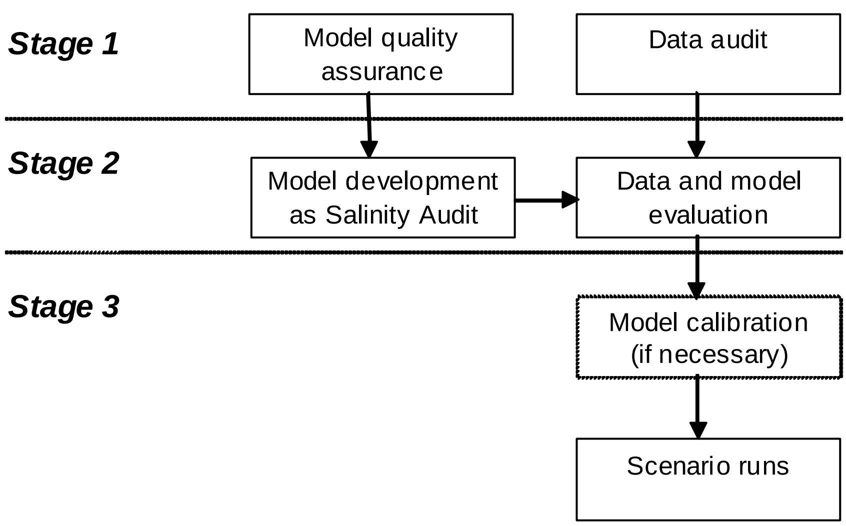


Figure 1.3. Stages of model development

1.5.1. Stage 1: Model QA and Data Audit

The existent IQQM that had been configured and calibrated for the Macquarie River 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 data bases. 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, and would have had the advantages of minimising to recalibrate the models, and also resulted in consistent outputs with those from 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.

(i) 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.

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

(iii) Time step: monthly were needed for the Salinity Audit, whereas daily are needed for the BSMS.

There are also important differences in the methods used:

(iv) 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.

(v) 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, and also 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 Macquarie-Bogan-Castlereagh System

2.1. PHYSICAL FEATURES OF THE CATCHMENT

2.1.1. General

The Macquarie-Bogan-Castlereagh system is one of the major NSW sub-catchments of the Murray-Darling Basin (Figure 2.1). It covers a total area of about 92,000 km^2 from the Great Dividing Range near Bathurst to the Barwon River near Brewarrina, 560 km to the north-west.

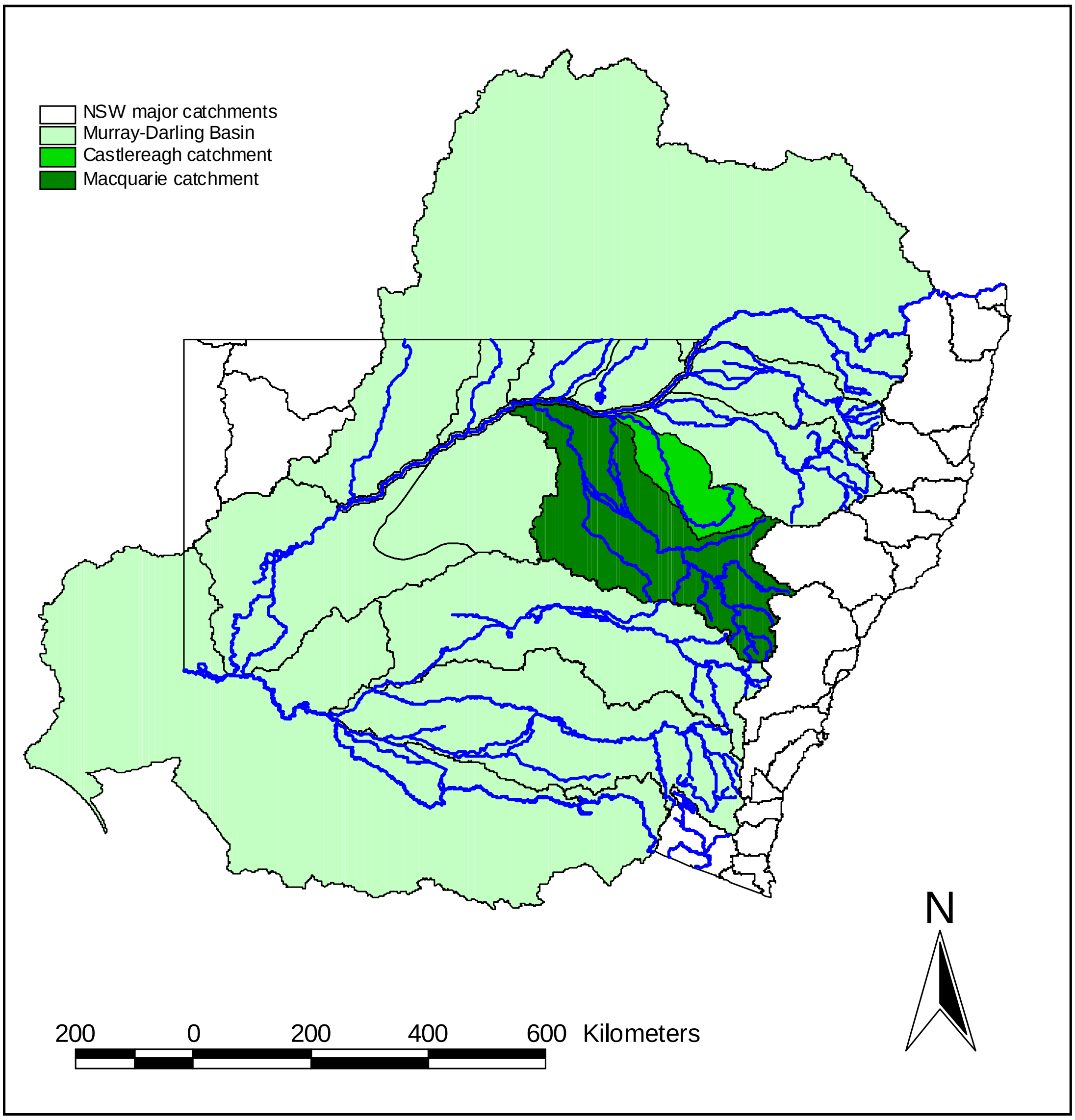


Figure 2.1. Relationship of Macquarie and Castlereagh catchments to Murray-Darling Basin

The Macquarie-Bogan-Castlereagh catchments include a number of small cities, including Dubbo, Orange and Bathurst, all with populations of about 30,000 people (Figure 2.2). There are also a number of towns, with populations ranging from 600-8,000 people. The total urban population in the Macquarie-Bogan-Castlereagh catchment is over 130,000 people.

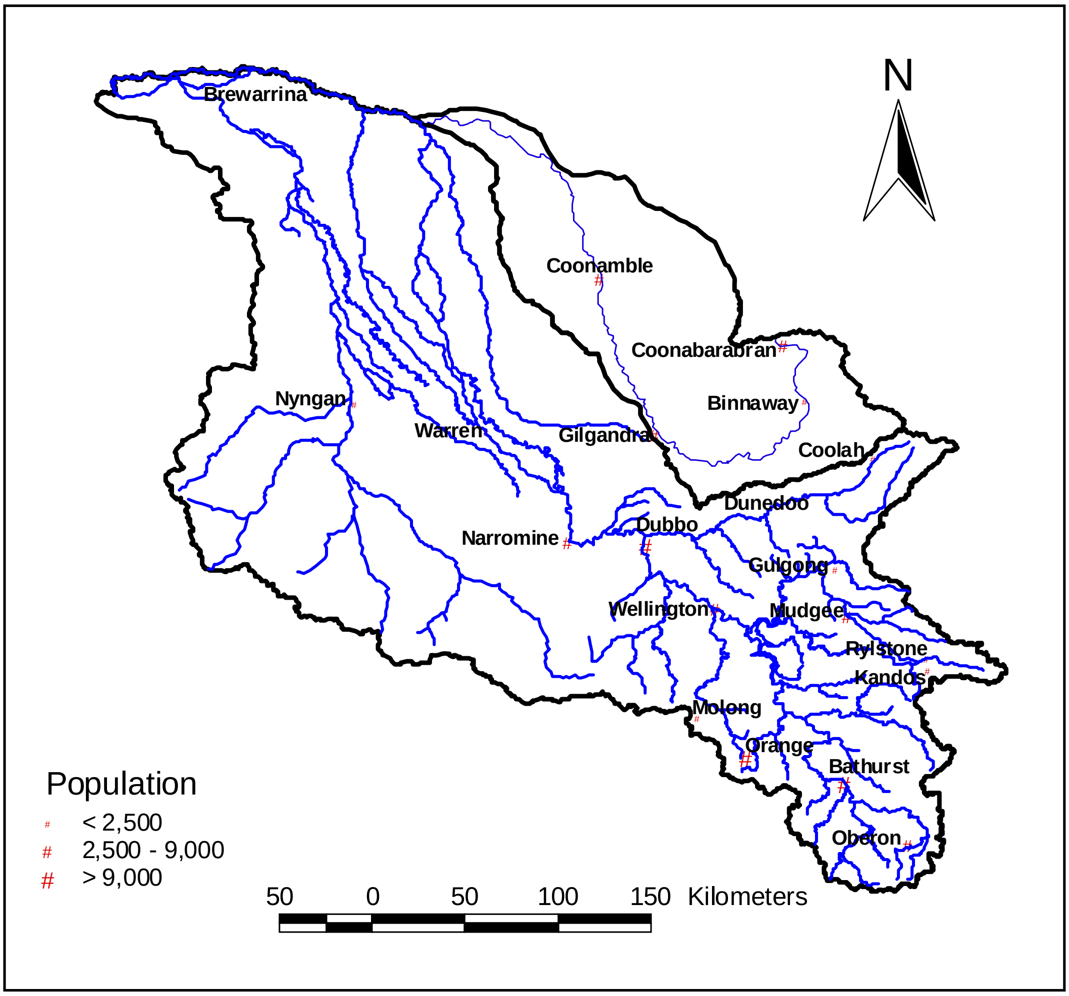


Figure 2.2. Cities and towns in Macquarie-Bogan-Castlereagh catchments.

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

(i) Cudgegong River (source region)

(ii) Macquarie River upstream of Burrendong Dam (source region)

(iii) Macquarie River from Burrendong Dam to upstream of Baroona (source and extraction region)

(iv) Upper Bogan River (source region)

(v) Lower Macquarie, including effluent streams and Macquarie Marshes (extraction region)

(vi) Castlereagh River (source region)

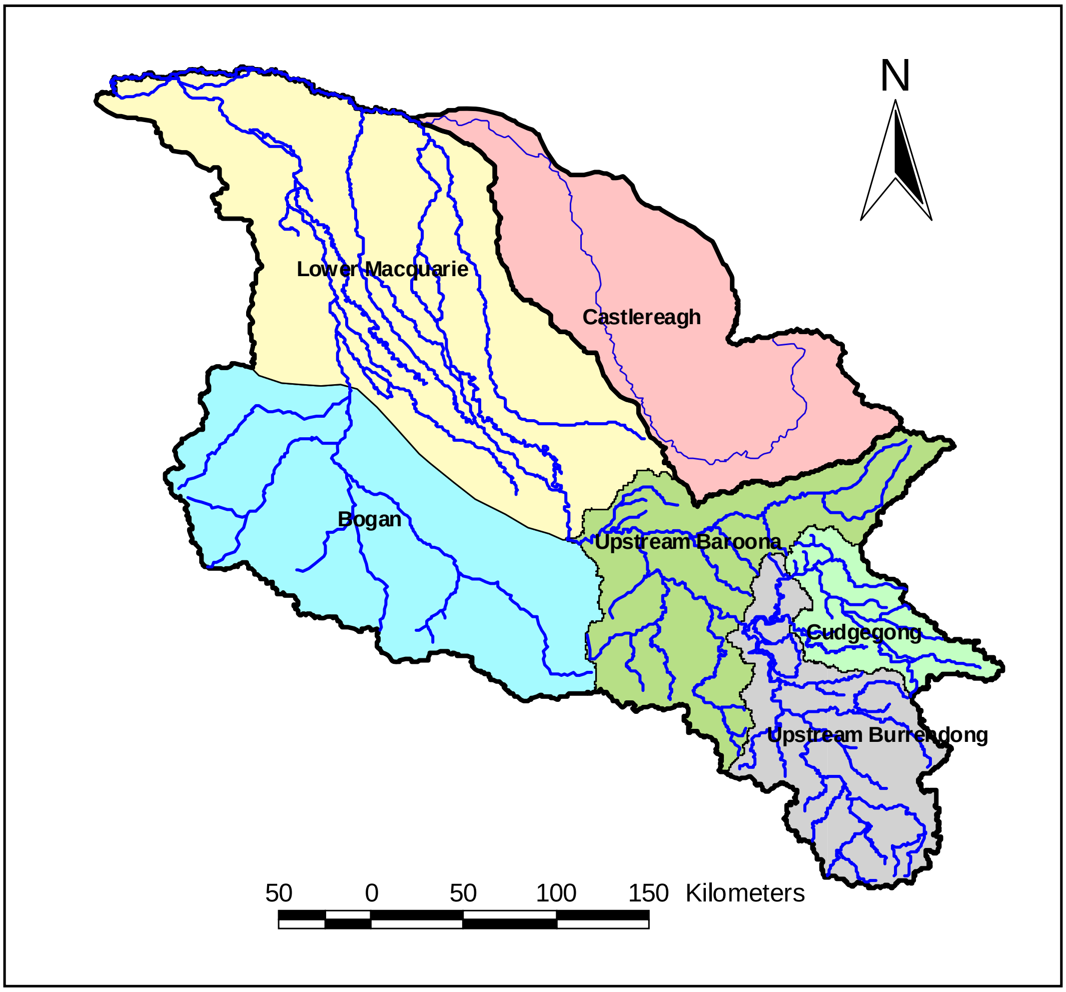


Figure 2.3. Major regions of Macquarie Catchment

2.1.2. Stream network

2.1.2.1. Macquarie River upstream of Burrendong Dam

The Macquarie River rises in the Great Dividing Range near Bathurst and flows north-west into Burrendong Dam. Major tributaries in this reach include Campbells, Fish, Turon and Crudine Rivers; Queen Charlottes and Lewis Ponds Creeks; and Winburndale Rivulet. There are also numerous small creeks. The rivers in this reach flow within well-defined channels and have only limited floodplains.

2.1.2.2. Cudgegong River

The Cudgegong River starts in the Great Dividing Range above Rylstone, flowing west into Windamere Dam. Below Windamere Dam the river continues into Burrendong Dam. Three major tributaries: Lawsons, Wyaldra and Meroo Creeks flow into the Cudgegong between Windamere and Burrendong Dams. The upper reaches of the Cudgegong River flow through narrow valleys, broadening into wide alluvial floodplains below Mudgee.

2.1.2.3. Macquarie River from Burrendong Dam to upstream of Baroona

The Macquarie River flows north-west from Burrendong Dam within a large natural channel, and is joined along the way by the Bell, Little and Talbragar Rivers, and Coolbaggie Creek, as well as numerous small ungauged creeks.

2.1.2.4. Bogan River

The Bogan River starts near Peak Hill and flows north-west to Nyngan. The western side of the catchment is drained by four major tributaries: Bullock, Bulbodney, Pangee and Whitbarrow Creeks. The eastern catchment between the Bogan and Macquarie Rivers is ill-defined and has only one major tributary: Mulla Cowal with a catchment area of 1,000 km^2. The total catchment area of the Bogan River upstream of Nyngan is approximately 18,000 km^2.

2.1.2.5. Lower Macquarie

From Baroona, the Macquarie River flows north-west to join the Barwon River between Walgett and Brewarrina. Three major tributaries flow into the Macquarie in this section: Ewenmar Creek upstream of the Marshes; Marthaguy Creek; and the Castlereagh River downstream of Carinda. The stream network in this section is characterised by numerous effluent channels. Between Marebone Weir and Carinda the river flows for 120 km through a meandering network of effluent channels and anabranches that form the Macquarie Marshes. The Marshes are a large and diverse system of wetlands with an area of approximately 200 000 ha, although the size of the wet area varies from 1,000 ha in dry periods to 300,000 ha during major floods. The Bogan River continues below Nyngan, to join the Barwon River between Brewarrina and Bourke.

Effluent streams in this region include the Albert Priest Channel, Gunningbar Creek and Duck Creek which flow west into the Bogan River; Terrigal Creek which flows east into Marthaguy Creek; and Crooked and Marra Creeks which converge and flow north into the Barwon River. There are no major tributaries in this reach although the lower Bogan River does receive water from the Macquarie River via the Albert Priest Channel, Gunningbar Creek and Duck Creek.

2.1.2.6. Castlereagh River

2.1.3. Hydrometeorology

2.1.3.1. rainfall

Average annual rainfall in the Macquarie catchment ranges from over 1200 mm in the south-east to less than 250 mm in the north-west (Figure 2.4). Rainfall is fairly uniform throughout the year (Figure 2.5), with a slight maximum in summer. 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, and the third quarter had extended periods of higher than average rainfall. The BSMS Benchmark Climatic period in the fourth quarter has about average rainfall over the whole period, while sampling droughts such as 1979-1983, and short wet periods. These can be seen in the detailed annual total rainfall over the Benchmark Climatic period at Dubbo (Figure 2.7).

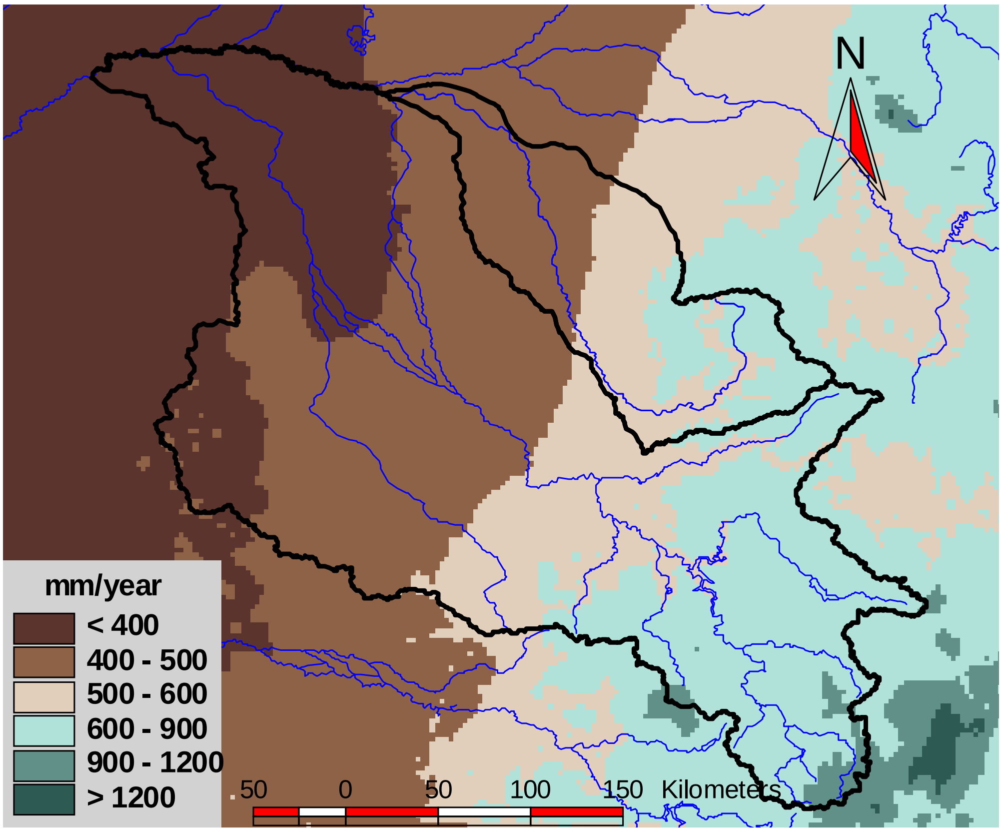


Figure 2.4. Average annual rainfall in Macquarie-Castlereagh-Bogan catchment

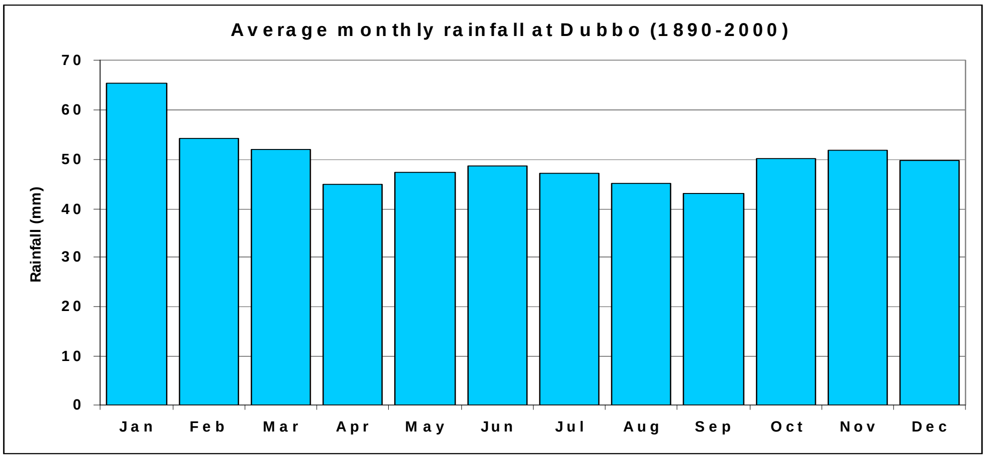


Figure 2.5. Average monthly rainfall at Dubbo 1890-2000.

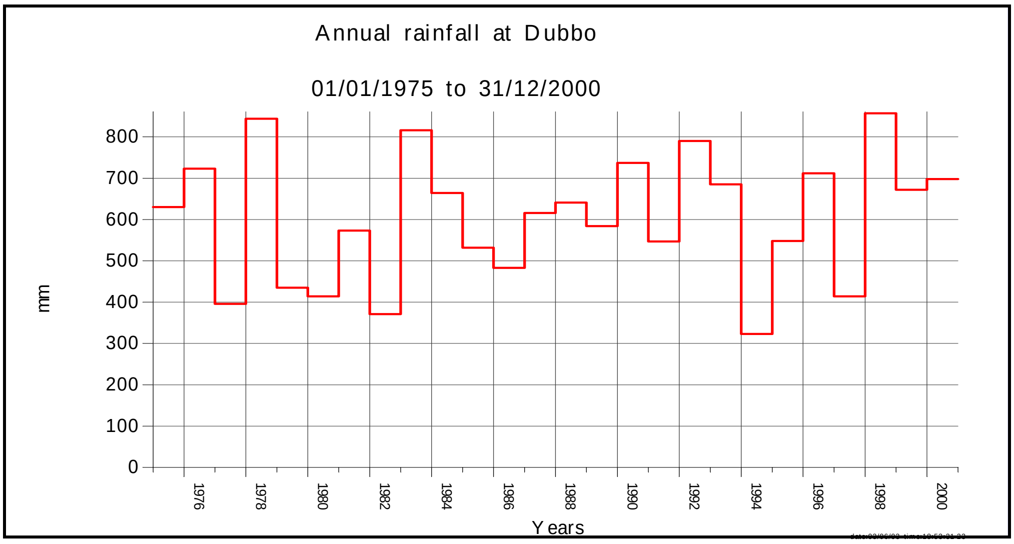


Figure 2.6. Residual mass curve of rainfall at Dubbo

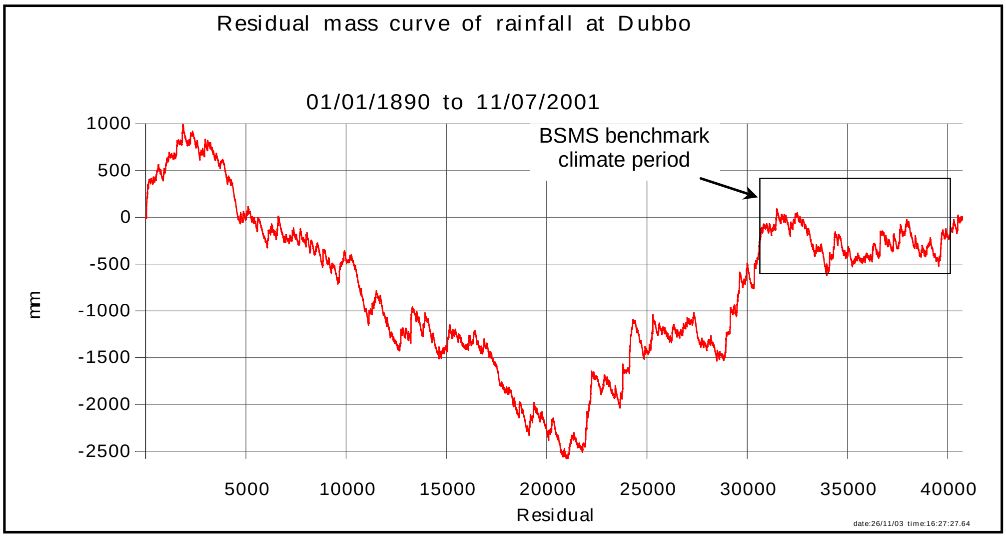


Figure 2.7. Annual rainfall at Dubbo 1975-2000

2.1.3.2. Evaporation

Pan evaporation in the Macquarie-Castlereagh-Bogan catchment has a strong east-west gradient (Figure 2.8). Average Class A pan evaporation varies from around 1000 mm/year in the south-east, to over 2200 mm/year in the north-west. Pan evaporation is also strongly seasonal, varying from 1 mm/d during July at Wellington, to 5.8 mm/d during January.

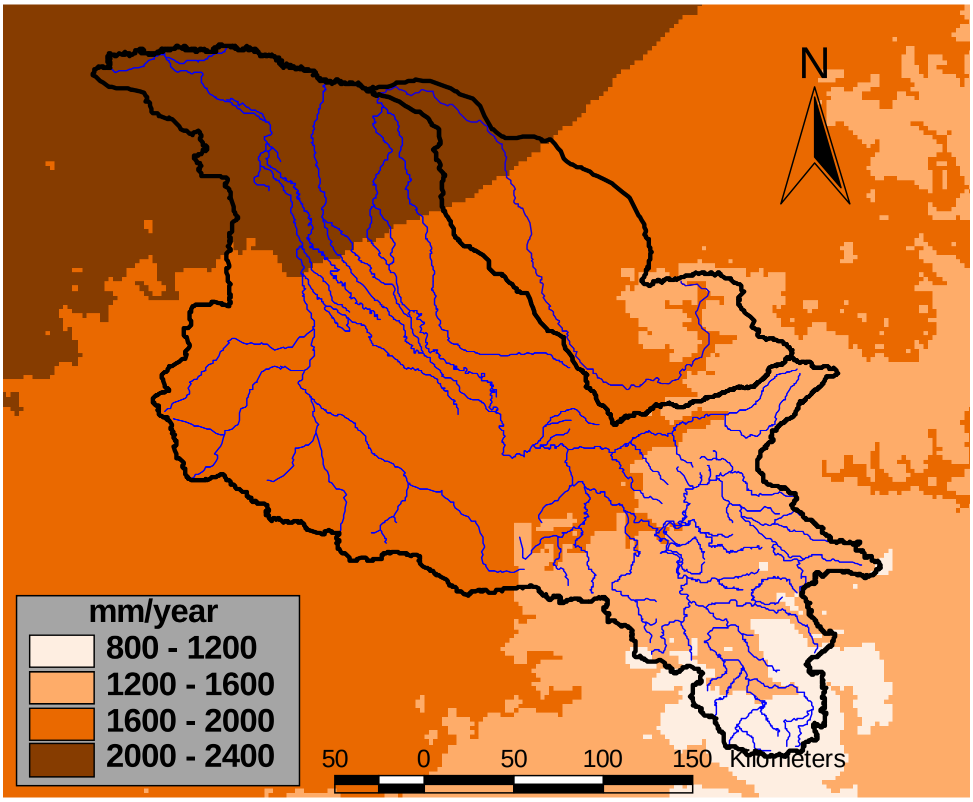


Figure 2.8. Average annual Class A Pan evaporation in Macquarie-Castlereagh Valley (1973-1995)

2.1.3.3. Flow

The following table outlines average annual flows from the major catchments in the Macquarie catchment.

Table 2.1. Average annual flows in Macquarie (1890 – 2000)

Tributary / catchment	Average annual inflow (GL/year)
Burrendong Dam inflows	1061
Bell River	116
Little River	39
Buckinbah Creek	23
Talbragar River	58
Coolbaggie Creek	26

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 Macquarie R. 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. Salt can also leave the river system to the groundwater by recharge.

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.

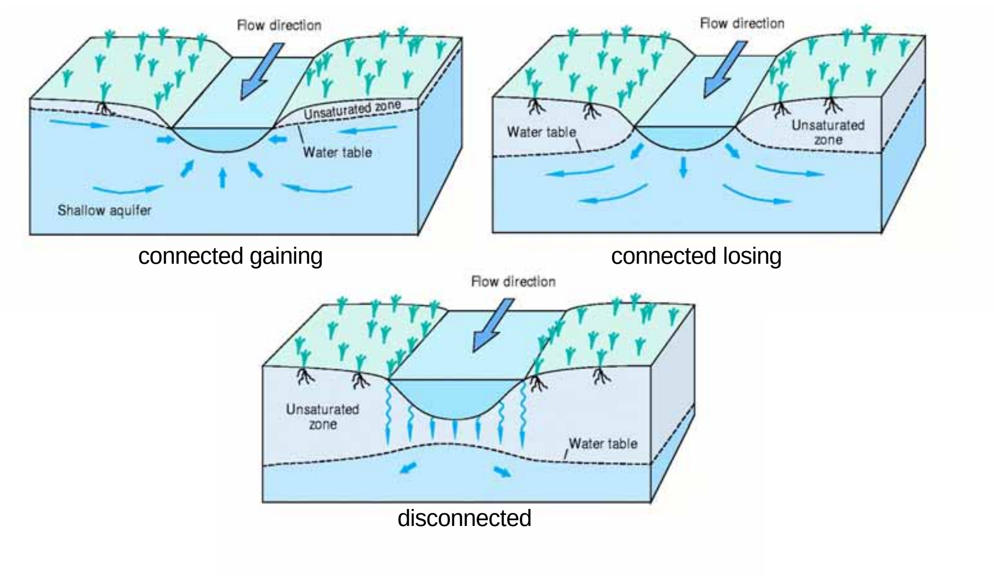


Figure 2.9. Types of river reach with respect to groundwater interaction
(*after Braaten and Gates, 2002*)

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 high 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 Macquarie R. between Burrendong Dam and Gin Gin, and the lower Bogan R. However, the lower reaches of the Castlereagh R. and Macquarie R., including the distributive channels of the Marshes, are atypical as they are hydraulically connected, with the direction of flux varying over time.

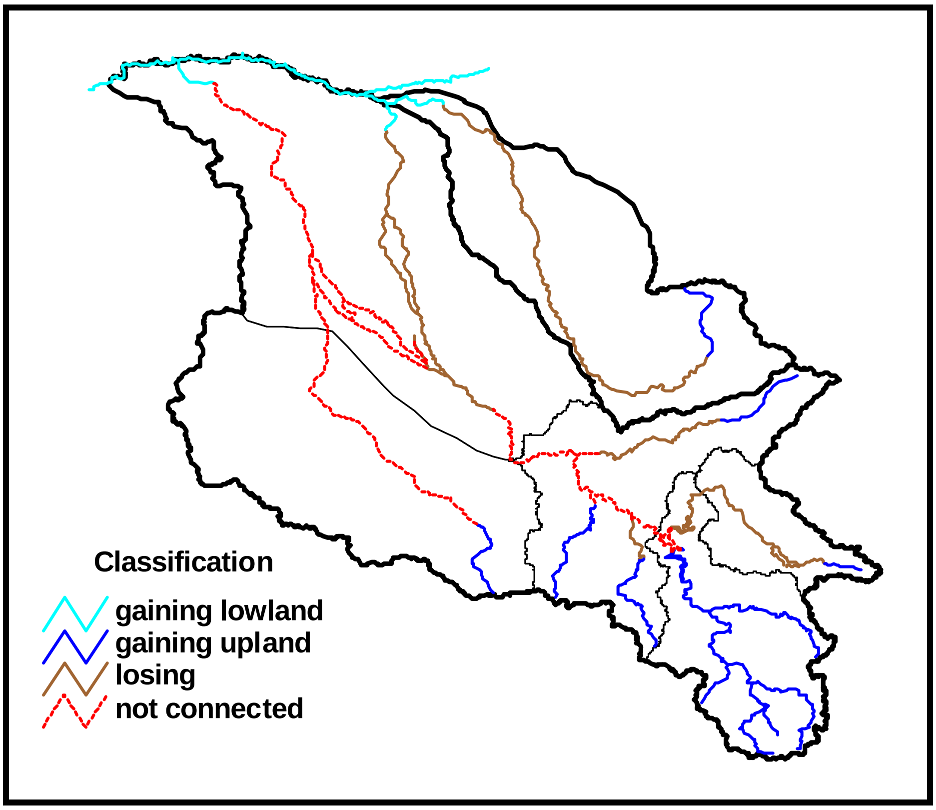


Figure 2.10. Hydraulic connection between rivers and groundwater

2.1.5. Land Use

Land use in the Macquarie-Castlereagh-Bogan catchment is dominated by extensive agriculture (Table 2.2) with nearly three-quarters of the catchment used for grazing, and a most of the remainder for dryland crops. Irrigated crops, while economically important, cover less than one percent of the catchment area, and forests and conservation areas combined about seven percent.

The grazing land is distributed throughout the catchment, and features heavily in all the regions (Figure 2.11). Dryland agriculture is mostly downstream of Burrendong Dam, with a heavy distribution through the mid-Castlereagh, and the Lower Macquarie region. The larger irrigation areas are also located in this Lower Macquarie region, with areas of horticulture and viticulture in the Upper Macquarie and Cudgegong regions. Forest areas are concentrated in the Upper Macquarie Region, the upper part of the Bogan Region, and a large area in the Warrumbungle Ranges, north-east of Dubbo.

Table 2.2. Land use statistics for Macquarie-Castlereagh-Bogan catchment

Land use description	Area ('000 ha)	Proportion of total Area (%)
Nature conservation / minimal use	357	4
Grazing	6407	69
Forestry	260	3
Dryland agriculture	2101	23
Irrigation agriculture	60	1
Build environment	15	< 1
Water bodies	19	< 1

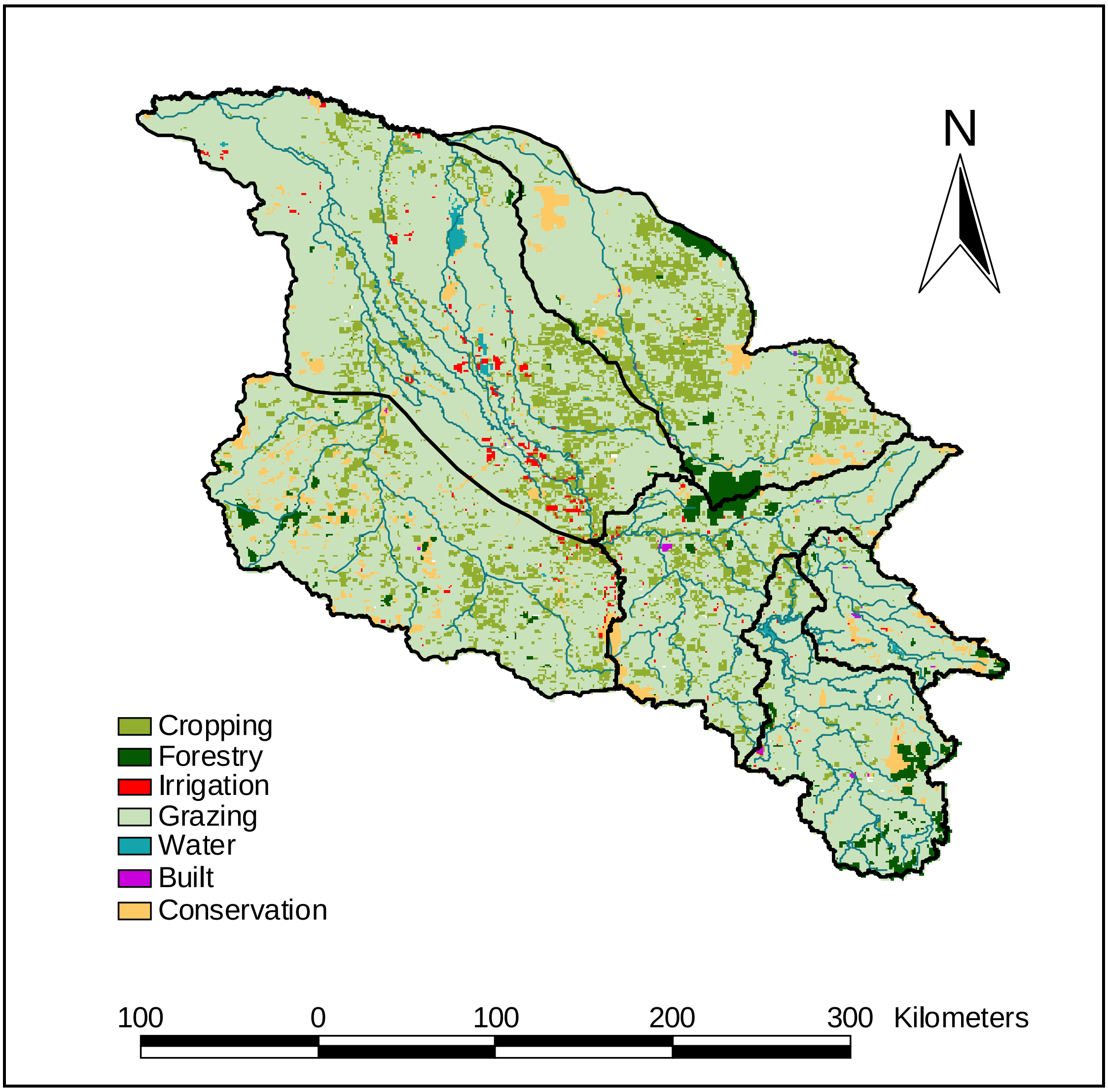


Figure 2.11. Landuse in Macquarie-Bogan-Castlereagh catchment

2.2. WATER RESOURCE MANAGEMENT

Much of the water resources in the Macquarie-Bogan-Castlereagh catchment are regulated, with runoff from the Upper Macquarie and Cudgegong catchments stored in Windamere and Burrendong Dams, and released from these storages for extractive and in-stream uses. Windamere Dam supplies water for irrigators along the Cudgegong, as well as to supplement water in Burrendong Dam, to ensure downstream demands are met. Burrendong supplies water to irrigators and towns downstream. Water is released from both 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 Castlereagh River and Bogan River are unregulated.

2.3. SALINITY IN CATCHMENT

Known occurrences of dryland salinity in the Macquarie-Bogan-Castlereagh catchments as identified by aerial photo interpretation are shown in Figure 2.12. These are heavily concentrated in the upper part of the Cudgegong Region, in the Pyramul Creek catchment in the Upper Macquarie Region, and throughout the Talbragar River and Little River and Buckinbah Ck catchments in the u/s Baroona Region.

Salt loads from subcatchments in the Cudgegong, Upper Macquarie, and u/s Baroona regions were estimated as part of the Salinity Audit (Beale et al., 1999), and are mapped in Figure 2.13. This distribution of salt loads has interesting features compared with the mapped occurrences of dryland salinity in Figure 2.12. For example Talbragar River and Little River seem to have low export rates, even though there are a number of occurrences of dryland salinity in these catchments. These would probably be explained as salt loads are the product of flow and salinity, and these catchments have lower rainfall (Figure 2.4) and probably lower flow compared with catchments to the east. The low export rate from the Cudgegong River would need additional investigation. The high export rate from Pyramul Creek is consistent with the concentration of dryland salinisation and high flows from this catchment.

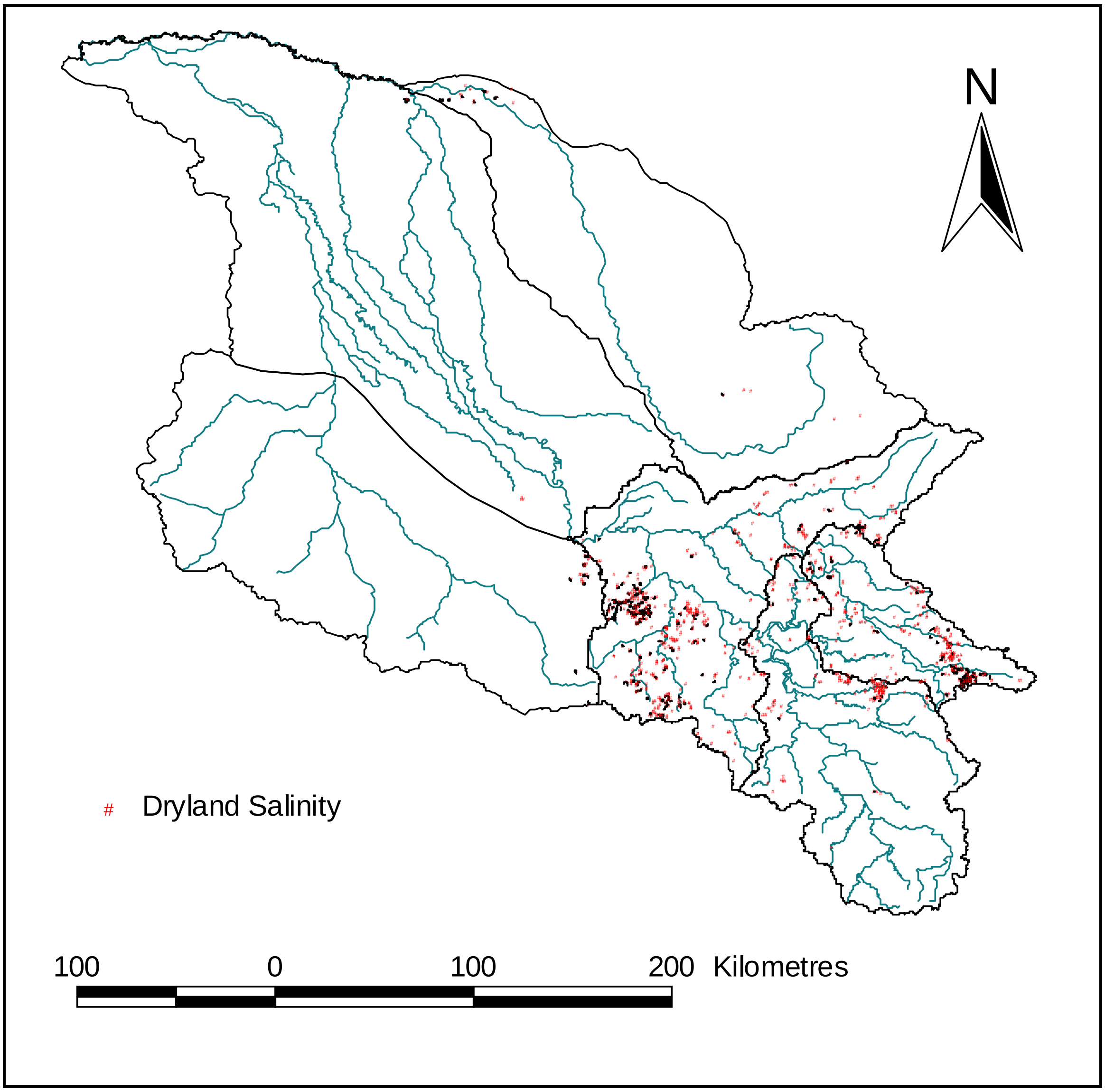


Figure 2.12. Dryland salinity occurrences in Macquarie-Bogan-Castlereagh catchment (mapped pre-1999)

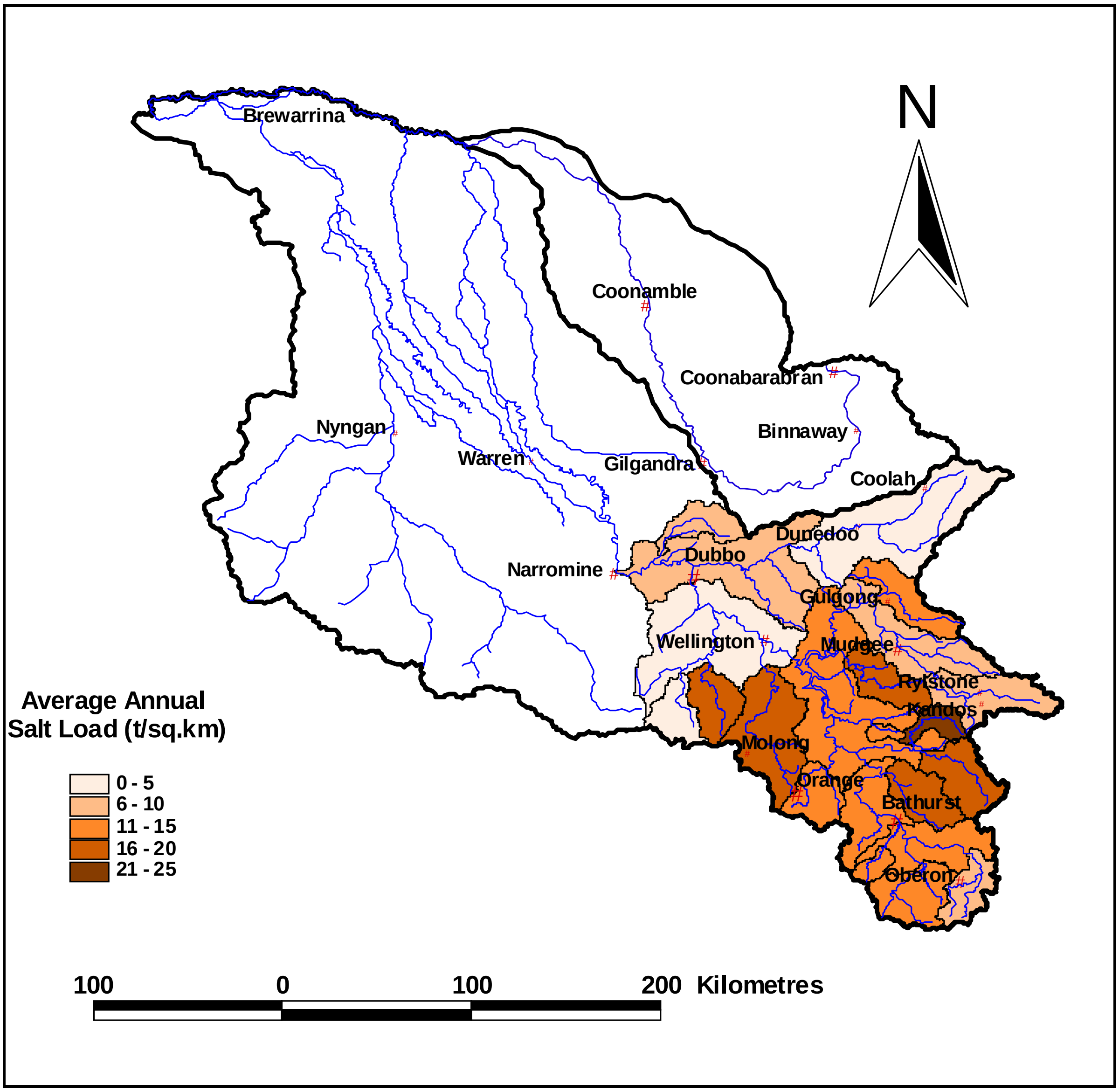


Figure 2.13. Modelled average annual salt export rates (tonnes/km^2) from Macquarie River catchments.

3. Salinity data

3.1. AVAILABLE DATA

All data for the Macquarie-Castlereagh-Bogan catchment was extracted from the DWE databases and tabulated in Appendix A. The distribution and relative length of the data is shown in Figure 3.1 for discrete EC data stations and Figure 3.2 for continuous EC data stations.

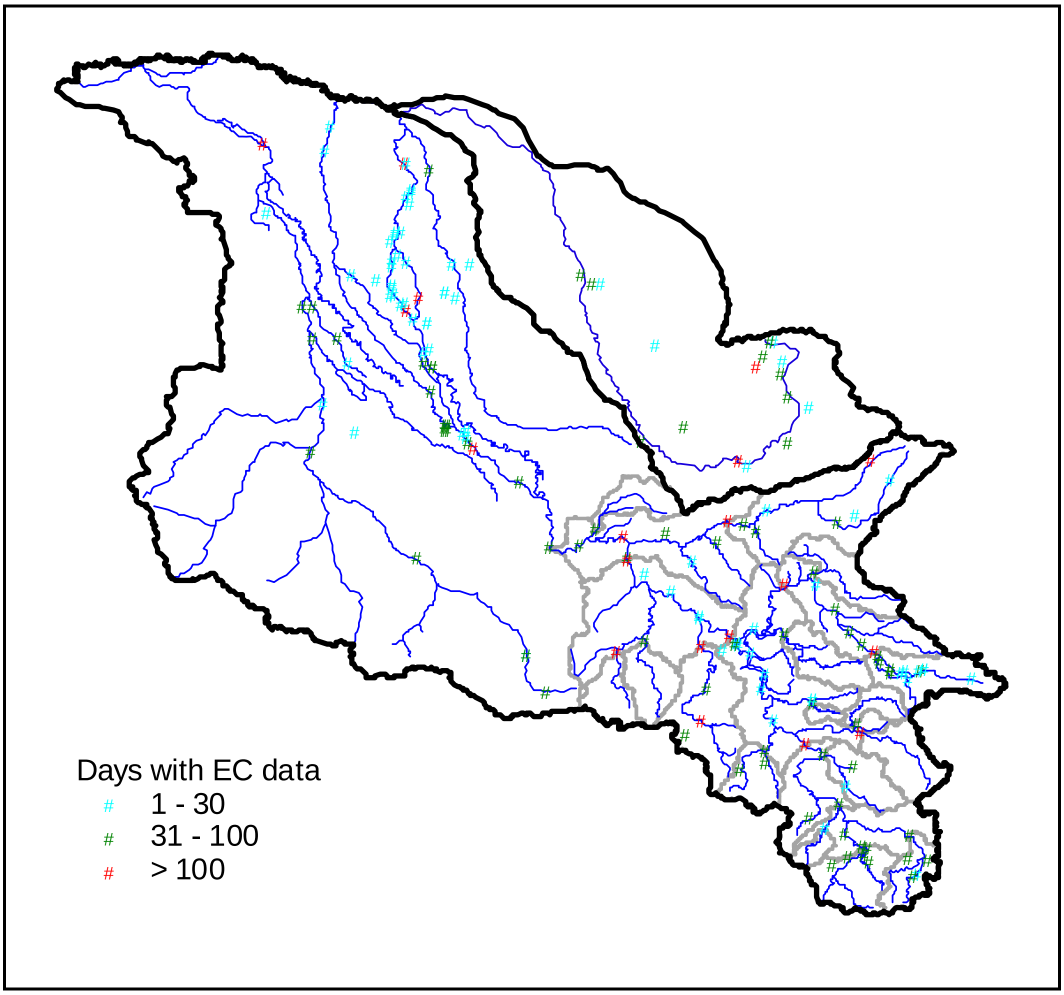


Figure 3.1. Location and record length size for discrete EC data stations

The legend used in Figure 3.1 and Figure 3.2 is indicative of the usefulness of the data for modelling purposes. Based on experiences a discrete data set with < 30 data points is of little value, from 30-100 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 168 total reported in Appendix A, 46% have less than 30 data points, and 11% have more than 100 data points. Many of these data sets with a small number of points are concentrated along the Macquarie River and in the Macquarie Marshes Region, ie most of the catchment has poor data. The other data sets look to give a good coverage across the whole catchment, although the Upper Macquarie Region does not appear to have many data sets with more than 100 points, especially in the headwaters, and between Bruinbun and Burrendong Dam. The data coverage in the Bogan River system is also quite sparse, and may reflect the percentage of time this river system flows.

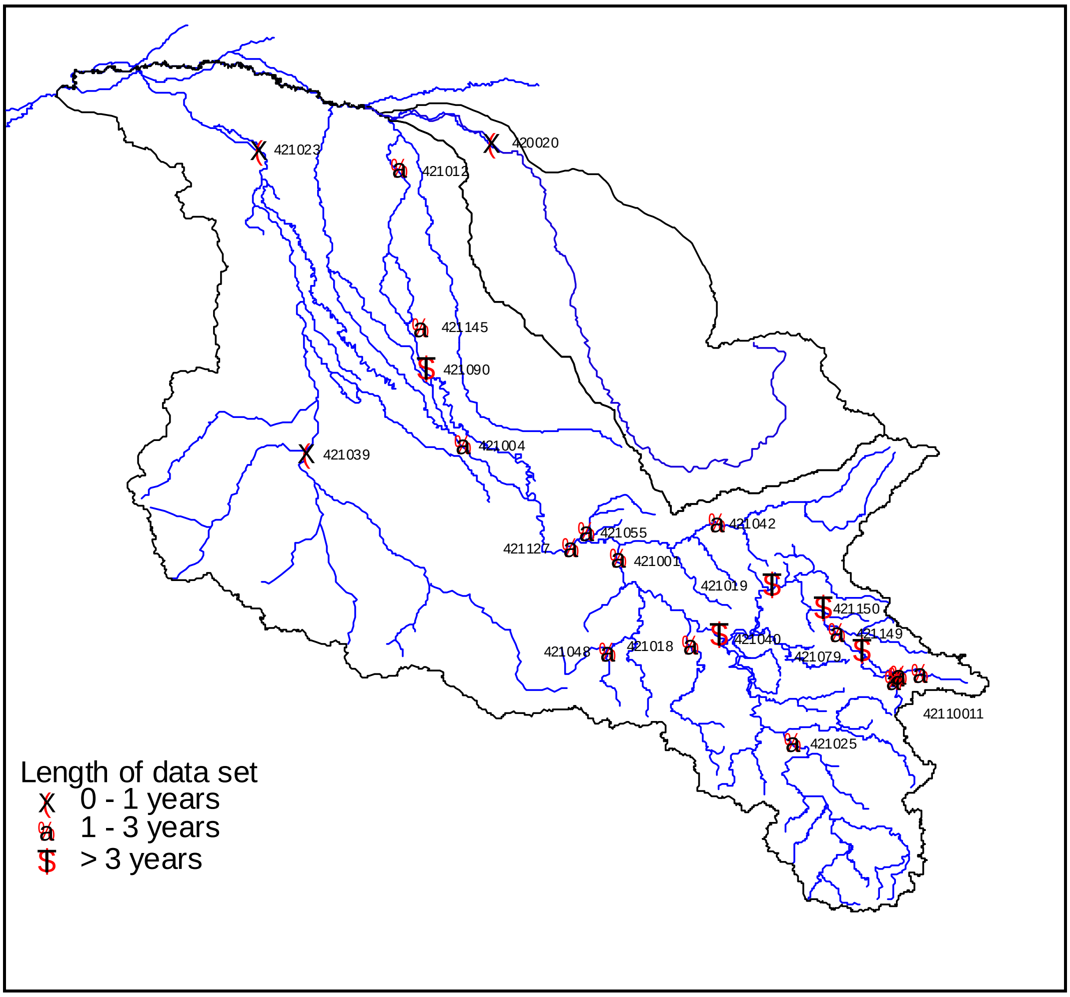


Figure 3.2. Location and record length for continuous EC data stations

The Macquarie River System has a good coverage of continuous stations compared with most other NSW MDB valleys, and reflects on the level of salinity management activity in the catchment. Of the 22 stations in total, only 3 have less than 1 year of data, and these are in the Bogan River and Castlereagh River. The 5 longer term stations with more than 3 years of data are concentrated along the Cudgegong River, along with a station downstream of Burrendong Dam, and a further station at Marebone Weir, just upstream of the Macquarie Marshes.

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. A total of 34 of the 168 stations with discrete EC data, and 16 of the 22 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 13 stations with discrete EC data in this list (Table 3.1), and 4 of these have continuous EC data. This data was screened to remove outliers and observations on days with no flow records. A further 17 stations with discrete EC data are also located at points that could be used to evaluate model results (Table 3.2). As well as the 4 stations with continuous EC data at IQQM inflow points, a further 12 stations with continuous EC data points are located at points that could be used to evaluate model results (Table 3.3). All of the continuous stations duplicate the locations of discrete stations.

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 such as the Talbragar River (Station No. 421042) and Buckinbah Creek (421059) contribute moderate quantities of high salinity water, the Bell River (421018) produces significant amounts of moderate salinity water, and that the Fish River (421035) contributes large amounts of low salinity water.

The longitudinal overview of median salinities (Figure 3.4) shows that the Cudgegong River has higher median salinities than the Upper Macquarie River, that Burrendong Dam reduces these median salinities as a result of storage effects, and that median salinity generally increases along the Macquarie River to the end of the system.

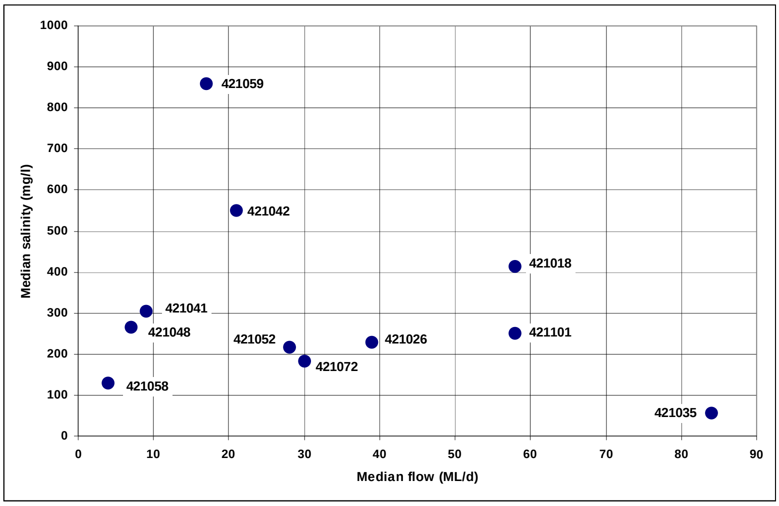


Figure 3.3. Median salinity versus median flow for inflow sites with discrete EC data

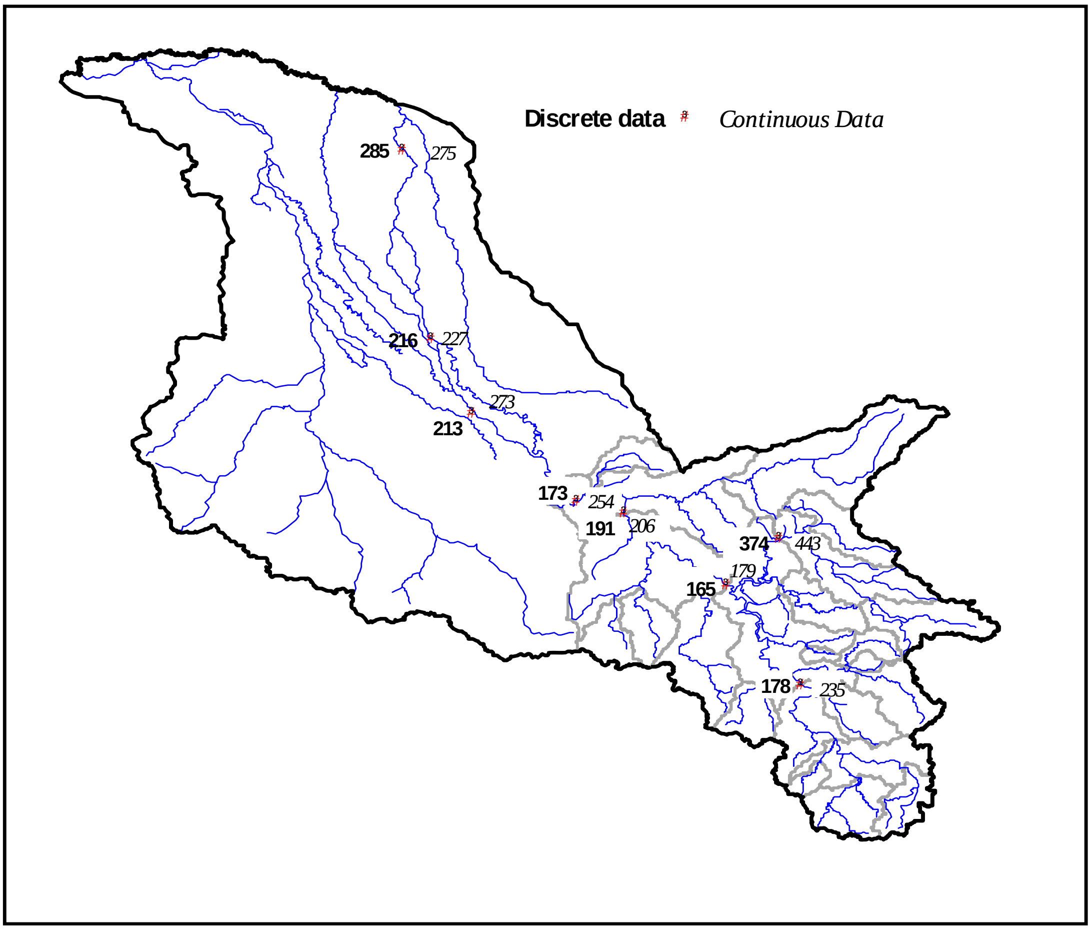


Figure 3.4. Median salinity along main stream

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

Station Number	Station Name	Data use	Data points removed			Final data days
			<15 µS/cm	*zero or missing flow*	*outliers*	
421018	Bell River @ Newrea	Inflow	*0*	*32*	*0*	104
421026	Turon River @ Sofala	Inflow	*1*	*6*	*1*	115
421035	Fish River u/s Tarana Road Bridge	Inflow	*1*	*2*	*1*	93
421041	Crudine Creek u/s Turon River Junction	Inflow	*2*	*8*	*0*	41
421042	Talbragar River @ Elong Elong	Inflow	*1*	*20*	*0*	166
421048	Little River @ Obley No.3	Inflow	*0*	*9*	*0*	127
421052	Lewis Ponds Creek @ Ophir	Inflow	*0*	*3*	*0*	51
421055	Coolbaggie Creek @ Rawsonville	Inflow	*0*	*19*	*0*	57
421058	Wyaldra Creek @ Gulgong	Inflow	*0*	*5*	*0*	43

Station Number	Station Name	Data use	Data points removed			Final data days
			<15 µS/cm	*zero or missing flow*	*outliers*	
421059	Buckinbah Creek @ Yeoval	Inflow	*0*	*2*	*0*	74
421066	Green Valley Creek @ Hill End	Inflow	*0*	*21*	*0*	39
421072	Winburndale Rivulet @ Howards Bridge	Inflow	*0*	*14*	*0*	28
421101	Campbells River d/s Ben Chifley Dam	Inflow	*0*	*4*	*0*	56
421042	*Talbragar River @ Elong Elong*	*Inflow*	*0*	*0*		*595*
421048	*Little River @ Obley No.3*	*Inflow*	*0*	*0*		*924*
421055	*Coolbaggie Creek @ Rawsonville*	*Inflow*	*57*	*0*		*748*
421018	*Bell River @ Newrea*	*Inflow*	*0*	*0*		*982*

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

Station Number	Station Name	Data use	Data points removed			Final data days
			<15 µS/cm	*zero or missing flow*	*outliers*	
421001	Macquarie River @ Dubbo	Evaluation	*0*	*0*	*0*	57
421004	Macquarie River @ Warren Weir	Evaluation	*0*	*19*	*1*	302
421006	Macquarie River @ Narromine	Evaluation	*0*	*28*	*0*	37
421007	Macquarie River @ Bathurst post Queen Charlottes Div	Evaluation	*0*	*1*	*0*	51
421012	Macquarie River @ Carinda	Evaluation	*0*	*13*	*3*	305
421019	Cudgegong River @ Yamble Bridge	Evaluation	*0*	*5*	*1*	256
421022	Macquarie River @ Oxley Station	Evaluation	*0*	*61*	*0*	205
421025	Macquarie River @ Bruinbun	Evaluation	*1*	*1*	*0*	163
421031	Macquarie River @ Gin Gin	Evaluation	*0*	*6*	*0*	64
421040	Macquarie River d/s Burrendong Dam	Evaluation	*4*	*10*	*0*	185
421057	Campbells River @ Apsley	Evaluation	*0*	*4*	*0*	39
421074	Cudgegong River @ Apple Tree Flat	Evaluation	*0*	*1*	*0*	32
421079	Cudgegong River d/s Windamere Dam	Evaluation	*4*	*12*	*0*	514
421090	Macquarie River d/s Marebone Weir	Evaluation	*0*	*9*	*1*	63
421127	Macquarie River @ Baroona	Evaluation	*0*	*1*	*0*	62
421149	Cudgegong River @ Rocky Water Hole	Evaluation	*0*	*9*	*0*	30
421150	Cudgegong River @ Wilbertree Road	Evaluation	*0*	*3*	*0*	37

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

Station number	Station name	Data use	Data days		Comments for data errors	Final data days
			Missing flow	*Data errors*		
421001	Macquarie River @ Dubbo	Evaluation	11	0		929
421004	Macquarie River @ Warren Weir	Evaluation	0	0	Gauge systematically overestimates up to 10%	954
421012	Macquarie River @ Carinda	Evaluation	0	0		745
421019	Cudgegong River @ Yamble Bridge	Evaluation	7	24	Large drops in salinity during a constant flow	1557
421023	Bogan River @ Gongolgon	Evaluation	0	0		324
421025	Macquarie River @ Bruinbun	Evaluation	7	0		646
421040	Macquarie River d/s Burrendong Dam	Evaluation	138	0		1266
421079	Cudgegong River d/s Windamere Dam	Evaluation	0	172	Constant low EC value for extended period, no response to flow events.	1213
421090	Macquarie River d/s Marebone Weir	Evaluation	63	0		2072
421127	Macquarie River @ Baroona	Evaluation	11	0		920
421149	Cudgegong River @ Rocky Water Hole	Evaluation	0	0		1018
421150	Cudgegong River @ Wilbertree Road	Evaluation	193	0		1566

Table 3.4. Cumulative distribution statistics of screened EC data sets

Station Number	Station name	Data type	Data use	Salinity statistics kg/ML C_{25}	C_{50}	C_{75}	Q_{50} ML/d
421001	Macquarie River @ Dubbo	Discrete	Evaluation	234	191	164	1986
421001	Macquarie River @ Dubbo	Continuous	Evaluation	321	206	167	
421004	Macquarie River @ Warren Weir	Discrete	Evaluation	258	213	181	746
421004	Macquarie River @ Warren Weir	Continuous	Evaluation	412	273	215	
421006	Macquarie River @ Narromine	Discrete	Evaluation	258	184	174	N/A
421007	Macquarie River @ Bathurst Post Q.Charlottes Div	Discrete	Evaluation	198	169	164	N/A
421012	Macquarie River @ Carinda	Discrete	Evaluation	326	285	252	107
421012	Macquarie River @ Carinda	Continuous	Evaluation	351	275	238	
421018	Bell River @ Newrea	Discrete	Inflow	457	413	335	58
421018	Bell River @ Newrea	Continuous	Inflow	459	409	346	
421019	Cudgegong River @ Yamble Bridge	Discrete	Evaluation	420	374	325	61
421019	Cudgegong River @ Yamble Bridge	Continuous	Evaluation	529	443	381	
421022	Macquarie River @ Oxley Station	Discrete	Evaluation	269	222	191	405
421025	Macquarie River @ Bruinbun	Discrete	Evaluation	224	178	143	230
421025	Macquarie River @ Bruinbun	Continuous	Evaluation	265	235	184	
421026	Turon River @ Sofala	Discrete	Inflow	261	229	179	39
421031	Macquarie River @ Gin Gin	Discrete	Evaluation	254	187	169	N/A
421035	Fish River u/s Tarana Road Bridge	Discrete	Inflow	67	57	48	84
421040	Macquarie River d/s Burrendong Dam	Discrete	Evaluation	185	165	142	1644
421040	Macquarie River d/s Burrendong Dam	Continuous	Evaluation	172	159	137	
421041	Crudine Creek u/s Turon River Junction	Discrete	Inflow	400	303	260	9
421042	Talbragar River @ Elong Elong	Discrete	Inflow	732	550	385	21
421042	Talbragar River @ Elong Elong	Continuous	Inflow	932	813	637	
421048	Little River @ Obley No.3	Discrete	Inflow	408	266	142	7
421048	Little River @ Obley No.3	Continuous	Inflow	666	524	368	
421052	Lewis Ponds Creek @ Ophir	Discrete	Inflow	325	216	180	28
421055	Coolbaggie Creek @ Rawsonville	Discrete	Inflow	83	64	55	0
421055	Coolbaggie Creek @ Rawsonville	Continuous	Inflow	99	82	67	

Station Number	Station name	Data type	Data use	Salinity statistics kg/ML			Q_{50} ML/d
				C_{25}	C_{50}	C_{75}	
421057	Campbells River @ Apsley	Discrete	Evaluation	300	274	234	N/A
421058	Wyaldra Creek @ Gulgong	Discrete	Inflow	167	130	99	4
421059	Buckinbah Creek @ Yeoval	Discrete	Inflow	958	859	655	17
421066	Green Valley Creek @ Hill End	Discrete	Inflow	217	177	150	0
421072	Winburndale Rivulet @ Howards Bridge	Discrete	Inflow	265	182	147	30
421074	Cudgegong River @ Apple Tree Flat	Discrete	Evaluation	399	336	313	N/A
421079	Cudgegong River d/s Windamere Dam	Discrete	Evaluation	365	321	276	33
421079	Cudgegong River d/s Windamere Dam	Continuous	Evaluation	348	313	271	
421090	Macquarie River d/s Marebone Weir	Discrete	Evaluation	246	216	186	N/A
421090	Macquarie River d/s Marebone Weir	Continuous	Evaluation	308	227	186	
421101	Campbells River u/s Ben Chifley Dam	Discrete	Inflow	300	251	204	58
421127	Macquarie River @ Baroona	Discrete	Evaluation	234	173	156	N/A
421127	Macquarie River @ Baroona	Continuous	Evaluation	385	254	192	
421149	Cudgegong River @ Rocky Water Hole	Discrete	Evaluation	372	348	302	N/A
421149	Cudgegong River @ Rocky Water Hole	Continuous	Evaluation	410	365	316	
421150	Cudgegong River @ Wilbertree Road	Discrete	Evaluation	455	388	348	N/A
421150	Cudgegong River @ Wilbertree Road	Continuous	Evaluation	481	429	364	

4. The Macquarie IQQM

4.1. QUANTITY MODEL

The Macquarie IQQM is currently split to two separate models. The first is a simple model of the Chifley system, covering the Macquarie River from its headwaters to a point upstream of Burrendong Dam. The end-of system outflows from the Chifley System IQQM are used as inflows to the Macquarie System IQQM, which extends to Carinda, close to the confluence with the Barwon-Darling River.

There are historical reasons why this was done. The model was originally developed for water quantity only, and there were no actions in the Macquarie R. upstream of Burrendong Dam that would have caused any changes to the quantity or timing of inflows to the storage. Therefore, there was no need to repeat the simulation of this part of the Macquarie system each time, and the computational overhead was not justified with the slower computer speeds of the time. The Chifley system is represented in the Macquarie System as a single inflow node.

The historical reasons do not apply for the quality model. Actions in the upper Macquarie R. are likely to change the quantity of water, and salt, entering Burrendong Dam. In addition, the computational overhead is no longer high as computer speeds have increased by 1-2 orders of magnitude in the intervening period. Work is currently underway to integrate these models without changing quantity results in the Macquarie system.

A full description of the features and calibration of the Chifley System IQQM and Macquarie System IQQM is presented in O'Neill and Burns (2000).

4.1.1. Chifley System

The Chifley System IQQM configuration is shown schematically in Figure 4.1.The system includes eleven inflow nodes in total, with seven of these representing gauged tributary inflows. The ungauged tributary inflows below these were calibrated at two gauging stations, Macquarie R. @ Bathurst and Macquarie R. @ Bruinbun. The additional tributary inflows below Macquarie R. @ Bruinbun are calibrated within the Macquarie System IQQM (see Section 4.1.3).

The only water management features of significance in the Chifley System IQQM are Ben Chifley Dam (15,500 ML), and the associated town water supply for Bathurst (6,654 ML/year, seasonally distributed).

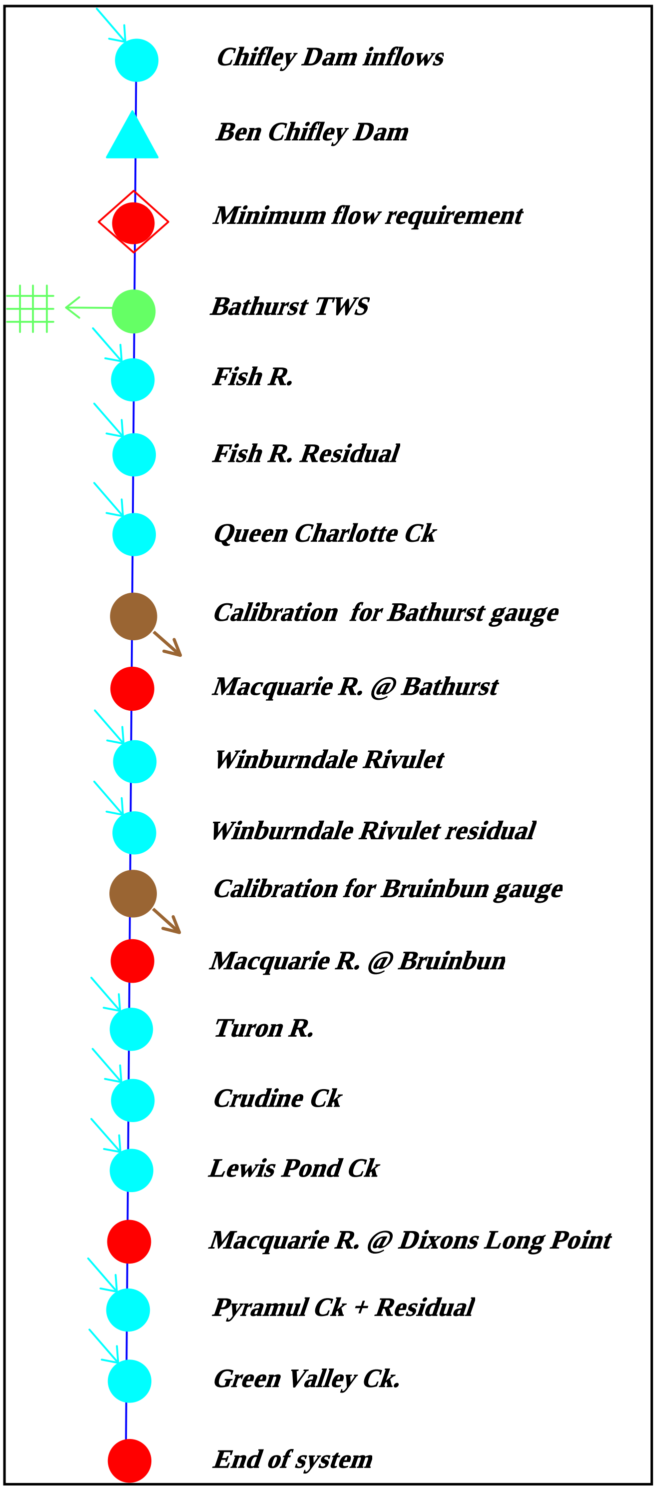


Figure 4.1. Schematic of Chifley System IQQM

4.1.2. Macquarie System

The Macquarie System IQQM was the first of its kind to be completed to be able to simulate scenarios, in 1995. The model has since been refined to enable it to handle 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 Macquarie System IQQM is shown in Figure 4.2.

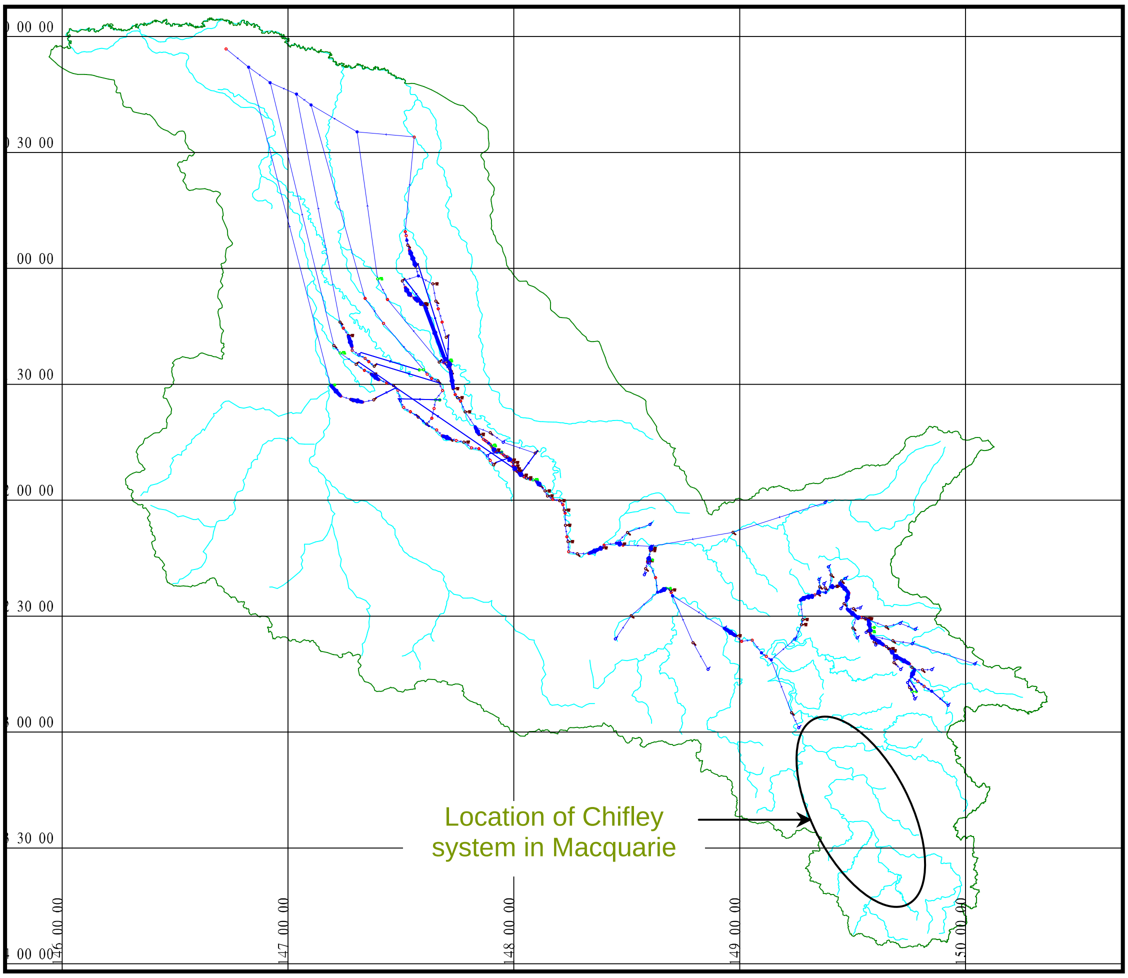


Figure 4.2. Schematic of Macquarie System IQQM

This figure is only meant to present an overview of the Macquarie System IQQM. The complexity of the Macquarie System IQQM, with over 250 nodes, is such that the detail cannot be presented a single A4 page in the way that the Chifley System IQQM was. 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 4.3 to Figure 4.6)
- storages (Figure 4.7)
- irrigation demands (Figure 4.8 to Figure 4.11), and
- instream and environmental nodes (Figure 4.12)

The features of the Macquarie System IQQM are discussed in Sections 4.1.3 to 4.1.6.

4.1.3. Inflows and calibration

Macquarie System IQQM has thirty-three inflow nodes along with thirty-eight calibration nodes to calibrate the flow along the main stream. The magnitude and distribution of these inflow and effluent nodes is shown in Figure 4.3 to Figure 4.6. These inflow nodes match catchment boundaries as described in Section 4.3. The magnitude of these inflows is also further described there.

The largest single inflow in the Macquarie System IQQM is the flow that comes from the Chifley System IQQM, which is followed directly with a calibration node that removes 38% of the inflow. The large relative size of the calibration node to the inflow from the Chifley system is of some concern for quality modelling. The result was accepted at the time, as the objective was to get mass balance of inflows to Burrendong Dam. The higher percentage of flow removed with the calibration node compensated for limitations in the methods used at the time to estimate flow from residual catchments

The Cudgegong arm of the Macquarie System has a high density of inflows and associated loss nodes. This feature is an enhancement of earlier versions of the Macquarie System IQQM to better represent water availability for high security irrigators in these reaches.

In the Lower Macquarie System there is only the one inflow node, but several effluent nodes. These were necessary to get good flow calibration at the mainstream gauges and along the effluent system. The effluents represented are non-returning; there are nine other effluent nodes in the model that return flow back into another part of the river system, and are not shown.

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 Macquarie Valley Cap calibration report (O’Neill & Burns 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.

4.1.4. Storages

Four storages are modelled in the Macquarie System IQQM, and their locations are shown along with their sizes in Figure 4.7. However, only Burrendong and Windamere are true regulating storages. Warren Weir is used to catch surplus water, originating either from rainfall rejection or tributary inflows, and redistributes this water to downstream irrigators (see O’Neill and Burns, 2000, Section 4.3), whereas Macquarie Marshes is configured as a conceptual storage, so that the impacts of water movement, evaporation and rainfall on the marshes can be simulated.

Windamere Dam releases water for:

- General and high security irrigators along the Cudgegong R., upstream of Burrendong Dam;
- Environmental releases in the Cudgegong R.;
- Augmenting water in Burrendong Dam to improve reliability for irrigators downstream.

The releases to Burrendong Dam are constrained to a pattern ranging from 600 ML/d to 1,400 ML/d to protect in-stream habitat for platypus breeding.

Burrendong Dam releases water for:

- General and high security irrigators along the Macquarie R.;
- Environmental and instream releases as described in Section 4.1.6;
- Town water supplies for Wellington (2,091 ML/year), Dubbo (8,514 ML/year) and Nyngan (7,997 ML/year); and
- Flood operation.

Airspace amounting to 472,670 ML is set aside in Burrendong Dam for flood mitigation. When the volume of water in Burrendong Dam exceeds 1,188,000 ML, water is released according to flood operation guidelines to minimise downstream flooding.

4.1.5. Extractive demands

Allocation of water to irrigators in the Macquarie River System occurs under a volumetric allocation system, as with other regulated river systems. The total active licence entitlement in this river system is 670 GL, of which about 6% are for high security users, including town water supplies and permanent crop types such as orchards. The majority of the licences are general security, for irrigating crops, with the dominant crop types being lucerne, cereals and pasture in the upper reaches of the river system, and cotton in the lower reaches.

The distribution of water usage for irrigation is shown in Figure 4.8 to Figure 4.11, and shows that the majority of the water usage is downstream of Baroona, with significant usage along the Cudgegong R. and also between Burrendong Dam and Baroona.

4.1.5.1. Surplus water usage

Unregulated river water, in addition to that released specifically by Burrendong Dam can also be extracted by licence holders, and is 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 Burrendong Dam. 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, and the total volume that can be extracted by all users is restricted to 50 GL/year.

4.1.6. In-stream demands

In-stream demands are simulated at fourteen locations in the Macquarie System IQQM Figure 4.12 using Type 9.0, and Type 10 nodes. The purpose of these particular nodes is described in Table 4.1.

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

Node type	In-stream ordering node name	Purpose
9.0	Wilbertree Rd Minimum Flow Requirement (MFR)	Orders water from Windamere Dam to maintain a minimum 20 ML/d at location.
9.0	Yamble Bridge MFR	Orders water from Windamere Dam to maintain a minimum 30 ML/d at location.
10.4	Warren Weir flood mitigation target	Governs flood operations of Burrendong Dam, by restricting releases to target a flow at location of 5,000 ML/d when Burrendong is between 1,188 GL, and 1,425 GL. Above 1,425 GL the control node at Gin Gin sets the target release rates.
10.4	Gin Gin flood mitigation target	Governs flood operations of Burrendong Dam, by restricting releases to target a flow at location of 12,000 ML/d when Burrendong is above 1,425 GL, and 18,000 ML/d when Burrendong is above 1,544 GL.
10.3	Macquarie Marshes replenishments	Targets a flow at site of between 1,000-4,000 ML/d . This target flow window is passed up to Burrendong Dam, and is adjusted on the way to allow for losses and tributary inflows. Releases above other requirements are made at Burrendong Dam based on the size of the inflow compared with the target window. If inflows to Burrendong are: (i) below the window; no water is released. (ii) within the window; all the inflow is released; (iii) above the window; releases are made at the upper value of the target flow window. These releases are only during the months of April-May, and Jul-October. The total amount of release each year is limited to 50 GL of High Security water, and up to 75 GL of General Security water. The unused part of this entitlement can be carried over to subsequent years, subject to certain other conditions. The High Security water is only available if the valley wide irrigation allocation level is higher than 10%.
10.2	Lower Bogan Replenishment	Orders water from Burrendong Dam during July-September if less than 15 GL has passed Gunningbar Offtake in the previous three months. Water is ordered to target a flow of 150 ML/d at this site. The maximum amount ordered in combination with previous three months flow is restricted to a maximum 15 GL.
9.0	Bulgeraga MFR	Orders water from Burrendong Dam to maintain a minimum 20 ML/d at location.
9.0	Oxley MFR	Orders water from Burrendong Dam to maintain a minimum 50 ML/d at location.

Node type	In-stream ordering node name	Purpose
10.2	Marra Ck Replenishment	Orders water from Burrendong Dam during May-June if less than 15 GL has passed Marra Creek in the previous two months. Water is ordered to target a flow of 250 ML/d at this site. The maximum amount ordered in combination with previous three months flow is restricted to a maximum 15 GL.
9.0	Duck Ck MFR	Orders water from Burrendong Dam to maintain a minimum flow varying from 14 ML/d in winter to 80 ML/d in summer.
9.0	Crooked Ck MFR	Orders water from Burrendong Dam to maintain a minimum flow varying from 12 ML/d in winter to 40 ML/d in summer.
9.0	DS Gunningbar weir MFR	Orders water from Burrendong Dam to maintain a minimum flow varying from 14 ML/d in winter to 80 ML/d in summer.

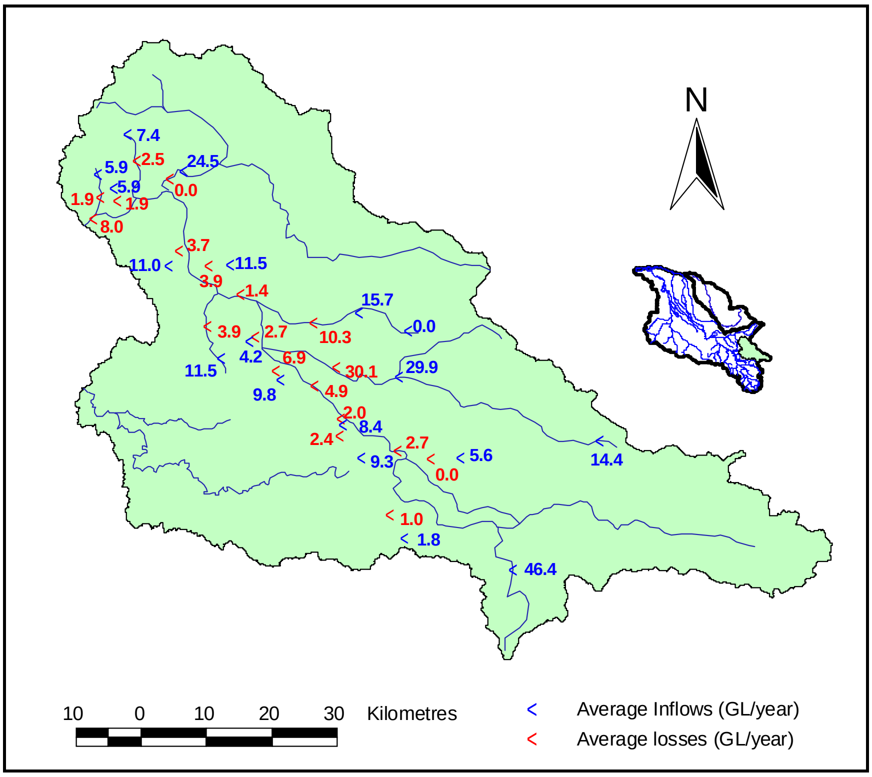


Figure 4.3. Distribution of modelled annual average (1975-2000) inflows and losses in Cudgegong region of Macquarie Valley.

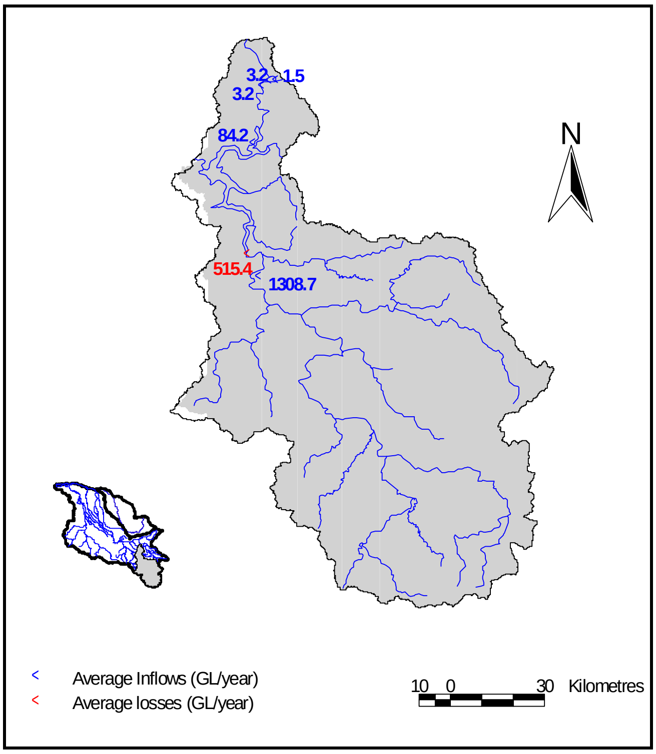


Figure 4.4. Distribution of modelled annual average (1975-2000) inflows and losses in Upper Macquarie region of Macquarie Valley

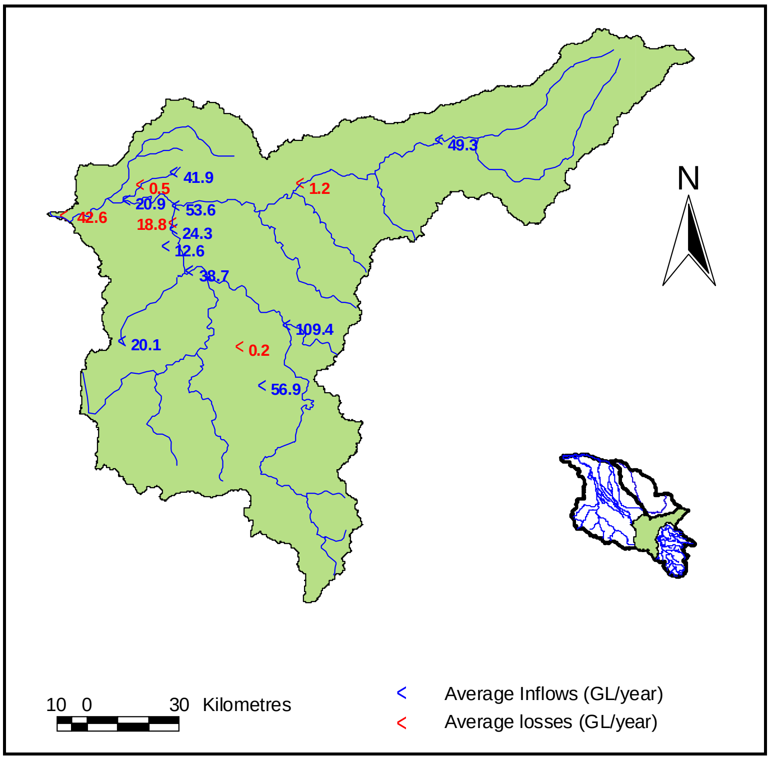


Figure 4.5. Distribution of modelled annual average (1975-2000) inflows and losses in Burrendong Dam to Baroona region of Macquarie Valley

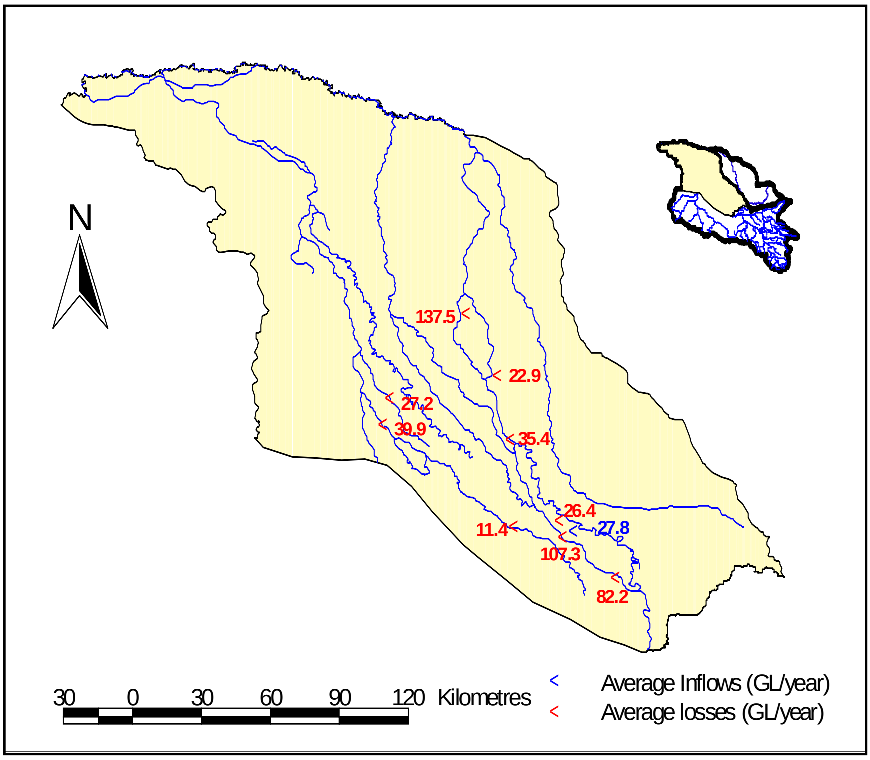


Figure 4.6. Distribution of modelled annual average (1975-2000) inflows and losses in Lower Macquarie region of Macquarie Valley

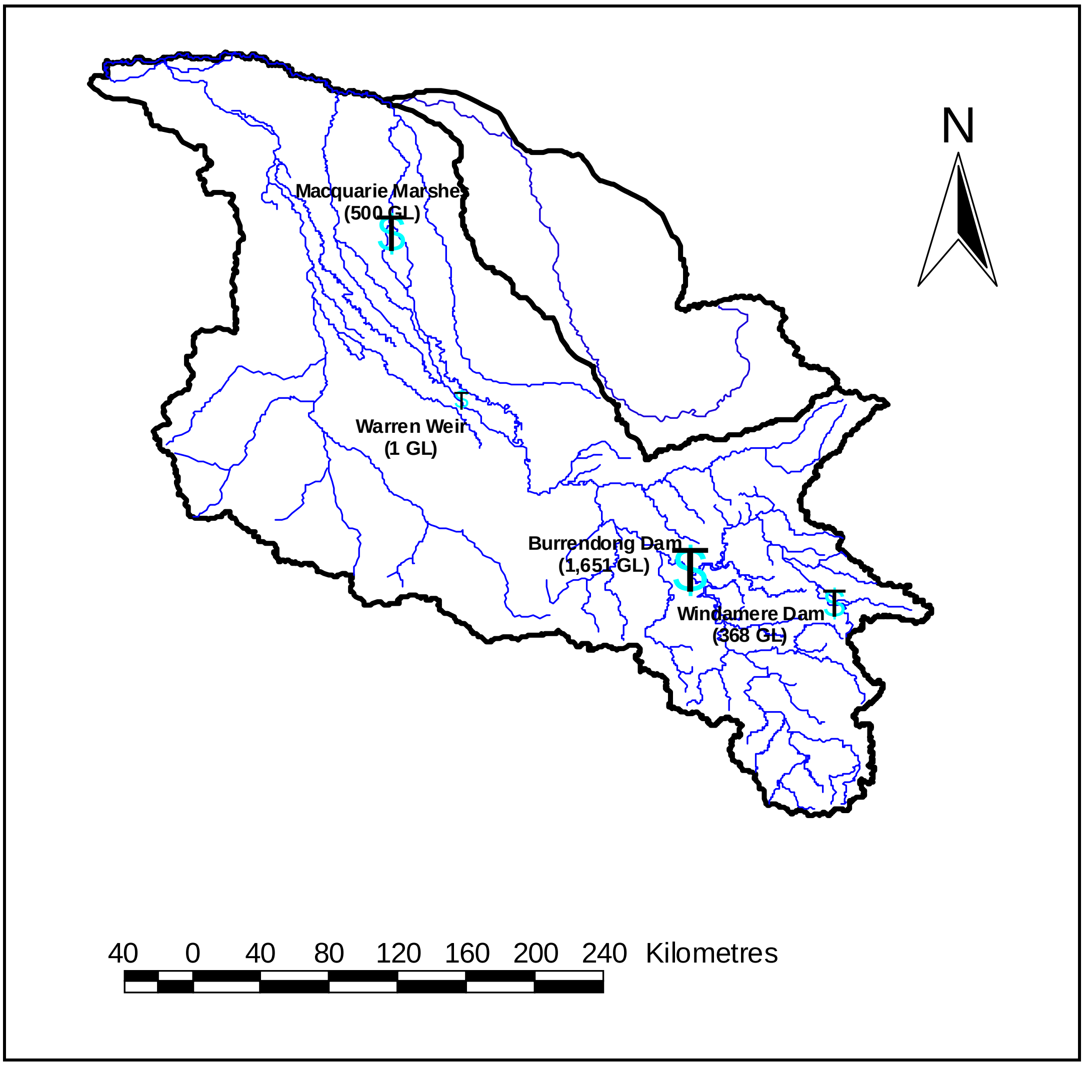


Figure 4.7. Modelled storage in Macquarie System IQQM

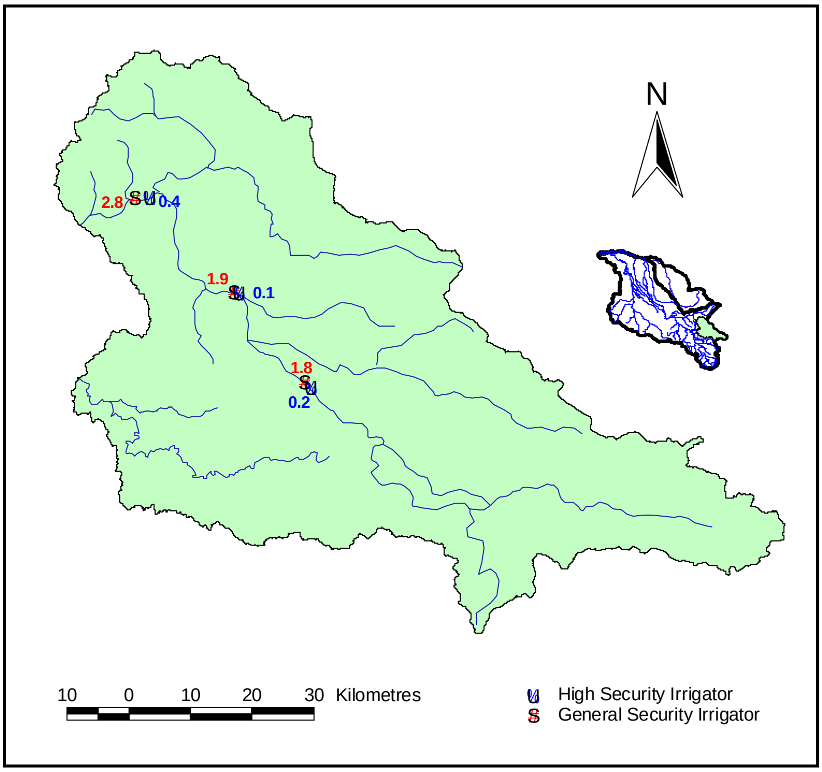


Figure 4.8. Modelled average annual irrigation diversions (GL/year; 1975-2000) for Cudgegong region.

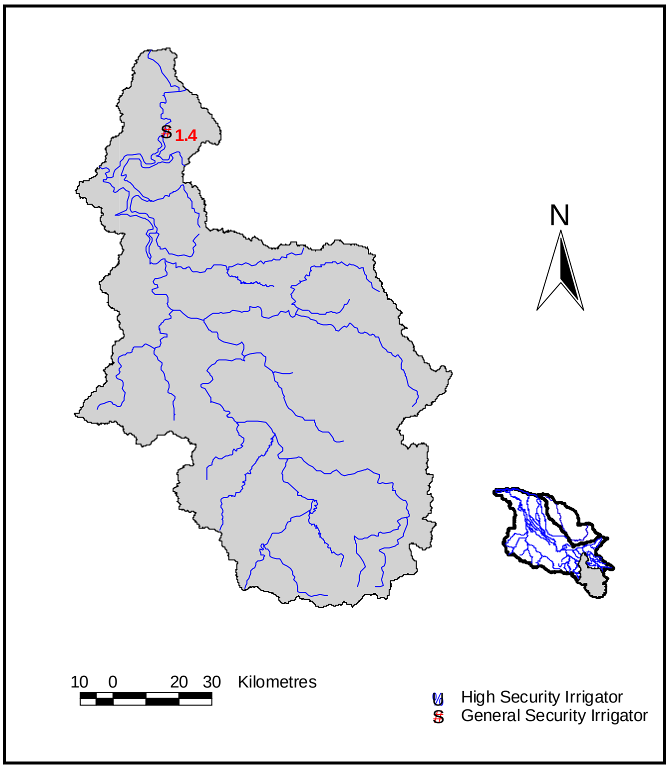


Figure 4.9. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Upper Macquarie Region

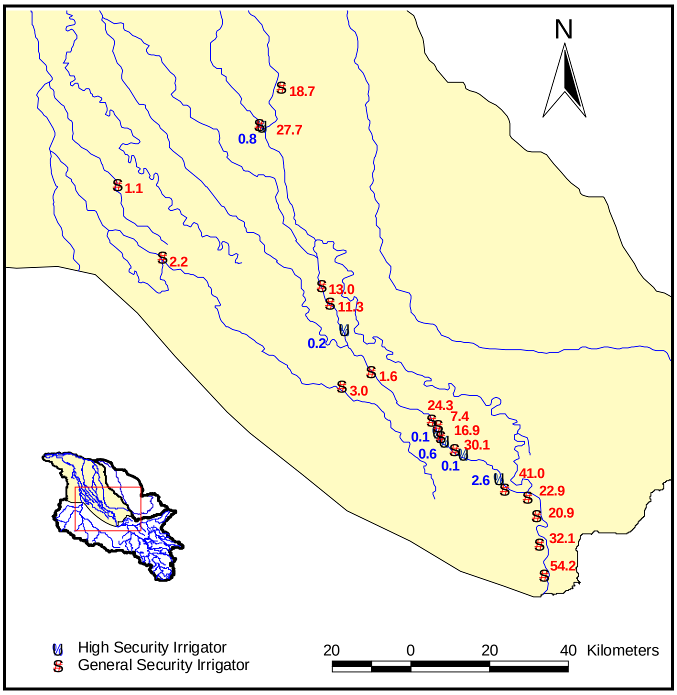


Figure 4.10. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Burrendong to Baroona Region

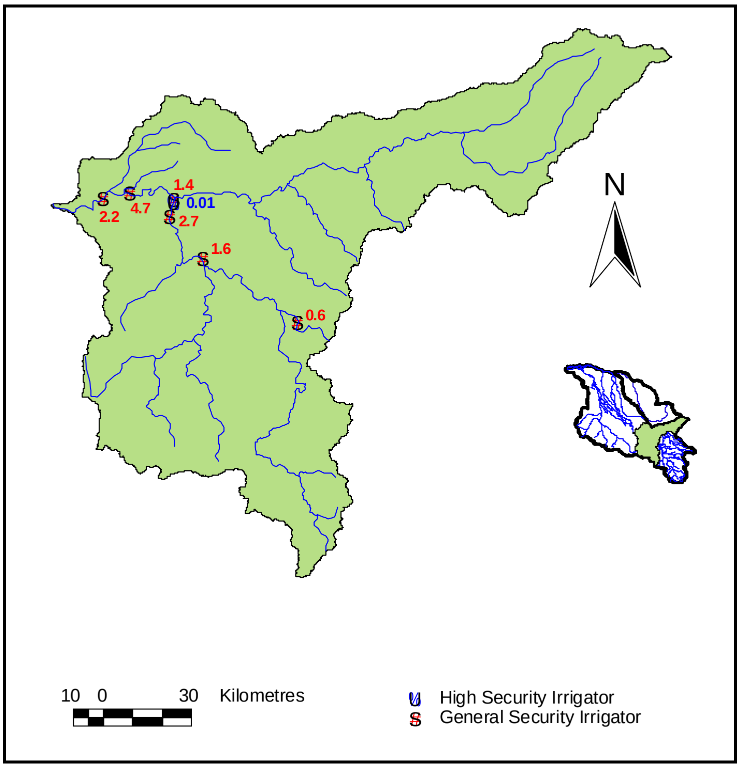


Figure 4.11. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Lower Macquarie Region

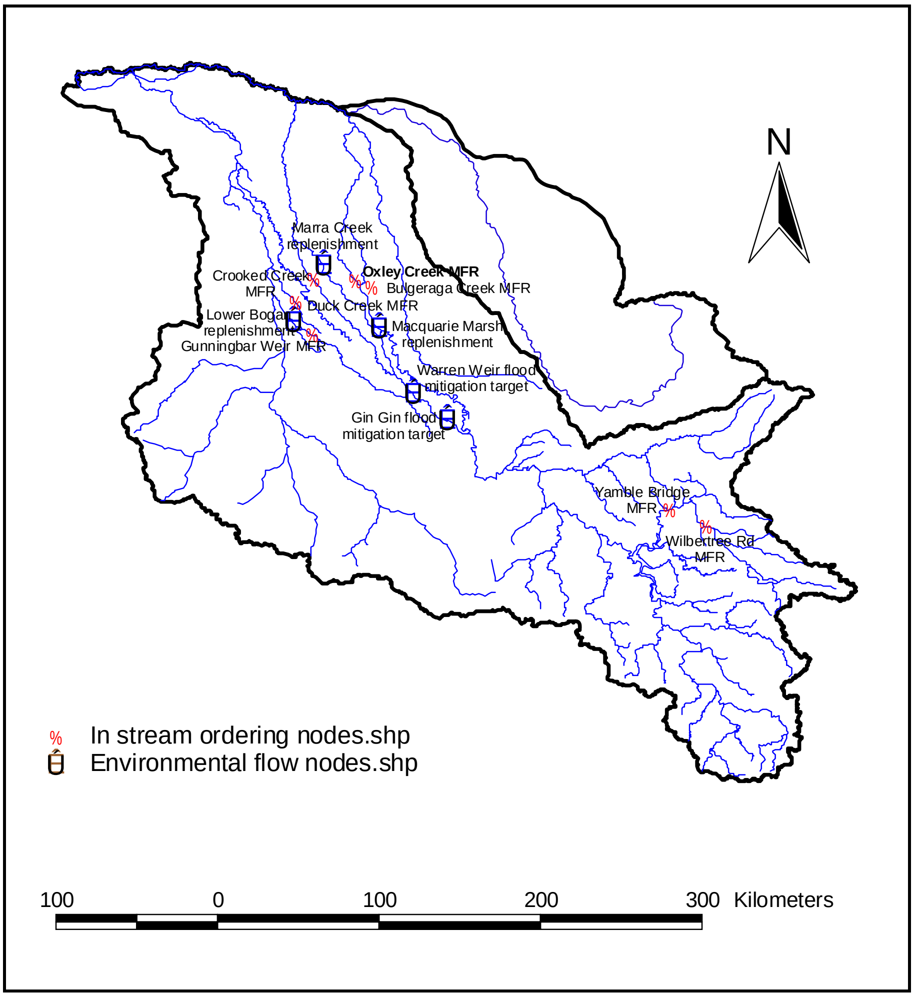


Figure 4.12. Distribution of nodes for ordering in-stream and environmental flow requirements

4.1.7. Peer Review

The University of Newcastle peer reviewed the quantity component of Macquarie Rivers IQQM . The review aimed to assess the suitability of the model for developing and evaluating river management options. Findings from this review assessed the model to be satisfactory. Consultation with Macquarie Rivers irrigators has been undertaken to ensure model 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.

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 $69*10^6$ 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 Macquarie IQQM, 1993/4 Cap Scenario for 1975-2000.

Water balance component	Sum over simulation period (ML)
Inflows	69,546,187
Losses	57,376,609
Extractions	11,650,331
Storage change	519,258
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 there were 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 in the software.

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

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

Water balance component	QA Test 1 Sum over simulation period (ML)	QA Test 2 Sum over simulation period (ML)
Inflows	69,546,187	69,546,187
Losses	57,376,609	57,376,609
Extractions	11,650,331	11,650,331
Storage change	519,258	519,258
Error	11	11

Table 4.4. Salt mass balance report for Macquarie 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 ± 0.4 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 100.0 ± 3.5 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 4.13. 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 exactly match; 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.

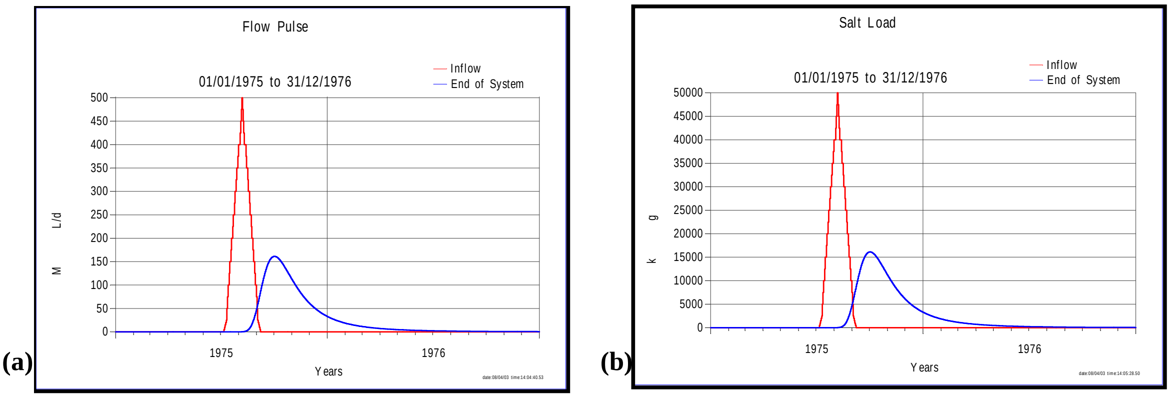


Figure 4.13. (a) Inflows and resultant EOS flows; (b) Salt load inflows and EOS salt loads

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 varying linearly from 0 to 500 mg/L over a period of one month, and then decreased back to 0 mg/L over a period of one 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 4.14. 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.

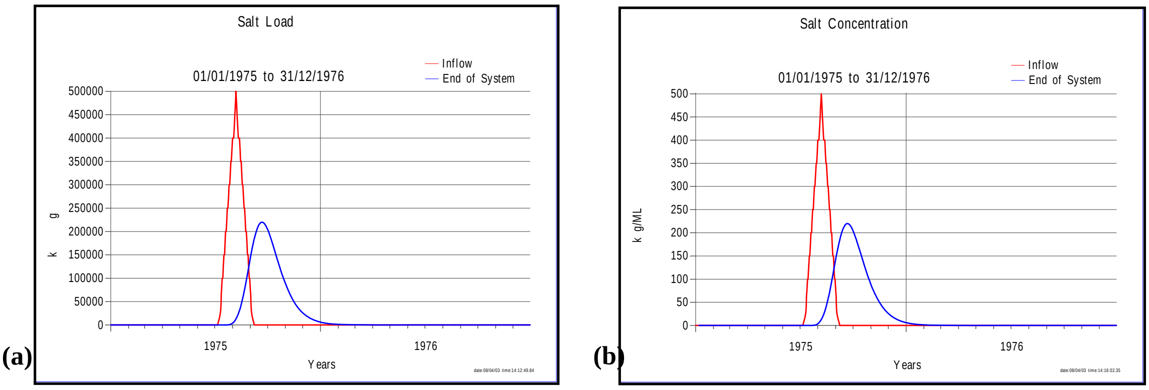


Figure 4.14. (a) Salt load inflows and EOS salt loads; (b) Concentration inflows and EOS concentration

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 Test 3 were worked around by post-processing the salinity data for the model evaluation work.

5. Salt inflow estimates and evaluation

5.1. INITIAL ESTIMATE

Salt loads were input to the model at all the inflow nodes. The initial estimates for the salt load inflows were based on the relationships documented in Table 5.7 of the Salinity Audit (Beale et al, 1999). These relationships are the basis of the 'first cut' models. The flow and salt load results from the 'first cut' model are firstly tested for consistency with the Salinity Audit results (Section B.1). 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 5.9 of the Salinity Audit is reproduced in geographical form for reference (Figure 5.1), with Figure 5.2 showing the catchment boundaries for these inflow and balance points.

The relationships from Table 5.9 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$\rightarrow$salinity conversion factor.

(iv) Concentration capped to highest observed.

(v) Accounting for different benchmark climatic condition Audit compared with Basin Salinity Management Strategy (BSMS).

The relationship between the IQQM network structure and the Salinity Audit inflows referred 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, e.g., catchments 421035, and 421101, whereas others there the parameters had to be modified as more than one IQQM inflow node was used to model flow from that catchment, e.g., 421079 with two nodes, or R4 with fourteen inflow nodes. The concentration cap adopted for point (iv) above is also shown in Table 5.1 and Table 5.2.

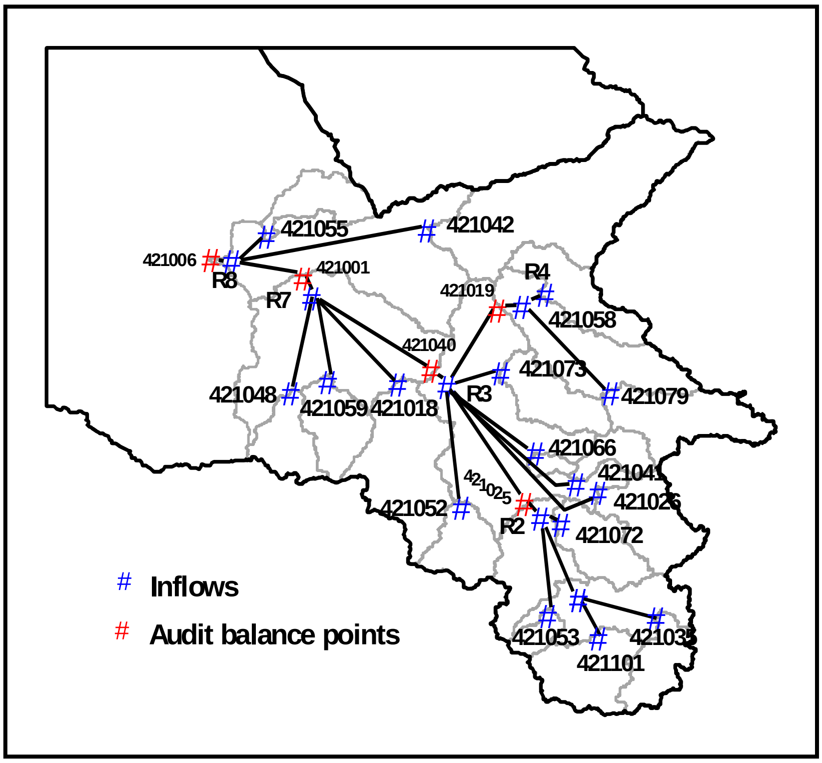


Figure 5.1. Geographic representation of 1999 Salinity Audit schematic of inflows and balance points

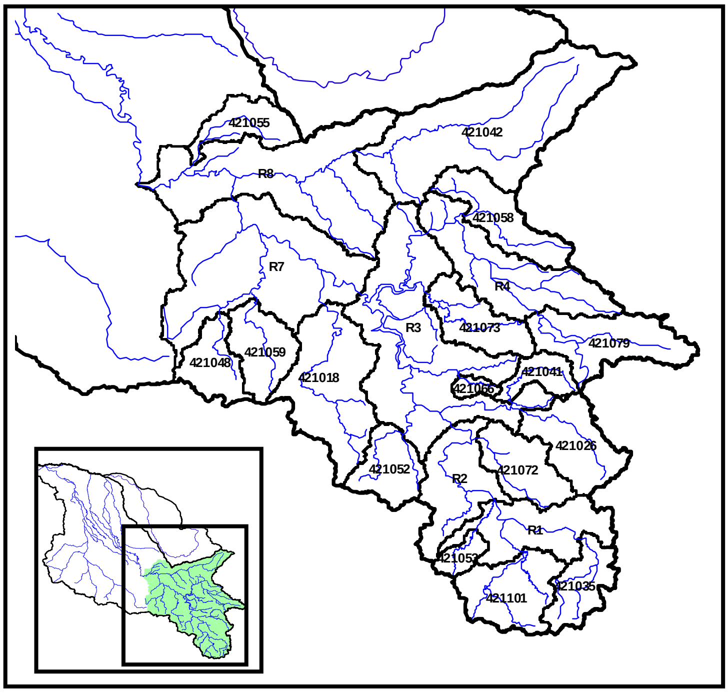


Figure 5.2. Inflow catchments used for 1999 Salinity Audit

Table 5.1. Salt inflow model parameters for gauged catchments

Gauge number	Subcatchment Station name	IQQM inflow node number	Audit load flow model Type	η	λ	C_{max} (mg/L)
	Chifley System model					
421035	Fish River @ Tarana	015	IIA	-4.41	3.86	280
421035		*015*	*IID*			*280*
421101	Campbells River u/s Ben Chifley Dam	012	IIC	16.05	7.09	500
421072	Winburndale Rivulet @ Howards Bridge	018	IIC	15.30	8.30	380
421052	Lewis Ponds Creek @ Ophir	022	IIC	10.50	6.70	420
421041	Crudine River u/s Turon River junction	021	IIC	10.50	6.70	550
421026	Turon River @ Sofala	020	IIC	13.56	9.14	390
421066	Green Valley Creek @ Hill End	025	IIC	0.50	8.96	315
421053	Queen Charlottes Creek @ Georges Plain	016	IIC	20.3	10.0	420
	Macquarie System model					
421079	Cudgeong River @ Windamere Dam site	300	IIC	1.46	9.14	1070
		001	IIC	11.8	9.14	1070
421058	Wyaldra Creek @ Gulgong	316	IIC	23.20	18.30	400
421073	Meroo Creek @ Yarrabin No. 2	017	IIC	13.60	9.14	500
421018	Bell River @ Newrea	035	IIA	-52.40	14.20	580
421018		*035*	*IID*			*580*
421059	Buckinbah Creek @ Yeoval	039	IIC	9.12	37.30	1150
421048	Little River @ Obley	038	IIC	11.35	14.60	1050
421042	Talbraga River @ Elong Elong	045	IIC	23.20	18.30	1900
421055	Coolbaggie Creek @ Rawsonville	047	IIC	27.40	17.80	520

Table 5.2. Salt inflow model parameters for residual catchments

Subcatchment		IQQM inflow	Audit load flow model			
Number	**Description**	**node number**	*Type*	η	λ	C_{max} *(mg/L)*
R4	Ungauged Cudgegong River u/s Yamble Bridge	350	IIC	1.40	18.3	538
		302	IIC	1.60	18.3	538
		304	IIC	1.90	18.3	538
		306	IIC	2.60	18.3	538
		307	IIC	4.60	18.3	538
		352	IIC	0.70	18.3	538
		309	IIC	N/A	N/A	538
		310	IIC	2.32	18.3	538
		312	IIC	1.86	18.3	538
		354	IIC	1.86	18.3	538
		314	IIC	1.60	18.3	538
		318	IIC	1.16	18.3	1000
		356	IIC	1.06	18.3	1000
		358	IIC	1.06	18.3	1000
R1	Ungauged Macquarie River u/s Bathurst	029	IIC	0.0	10.0	280
R2	Ungauged Macquarie River between Bathurst and Bruinbun	030	IIC	25.9	11.7	380
R3	Ungauged Macquarie River and Cudgegong River u/s Macquare Dam	024	IIC	16.6	8.96	400
		025	IIC	0.5	8.96	315
		242	IIC	0.04	8.96	1000
		243	IIC	0.23	8.96	1000
		244	IIC	0.23	8.96	1000
R5/R6/R7	Ungauged Macquarie River between Burrendong Dam and Dubbo	261	IIC	17.2	14.6	580
		264	IIC	5.8	14.6	1050
		286	IIC	9.12	37.3	1150
		038	IIC	11.35	14.6	1050
R8/R9	Ungauged Macquarie and Talbragar Rivers u/s Narromine	268	IIC	14.7	19.2	1900
		270	IIC	14.7	19.2	520
R10	Ungauged Ewenmar Creek u/s Marebone Weir	075	IIC	27.4	17.8	1000

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 that will result in an incorrect estimate of simulated concentration at the gauge locations (C_{obs}).

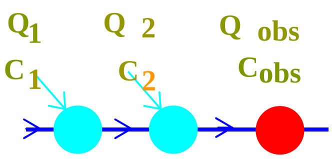


Figure 5.3. Calculating resultant concentration from two tributaries

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

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 Macquarie 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, i.e., how much water was released from the storage. No single configuration of the model estimates these releases well consistently 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 to this are when diversions are a significant proportion of the flow in the river. Simulated diversions in the Macquarie 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 estimated of simulated flow compared with observed. However, these errors would not significantly effect simulated concentrations, because most of the inflows have already entered the Macquarie River Figure 4.5 upstream of most of the diversions Figure 4.11.

5.2.2. Selection of evaluation sites

A total of seventeen locations have data that could be used for model evaluation (Table 3.2), and twelve of these have continuous data (Table 3.3). The performance measures have only been developed at this stage. The continuous data sets are too short, and methods have to be derived to account of serial correlation of the data sets. The model results were only compared at locations of interest, where there are salinity targets set, and for the headwater storages.

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

(i) Station 421012: Macquarie River @ Carinda.

Additional in-valley target sites defined in the Catchment Blueprint are:

(ii) Station 421019: Cudgegong River @ Yamble Bridge;

(iii) Station 421025: Macquarie River @ Bruinbun;

(iv) Burrendong Dam;

(v) Station 421001: Macquarie River @ Dubbo;

(vi) Station 421090: Macquarie River @ Marebone Weir, and

(vii) Station 421127: Macquarie River @ Baroona.

The final evaluation location is:

(viii) Windamere Dam

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

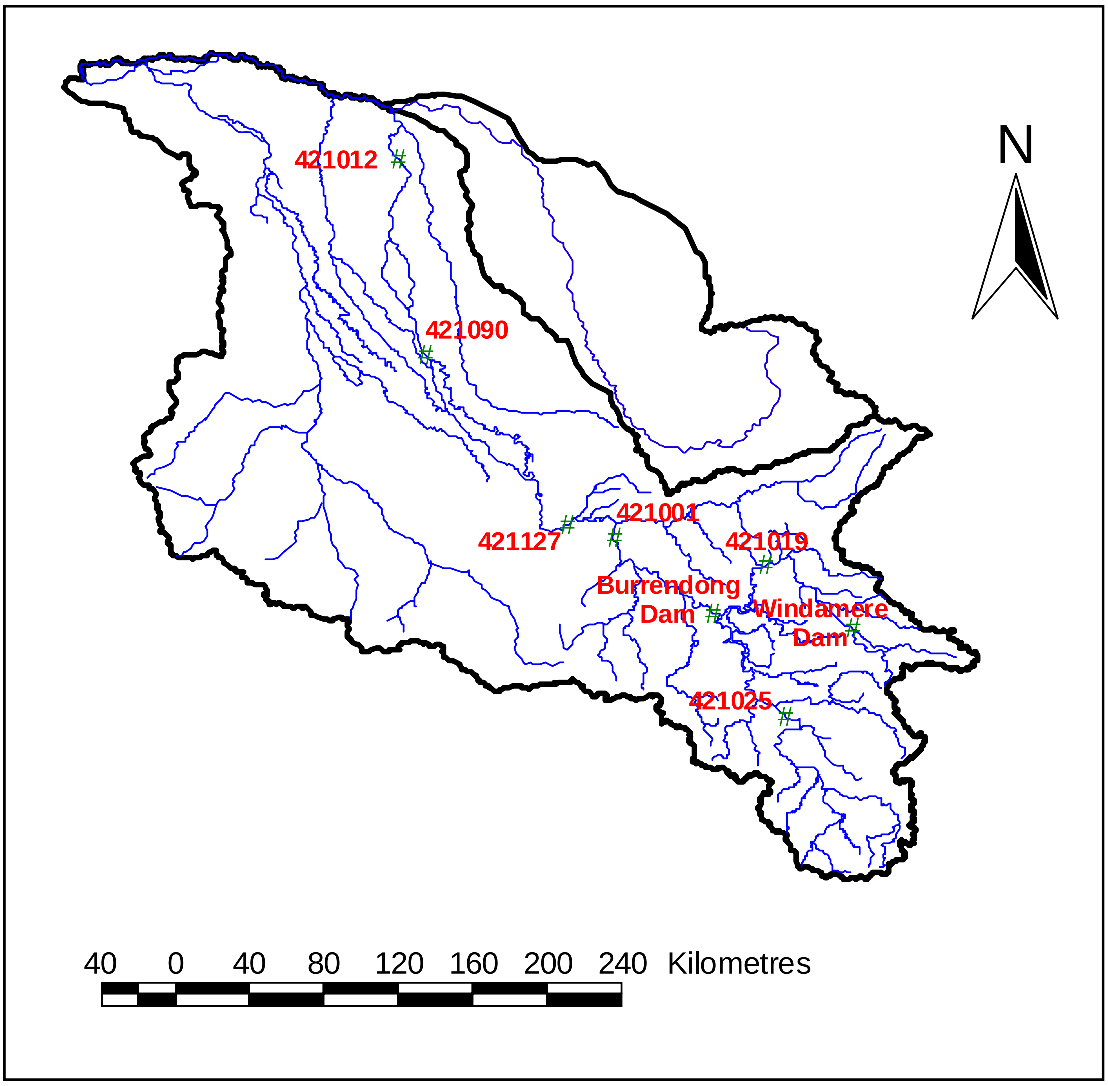


Figure 5.4. Location of evaluation sites

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 which all vary, including: 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 all of these. Because these 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.

Graphs of the full set of screened salinity data (Table 3.2) and observed flow at evaluation locations are shown in Appendix B. Performance measures (i), (ii), and (iii) from above are reported as shown in Table 5.4. The flow ranges referred 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 5.20 to Figure 5.27). Performance measures (i), (ii), and (iii) are reported as shown in Table 5.4, and 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 days concentrations, in addition to changes in water and salt into and out of the storage. (Equation). 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: (i) low flows have higher concentrations; and (ii) 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.

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

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 performance measures (i-iv) is zero, and for performance measure (v) the perfect result is one.

$$P = \frac{\sum_t \left| (O_{t+1} - O_i) - (S_{t+1} - S_t) \right|}{(n-1) \times \sigma_S} \qquad (5.3)$$

$$M = \left| \frac{\sum_t S_t}{\sum_t O_t} \right| - 1 \qquad (5.4)$$

$$E = \frac{\left| \sum_t S_t - \sum_t O_t \right|}{\sum_t O_t} \qquad (5.5)$$

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

$$R^2 = \frac{\sum_t (S_t - \overline{O})^2}{\sum_t (O_t - \overline{O})^2} \qquad (5.7)$$

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 5.2.2, as well as for the total flow range. For flow and concentration, the following are reported in tabular format for the observed and simulated data.:

(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 was evaluated at eight sites along the main streams of the Macquarie River System. The basis for selecting these sites is discussed in Section 5.2.2. Time series plots comparing observed and simulated salinity are located at the end of this chapter (Figure 5.28 to Figure 5.35), and discussion of these results with performance measures are presented in Sections 5.3.1 to 5.3.8.

5.3.1. Windamere Dam

Windamere Dam was commissioned in 1985, and salinity data was collected at intervals of 1-2 months up until 1997. The data was collected at Station 421079: Cudgegong River d/s Windamere Dam (see Table 3.1). The salinity during this period ranges from 250-350 mg/L, with a median salinity of 321 mg/L for the period of record. As would be expected for storages, the salinity does not vary greatly over time.

The simulation using Salinity Audit relationships significantly underestimates salinities in the storage (Figure 5.28), with a poor result for mean match (Table 5.3). The pattern of simulated salinity appears to be following the pattern of observed salinity; increasing during periods of stable or decreasing storage volumes (Figure 5.20), and abrupt decreasing after significant inflows. Results for average error reflect the model underestimates. A poor result for the range match is caused by IQQM underestimating salt load inflows after having the same salinity at the start of the simulation period.

Table 5.3. Results of performance measures for observed versus simulated salinities in Windamere Dam using Salinity Audit relationships

Performance measure	Result
Pattern match	0.521
Mean match	0.231
Average error	0.231
Range match	0.741
R^2	0.656

5.3.2. Station 421019: Cudgegong River @ Yamble Bridge

The gauging station along Cudgegong River @ Yamble Bridge has had data collected consistently every 1-2 months over the evaluation period (1985-2000), with the exception of a gap in 1991, and a period of daily data in winter-spring 1996 (Figure 5.21). The salinity ranges from about 120-560 mg/L, with a median salinity of 374 mg/L; over 50 mg/L higher than the median salinity of water released from Windamere Dam. The data is representative of all the flow ranges and months (Table 5.4). There appears to be a slight bias with the high flow range over represented (43% of points) compared with the exceedance probability range (20% of time). This may be influenced by releases from Windamere Dam, as the standard deviation of the sample flows is a lot lower than that of the total flows (**Table 5.5**).

Other than for this flow range, the data has similar statistical characteristics to the whole flow record for all flow ranges. The results for the simulation using the Salinity Audit relationships show that the observed flow distribution is being maintained (Figure 5.5.b) as would be expected with forced releases from Windamere Dam, but that that observed salinity data is consistently underestimated (Figure 5.29) as would be expected with the underestimate of salinity in Windamere Dam. The salinity distribution is much flatter, except for the non-exceedance probability of 90% and greater, where it rises steeply compared with the non-exceedance curve for the observed salinity. This characteristic is caused by high concentration flows from Swan Creek during periods of low releases from Windamere Dam.

Table 5.4. Distribution of flow with discrete EC across flow ranges and months for Station 421019: Cudgegong River @ Yamble Bridge

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1985-2000	23	4	1	5	4	1	0	0	2	1	0	3	0
Medium		83	5	10	3	2	4	6	7	2	5	7	5	7
High		81	0	0	0	2	3	2	2	6	4	3	2	2
All		187	9	11	9	7	8	9	7	9	9	10	10	9

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 Station 421019: Cudgegong River @ Yamble Bridge

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	21	6	3	29
	With EC obs	20	6	7	29
Medium	*All*	87	66	30	302
	With EC obs	114	86	30	298
High	*All*	1,608	3,940	303	51,325
	With EC obs	1,072	1,109	307	5770
ALL	*All*	377	1,866	3	51,325
	With EC obs	517	878	7	5770

(a) (b)

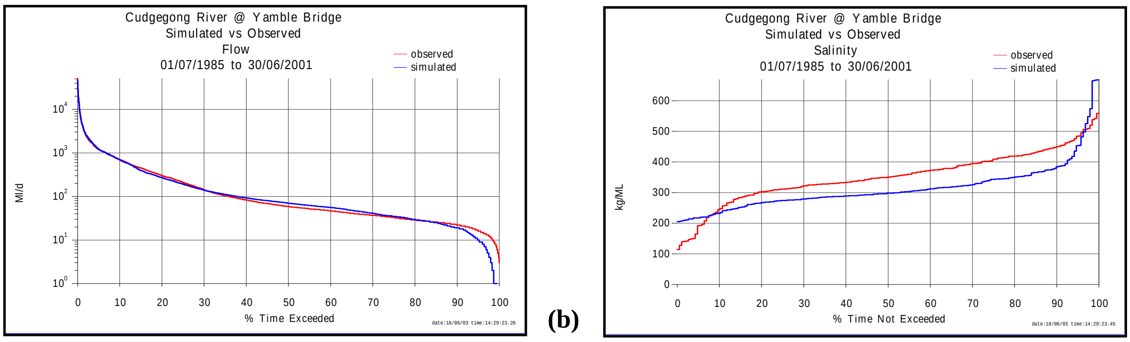


Figure 5.5. Station 421019: Cudgegong River @ Yamble Bridge; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.

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 421019: Cudgegong River @ Yamble Bridge

Flow range	Data set	Distributions								C_o v 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*	20	6	7	29	427	55	334	558	68	0.32	9
	Simulated	51	40	0	145	441	99	334	676			21
Medium	*Observed*	114	87	30	298	391	60	224	542	89	0.16	42
	Simulated	135	136	10	774	444	114	248	728			51
High	*Observed*	1,072	1,110	307	5,770	289	67	114	390	47	0.35	270
	Simulated	973	1,077	82	6,016	302	76	206	675			246
All	*Observed*	518	878	7	5,770	351	84	114	558	68	0.45	136
	Simulated	487	830	0	6,016	382	119	206	728			131

5.3.3. Station 421025: Macquarie River @ Bruinbun

The gauging station Macquarie River @ Bruinbun has had data collected consistently every 1-2 months over the evaluation period (1985-2000), with the exception of a gap in 1991 (Figure 5.22). The data is uniformly distributed across the flow ranges, as well as throughout the year (Table 5.7), and the days salinity data was collected represent the flows well for the low and medium flow ranges, but appears to miss the high end of the high flow range. The median salinity at this site is 178 mg/L (Table 3.4), significantly lower than that for the Cudgegong River.

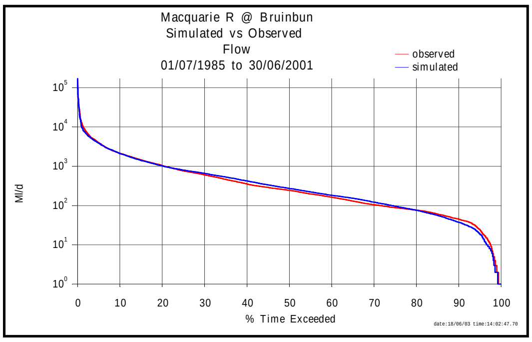
The simulated flows match the distribution of the observed well, which is to be expected as the model was calibrated to get this result. The simulated salinity data appears to generally match the observed salinity data at the scale plotted (Figure 5.22). However, the simulated salinity trace shows periods several weeks long with high salinity, eg., 1991, 1995, 1998, which are not evident in the observed record. This characteristic is also apparent in the steeply rising part of the simulated non-exceedance curve compared with the observed (Figure 5.6).

Table 5.7. Distribution of flow with discrete EC across flow ranges and months for Station 421025: Macquarie River @ Bruinbun

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1985-2001	25	2	4	6	3	2	1	0	1	0	0	2	2
Medium		45	5	3	2	2	3	5	6	3	2	4	5	3
High		14	0	0	0	0	0	2	1	1	3	3	1	1
All		84	7	8	7	5	5	8	7	6	5	7	8	6

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 421025: Macquarie River @ Bruinbun

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	43	23	0	77
	With EC obs	39	23	1	75
Medium	*All*	331	248	78	1044
	With EC obs	342	258	78	1004
High	*All*	4,593	10,849	1048	155,818
	With EC obs	2,841	1,517	1096	6,652
ALL	*All*	1,122	5,147	0	155,818
	With EC obs	668	1,170	1	6,652

(a)


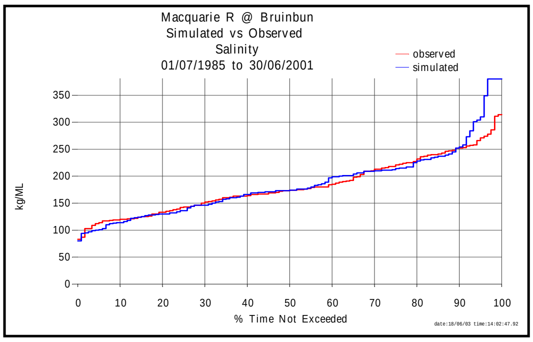
(b)


Figure 5.6. Station 421025: Macquarie River @ Bruinbun; (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 421025: Macquarie River @ Bruinbun

Flow range	Data set	Distributions								C_o v 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	29	26	0	75	221	46	120	314	44	0.10	7
	Simulated	169	252	23	1,350	204	61	80	380			28
Medium	Observed	342	258	78	1,004	172	38	112	257	39	0.08	55
	Simulated	376	263	5	1,310	176	50	97	380			62
High	Observed	2,841	1,518	1,096	6,652	125	31	83	180	15	0.73	329
	Simulated	2,608	2,027	473	7,468	135	32	101	201			315
All	Observed	610	1134	0	6,652	182	52	83	314	37	0.24	80
	Simulated	641	1163	5	7,468	180	56	80	380			88

5.3.4. Burrendong Dam

The data is represented by station 421040: Macquarie River d/s Burrendong Dam (see Table 3.2). The salinity during this period ranges from just over 100 mg/L after periods of high inflows relative to storage volume, increasing gradually to over 300 mg/L after an extended period of low inflows, and presumably high evaporation relative to storage volume (Figure 5.23). The median salinity for this data is 165 mg/L, which is slightly lower than that upstream. This phenomenon would be because of the averaging effects of the storage.

The simulation both underestimates and overestimates the salinity in Burrendong Dam during different times, with a net underestimate over the whole period. The particular periods when it underestimates are when the volume in the storage is decreasing, during periods of low flows (Figure 5.23). The most obvious example of this is during 1996-7, and also 1998-9. However, during periods of high inflows, such as 1986 and 1998, the model underestimates the change in concentration quite significantly. These two characteristics combined results in a poor score on the range match. The model does seem to get the pattern of concentrations correct, and gets a fair score on this match.

Table 5.10. Results of performance measures for simulated versus observed concentrations at Burrendong Dam using Salinity Audit Relationships

Performance measure	Result
Pattern match	0.408
Mean match	0.154
Average error	0.188
Range match	0.650
R^2	0.552

5.3.5. Station 421001: Macquarie River @ Dubbo

There is unfortunately only a small amount of discrete data at Dubbo during the evaluation period (1985-2000), some from 1986-1990, and in 2000 (Figure 5.24). This data is across all flow ranges, and is distributed across all months, with the exception of October (Table 5.11). The flow on the days on which data was collected has similar statistical characteristics to the flow on all days over the evaluation period, but misses the high end of the high flow range.

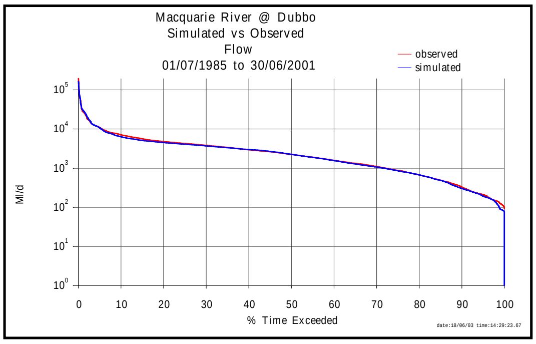
The match of flow distribution at this site is quite good, and the distribution of salinities also appears good, however, this is too small a sample to rely on.

Table 5.11. Distribution of flow with discrete EC across flow ranges and months for Station 421001: Macquarie River @ Dubbo

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1985-2000	6	0	0	0	2	2	1	1	0	0	0	0	0
Medium		11	2	1	1	1	1	2	1	1	0	0	0	0
High		10	1	1	0	0	0	0	0	0	2	0	2	2
All		27	4	2	1	3	3	3	2	1	3	0	2	2

Table 5.12. Comparison of statistics within flow ranges of *all observed flows versus observed flows on days with discrete EC* data during evaluation period for Station 421001: Macquarie River @ Dubbo

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	352	165	94	675
	With EC obs	298	116	198	490
Medium	*All*	2402	1,191	676	4,785
	With EC obs	2683	1,521	798	4,767
High	*All*	11,344	14,706	4,786	192,545
	With EC obs	7,950	2,014	5,144	10,767
ALL	*All*	3,779	7,680	94	192,545
	With EC obs	4,104	3,490	198	10,767

(a)


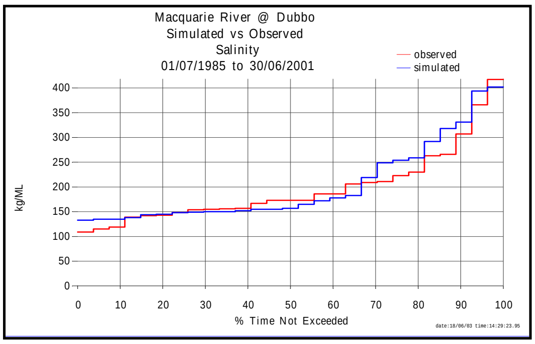
(b)


Figure 5.7. Station 421001: Macquarie River @ Dubbo; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.13. 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 421001: Macquarie River @ Dubbo

Flow range	Data set	Distributions								C_o v 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*	298	116	198	490	279	93	173	417	168	0.90	80
	Simulated	264	231	1	556	447	215	251	755			88
Medium	*Observed*	2,517	1,494	798	4,767	197	57	119	307	227	0.40	443
	Simulated	1,201	1,761	0	4,820	422	188	136	655			232
High	*Observed*	7,950	2,015	5144	10,767	149	24	109	186	191	0.09	1199
	Simulated	2,808	4,102	0	10,877	339	166	142	534			443
All	*Observed*	4,095	3,559	198	10,767	198	75	109	417	200	0.40	650
	Simulated	1,603	2,874	0	10,877	396	185	136	755			280

5.3.6. Station 421127: Macquarie River @ Baroona

There is slightly more data at Baroona than upstream at Dubbo (Figure 5.25), and represents the flow ranges and months uniformly (Table 5.14). The statistical representativeness within each flow range is also good, and samples the high end of the high flow range (Table 5.15).

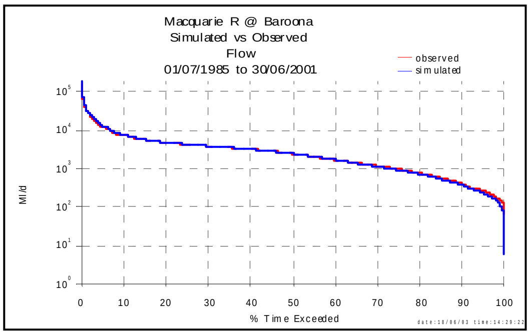
The simulated salinity appears to represent the observed data reasonably well during the evaluation period (Figure 5.8), and the distribution of simulated flows and salinities appear to match the distribution of observed data. Simulated flow and salinity appear to have a good match to the observed data (Table 5.16).

Table 5.14. Distribution of flow with discrete EC across flow ranges and months for Station 421127: Macquarie River @ Baroona

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1985-2001	7	0	0	0	2	1	1	1	1	0	0	0	0
Medium		18	4	1	4	2	0	1	1	1	1	1	0	1
High		18	1	2	0	1	1	0	1	1	4	1	2	2
All		43	5	3	4	5	2	2	3	3	4	2	2	3

Table 5.15. Comparison of statistics within flow ranges of *all observed flows versus observed flows on days with discrete EC* data during evaluation period for Station 421127: Macquarie River @ Baroona

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	415	184	65	753
	With EC obs	542	149	235	670
Medium	*All*	2508	1,185	754	4,816
	With EC obs	2911	1,024	926	4,293
High	*All*	12,834	16,167	4,817	174,041
	With EC obs	30,896	48,258	4,828	174,041
ALL	*All*	4,148	8,508	65	174,041
	With EC obs	14,240	33,886	235	174,041

(a) 

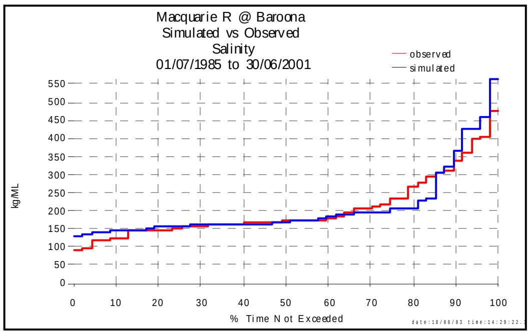
(b) 

Figure 5.8. Station 421127: Macquarie River @ Baroona; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.

Table 5.16. 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 421127: Macquarie River @ Baroona

Flow range	Data set	Distributions								C_o v 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*	474	236	0	670	306	101	166	474	116	0.14	153
	Simulated	1,333	2,487	192	7,470	370	124	193	565			335
Medium	*Observed*	2,911	1,024	926	4,293	207	79	124	399	34	0.63	583
	Simulated	2,973	1,168	869	4,601	188	41	147	321			530
High	*Observed*	30,896	48,259	4,828	174,041	157	37	93	234	33	0.05	3,954
	Simulated	30,871	46,850	4,816	166,763	158	16	130	189			4,913
All	*Observed*	13,916	33,558	0	174,041	204	87	93	474	49	0.47	1,884
	Simulated	14,088	32,698	192	166,763	209	97	130	565			2,288

5.3.7. Station 421090: Macquarie River @ Marebone Weir

The data at Marebone Weir is similar to that at Dubbo, quite sparse, but uniformly distributed (Figure 5.26, Table 5.17). The days on which data was collected are reasonably representative of the overall flow characteristics.

The results of the simulation appear to match the data reasonably well (Figure 5.34), however, the flow is not well simulated at this location, significantly overestimating the low flow frequency (Figure 5.9). The results of the salinity simulation appear to be OK, notwithstanding the flow differences, and estimates the mean salinity for the full data set to within 10% (Table 5.19).

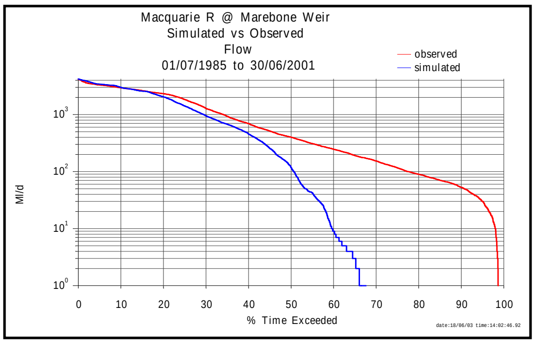
Table 5.17. Distribution of flow with discrete EC across flow ranges and months for Station 421909: Macquarie River @ Marebone Weir

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1985-2000	3	0	0	0	0	0	2	1	0	0	0	0	0
Medium		10	1	1	2	1	1	0	1	1	1	0	0	0
High		9	0	0	0	1	0	1	1	1	1	1	3	0
All		22	1	1	2	2	1	3	3	2	2	1	3	0

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 421090: Macquarie River @ Marebone Weir

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	52	27	0	94
	With EC obs	63	9	56	73
Medium	*All*	676	623	95	2339
	With EC obs	961	955	129	2249
High	*All*	3005	441	2340	4142
	With EC obs	2818	336	2392	3294
ALL	*All*	1002	1146	0	4142
	With EC obs	1598	1266	56	3294

(a)



(b)

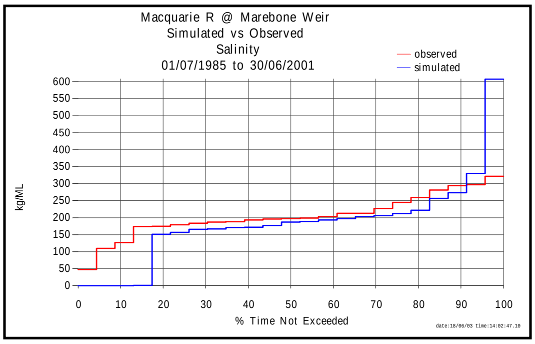


Figure 5.9. Station 421090: Macquarie River @ Marebone Weir; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.

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 for Station 421090: Macquarie River @ Marebone Weir

Flow range	Data set	Distributions								C_o v C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)				*Avg. error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*			
Low	*Observed*	38	35	0	73	239	64	187	322	156	0.01	9
	Simulated	1102	1444	0	2853	266	224	0	607			221
Medium	*Observed*	1138	997	129	2249	215	60	110	297	82	0.26	267
	Simulated	861	941	0	2631	150	99	0	273			165
High	*Observed*	2,818	336	2,392	3,294	180	61	48	259	44	0.02	494
	Simulated	2,472	873	1,247	3,419	190	32	151	257			454
All	*Observed*	1,575	1,293	0	3294	206	63	48	322	83	0.03	301
	Simulated	1,575	1,255	0	3419	193	123	0	607			296

5.3.8. Station 421012: Macquarie River @ Carinda

Carinda has a significant amount of data, sampled with a frequency approaching monthly, and periods of low salinity do appear to coincide with periods of higher flow (Figure 5.27). The median salinity at this site is 285 mg/L, significantly higher than that at Marebone Weir or Dubbo (Table 3.4). The data appears to be uniformly distributed across the flow ranges, and throughout the year (Table 5.20), and the statistics of the flows on the days with salinity data match the statistics for the whole flow record.

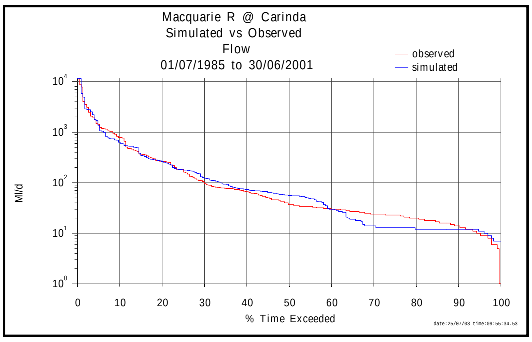
The simulated flow distribution at Carinda match the observed flow distribution well (Figure 5.10 a), however, the simulated salinity overestimates the observed salinity by several hundred percent.

Table 5.20. Distribution of flow with discrete EC across flow ranges and months for Station 421012: Macquarie River @ Carinda

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1985-2001	81	5	3	3	4	2	3	3	2	3	4	4	5
Medium		107	8	8	7	6	7	7	7	3	5	4	5	7
High		37	2	1	0	1	3	1	1	5	4	3	3	3
All		225	12	12	11	11	12	11	10	10	13	10	8	10

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 421012: Macquarie River @ Carinda

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	18	7	0	28
	With EC obs	18	7	3	28
Medium	*All*	100	72	29	351
	With EC obs	97	82	29	342
High	*All*	1,599	1,760	352	11,253
	With EC obs	1,930	2,618	355	11,253
ALL	*All*	382	995	0	11,253
	With EC obs	369	1260	3	11,253

(a)


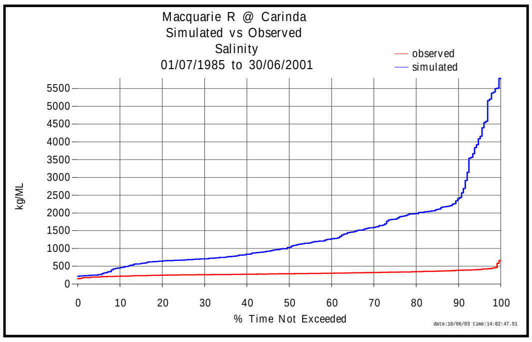
(b)


Figure 5.10. Station 421012: Macquarie River @ Carinda; (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 for Station 421012: Macquarie River @ Carinda

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*	18	7	3	28	337	71	182	658	1848	0.03	6
	Simulated	41	39	7	183	2,183	1,277	247	5,786			65
Medium	*Observed*	96	82	29	342	288	52	194	457	801	0.03	27
	Simulated	115	156	10	737	1,085	757	218	5370			91
High	*Observed*	1,928	2,619	355	11,253	245	50	150	342	295	0.11	393
	Simulated	1,747	2,709	18	11,565	539	235	226	1145			645
All	*Observed*	369	1,260	3	11,253	298	67	150	658	1095	0.15	80
	Simulated	357	1,255	7	11,565	1,390	1,120	218	5,786			173

5.3.9. Discussion of results from evaluation of results from simulation with Salinity Audit relationships

The results of the simulations using the Salinity Audit relationships for salt inflows significantly underestimated salt inflows to the two major headwater storages, and at the lower end of the Cudgegong River. The results for the Upper Macquarie, at Bruinbun appear to be good, although the model significantly overestimates salinities 10% of the time. In the absence of specific criteria for model acceptability, the results at Burrendong Dam and Windamere Dam suggest that the Salinity Audit relationships as used may not be estimating the distribution of salt loads well enough. An additional factor that may be contributing is the large residual combined with the large volumes of water removed by the calibration node where the Upper Macquarie enters Burrendong Dam. Undoubtedly, the underestimate into Windamere Dam translate to the underestimate at Yamble Bridge.

Results at the three stations downstream of Burrendong Dam appear to match the observed distributions well, however, the data at these locations is sparse. Further downstream, the results at Dubbo alone are not conclusive, however, the results compared with a better data set at Baroona suggest that the model is reproducing salinity patterns and magnitudes relatively well. Mean observed salinities are reproduced by the model at Marebone Weir are also not conclusive because of sparseness of data.

The results at Carinda at the end-of-valley are, however, emphatically overestimated. The over estimates at Carinda are not caused by incorrect estimates of salt inflows, as these have all entered the system already. These overestimates are because of the way that water balance was achieved for this part of the Macquarie System Quantity model. The Macquarie Marshes was modelled as a storage with a large surface area. The storage volume versus surface area relationship of the Macquarie Marshes was adjusted to achieve mass balance at Carinda.

Changes to the salt inflows into the storages will change model results downstream. Therefore, the model needs to be calibrated from top to bottom, requiring revision of salt inflows such that the statistical characteristics of the salinity are reproduced. In some cases there are known to be problems with the water balance. These cannot be addressed at this stage as it would require a re-calibration of the quantity model, which would take some time.

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 (Equation 5.8);

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

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

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.

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

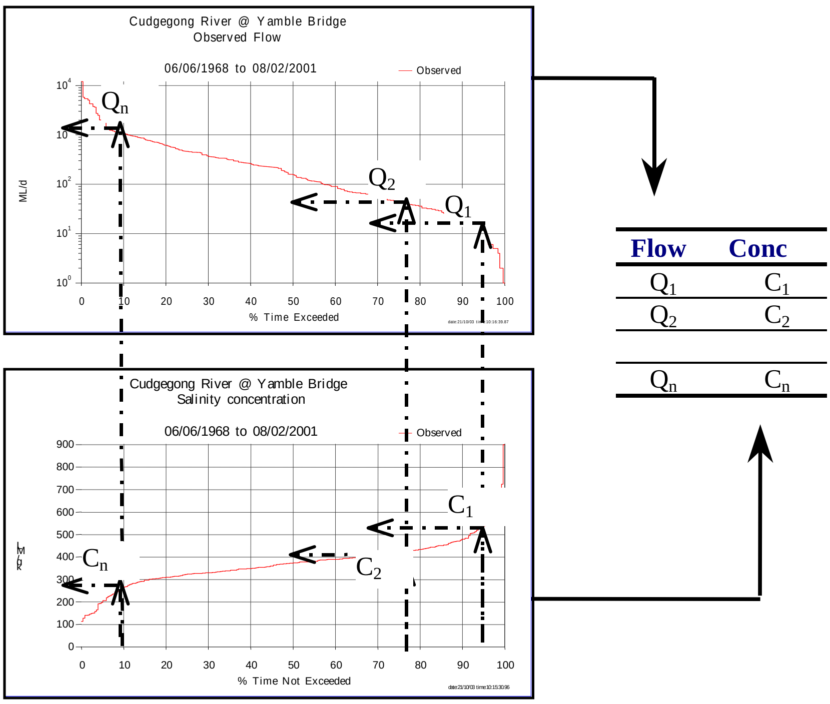


Figure 5.11. Derivation of flow versus concentration LUT from exceedance curves

5.4.1.2. Residual catchments

The salt inflows from residual catchments were calibrated using a procedure as illustrated in Figure 5.12. 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.

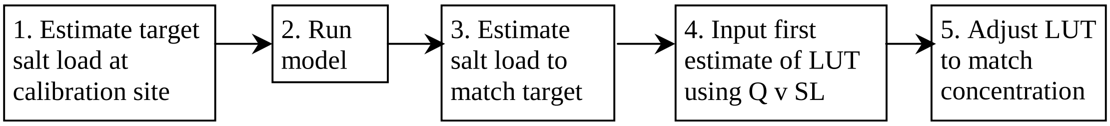


Figure 5.12. Procedure to calibrate salt inflows from residual catchments

5.4.2. Windamere Dam

The probable reason that Windamere Dam concentrations were underestimated is that it appears the inflow relationship used in the Salinity Audit was based on discrete salinity observations at the 421079 gauge from 1970-1995. Windamere Dam was commissioned in 1985, and the 421079 gauge was then moved downstream of the dam, and included another small tributary (Swan Creek.). The observed concentration data post 1985 would then not be representative of the storage inflows. A new relationship was generated using 1970-1984 data only, and converted to a flow-concentration LUT. This LUT was adjusted systematically to match the mean concentration of 300 mg/L of the 1985-2000 data set. The final result for this is set out in Table 5.23.

The results of this simulation can be seen shown in Figure 5.36. The match with observed data is overall quite good, however, the model overestimates concentrations in the latter period, and may be caused by the evaporation being over estimated during this period. The performance measures improved, with the mean match, average error and range all improving. The distribution of salinities also compare quite well with observed (Figure 5.11).

Table 5.23. Calibrated flow versus salinity relationship for Windamere Dam inflows

Flow (ML/d)	Concentration (mg/L)
0	0
1	320
10	320
250	250
500	220
2000	185
1e37	185

Table 5.24. Results of performance measures for simulated versus observed salinities in Windamere Dam using calibrated relationship

Performance measure	Result
Pattern match	0.525
Mean match	0.002
Average error	0.043
Range match	0.046
R^2	0.546

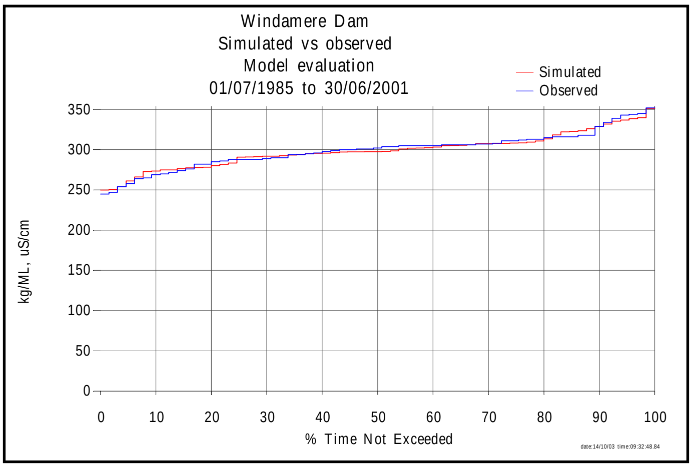


Figure 5.13. Non-exceedance curve for observed versus simulated salinity for calibrated model at Windamere Dam

5.4.3. Station 421019: Cudgegong River @ Yamble Bridge

Improving the results of the salinity simulation in Windamere Dam improved the results at this station. Further improvements were made by re-deriving the flow versus load relationship for the catchment Station 421058: Wyaldra Creek @ Gulgong (Equation 5.10). The flow-concentration LUT was derived using the method from Section 5.4.1.2, and the final calibrated relationship shown in Table 5.25.

The results of the simulation are shown in Figure 5.37, and appear to show a close match for most of the points. The distribution of simulated versus observed salinity data matches quite well, (Figure 5.14), with better results across all flow ranges (Table 5.26).

$$SL = e^{2.882} Q^{0.895} \qquad (5.10)$$

Table 5.25. Calibrated flow versus salinity relationship used for inflows in residual catchment R4

Flow (ML/d)	Concentration (mg/L)
0	0
1	700
25	530
30	180
50	70
75	100
400	700
600	700
800	800
1e37	800

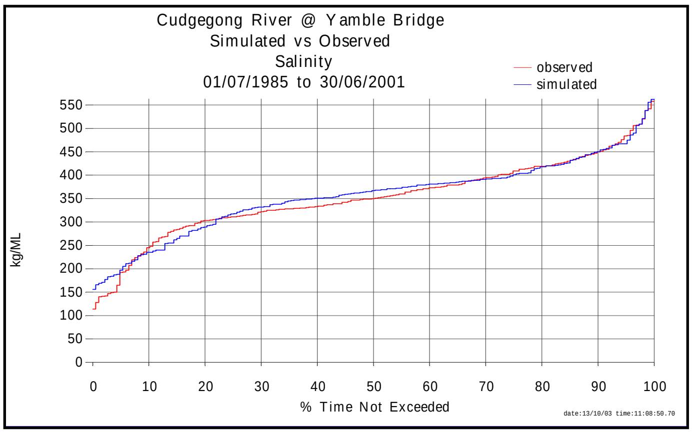


Figure 5.14. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421019: Cudgegong River @ Yamble Bridge

Table 5.26. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421019: Cudgegong River @ Yamble Bridge

Flow range	Data set	Distributions				C_o v C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	427	56	334	558	52	0.15	8
	Simulated	407	48	338	562			21
Medium	*Observed*	398	57	236	542	68	0.05	38
	Simulated	374	73	171	509			42
High	*Observed*	290	66	114	390	71	0.03	257
	Simulated	325	82	156	556			334
All	*Observed*	351	84	114	558	67	0.15	136
	Simulated	355	80	156	562			175

5.4.4. Station 421025: Macquarie River @ Bruinbun

The Bruinbun results were improved by re-deriving the salt inflows using a power relationship of flow versus salt load. The fact that this relationship form does not have an intercept means that there is a reduced incidence of concentrations at the inflow points at or near the maximum allowable concentration. This was expected to solve the problem with the periods of high concentration at Bruinbun discussed in Section 5.3.3. Parameters for the power relationships for: Station 421010; Campbells River u/s Ben Chifley Dam; Station 421035; Fish River @ Tarana; and Station 421072; Winburndale Rivulet @ Howards Bridge are reported in Equation 5.11, Equation 5.12, and Equation 5.13 respectively. The Salinity Audit relationships for the residual catchments R1 and R2 were converted to flow-concentration LUTs, which were adjusted to match the observed non-exceedance curve. The final LUTs are reproduced in Table 5.27 and Table 5.28 respectively.

The final simulation results for observed and simulated salinity is shown in Figure 5.38, which shows a slight improvement compared with the Salinity Audit relationships. The simulated versus observed non-exceedance curve (Figure 5.15) shows a slight improvement compared with the Salinity Audit relationships, but a significant improvement for salinities with a non-exceedance probability above 90%. The comparative statistics for the flow ranges are also quite close across all flow ranges (Table 5.29)

$$SL = e^{2.939} Q^{0.865} \tag{5.11}$$

$$SL = e^{1.733} Q^{0.851} \tag{5.12}$$

$$SL = e^{2.577} Q^{0.780} \tag{5.13}$$

Table 5.27. Calibrated flow versus salinity relationship for inflows in residual catchment R1

Flow (ML/d)	Concentration (mg/L)
0	0
1	420
8	420
15	275
30	195
60	150
150	125
400	115
1e37	110

Table 5.28. Calibrated flow versus salinity relationship for inflows in residual catchment R3

Flow (ML/d)	Concentration (mg/L)
0	0
1	370
35	360
75	240
90	200
200	150
10000	140
1e37	135

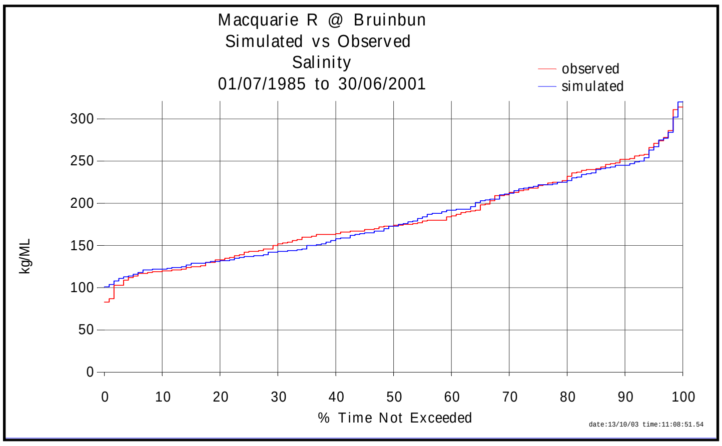


Figure 5.15. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421025: Macquarie River @ Bruinbun

Table 5.29. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421025: Macquarie River @ Bruinbun

Flow range	Data set	Distributions – Salinity (mg/L) Mean	S.D	Min	Max	C_o v C_s Avg. error (mg/L)	R^2	Mean load (t/d)
Low	*Observed*	221	48	120	314	37	0.11	6
	Simulated	211	44	101	275			27
Medium	*Observed*	175	39	112	257	37	0.08	53
	Simulated	173	43	121	320			55
High	*Observed*	125	31	83	180	16	0.55	329
	Simulated	129	18	104	164			318
All	*Observed*	182	52	83	314	34	0.31	80
	Simulated	179	49	101	320			86

5.4.5. Burrendong Dam

The salinities in Burrendong Dam were significantly underestimated using the Salinity Audit relationships alone. These were improved slightly after the Cudgegong River was calibrated. The first step in calibrating the salt inflows was to aggregate the inflows to Burrendong Dam, and using the simulated net concentration from the Audit Relationships as a starting point, developing a flow-concentration LUT that matched the Burrendong Dam salinities. This result is in Table 5.30.

This relationship then produced salt load target for calibration, and the procedure discussed in Section 5.4.1 used. The salt inflows for Station 421026 (Turon River @ Sofala), Station 421052: (Lewis Ponds Creek @ Ophir) and Station 421041(Crudine River u/s Turon River Junction) were re-estimated using the power relationship and all available data. The resultant relationships are referenced in Equation 5.14, Equation 5.15, and Equation 5.16 respectively. The Salinity Audit relationship for Residual Catchment R3 was converted to flow-concentration LUTs, and calibrated to the target relationship shown at Table 5.31.

Final results for the calibration are shown in Figure 5.31, and show a good average match, as well as reproducing the patterns of salinity in the storage well. The match during the years 1990-1995 is not as consistent, with the data showing variability inconsistent with that expected within a storage. All the performance measures improved compared with those using the results from the Salinity Audit simulation, especially the mean match, average error, and range match. There were slight improvements in the pattern match and R^2.

Table 5.30. Target Calibrated flow versus salinity relationship for net inflows to Burrendong Dam

Flow (ML/d)	Concentration (mg/L)
0	0
0.1	800
100	550
600	276
6000	100
$1*10^{37}$	40

$$SL = e^{2.846} Q^{0.836} \tag{5.14}$$

$$SL = e^{2.919} Q^{0.776} \tag{5.15}$$

$$SL = e^{2.953} Q^{0.811} \tag{5.16}$$

Table 5.31. Calibrated flow versus salinity relationship for inflows in residual catchment R3

Flow (ML/d)	Concentration (mg/L)
0	0
1	2000
5	2000
10	1800
50	850
100	400
500	310
800	310
2000	250
3000	90
5000	40
$1*10^{37}$	25

Table 5.32. Results of performance measures for simulated versus observed concentrations at Burrendong Dam using calibrated relationships

Performance measure	Result
Pattern match	0.380
Mean match	0.005
Average error	0.116
Range match	0.336
R^2	0.615

5.4.6. Station 421001: Macquarie River @ Dubbo

The improved match in salinity at Burrendong Dam changed the results at Dubbo. Improvements were made to the model be replacing the linear relationships with power relationships for the case of Station 421018 (Bell River @ Newrea (Equation 5.17)). Also by developing a flow-concentration LUT for Station 421059 (Buckinbah Creek @ Yeoval) using the PLUTO method (Table 5.33). Salt inflows from the Salinity Audit relationships for the residual catchments were converted to flow-concentration LUTs (Table 5.34, Table 5.35, and Table 5.36). After viewing the results, no further adjustments were made.

The results at this site are shown in Figure 5.40. The results at this site are not especially conclusive as to whether the model is simulating the observed data well. At some times the simulated concentration tends to match the observed data well, eg., 1988, 2000, 2001, whereas the model significantly overestimates the observed data in the early years, eg., 1986. However, the non-exceedance plots do match reasonably well (Figure 5.41), and the statistics of the simulated concentrations are similar to those for the observed across all flow ranges (Table 5.37).

$$SL = e^{3.549} Q^{0.856} \qquad (5.17)$$

Table 5.33. Calculated flow versus salinity relationship for salt inflows from catchment Station 421059: Buckinbah Creek @ Yeoval

Flow (ML/d)	Concentration (mg/L)
0	0
1	1146
2	1025
4	972
7	936
12	900
15	859
17	806
24	708
46	636
78	424
153	311
321	233
1497	144
$1*10^{37}$	144

Table 5.34. Calibrated flow versus salinity relationship for inflows in R5/6/7

Flow (ML/d)	Concentration (mg/L)
0	0
1	1032
2	438
3	380
6	313
11	266
20	213
49	172
103	130
206	101
516	81
1120	56
2617	55
$1*10^{37}$	55

Table 5.35. Calibrated flow versus salinity relationship for inflows in residual catchment R5/6/7

Flow (ML/d)	Concentration (mg/L)
0	0
1	580
150	374
274	276
931	193
5424	164
35152	160
$1*10^{37}$	160

Table 5.36. Calibrated flow versus salinity relationship for inflows in residual catchment R5/6/7

Flow (ML/d)	Concentration (mg/L)
0	0
1	1150
10	1150
25	800
50	590
150	470
500	410
$1*10^{37}$	410

Figure 5.16. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421001: Macquarie River @ Dubbo

Table 5.37. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421001: Macquarie River @ Dubbo

Flow range	Data set	Distributions				C_o v C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	279	93	173	417	67	0.37	80
	Simulated	297	41	242	353			90
Medium	*Observed*	202	58	119	307	30	0.50	411
	Simulated	195	51	155	319			401
High	*Observed*	150	22	109	186	20	0.02	1,117
	Simulated	150	12	135	178			1,108
All	*Observed*	196	74	109	417	34	0.60	651
	Simulated	198	67	135	353			646

5.4.7. Station 421127: Macquarie River @ Baroona

The salinity results at Baroona were improved by replacing the Salinity Audit relationships for catchments Station 421055: Coolbaggie Creek @ Rawsonville, and Station 421042: Talbragar River @ Elong Elong using the PLUTO method (Table 5.38 and

Table 5.40)respectively. The salt load inflows were converted to flow-concentration LUTs, and adjusted in several iterations to achieve a better result at the 20th and 80th percentiles. The final results are at Table 5.40 and Table 5.41.

The results for the calibration are shown in Figure 5.41. The patterns in this result are simular to the ones in the results for Dubbo, particularly the overestimate in 1986. Similarly, the non-exceedance plots match reasonably well (Figure 5.17) with the exception of an underestimate around the crucial 80% non-exceedance probability. The statistics of the simulated concentrations are similar to those for the observed data across all flow ranges (Table 5.37).

Table 5.38. Calculated flow versus salinity relationship for inflows from Station 421055: Coolbaggie Creek @ Rawsonville

Flow (ML/d)	Concentration (mg/L)
0	0
1	518
2	96
4	78
7	70
8	64
13	62
26	59
63	50
156	40
389	38
2370	26
14300	25
$1*10^{37}$	25

Table 5.39. Calculated flow versus salinity relationship for inflows from Station 421042: Talbragar River @ Elong Elong

Flow (ML/d)	Concentration (mg/L)
0	0
1	1740
2	792
9	681
22	587
38	550
55	489
84	426
125	332
195	228
448	180
1317	103
3837	66
$1*10^{37}$	66

Table 5.40. Calibrated flow versus salinity relationship for inflows in residual catchment R8/R9

Flow (ML/d)	Concentration (mg/L)
0	0
1	1900
10	1900
35	1000
75	600
200	500
600	430
5000	210
$1*10^{37}$	210

Table 5.41. Calibrated flow versus salinity relationship for inflows in residual catchment R8, R9

Flow (ML/d)	Concentration (mg/L)
0	0
1	520
100	520
200	380
400	360
1000	350
4000	220
$1*10^{37}$	210

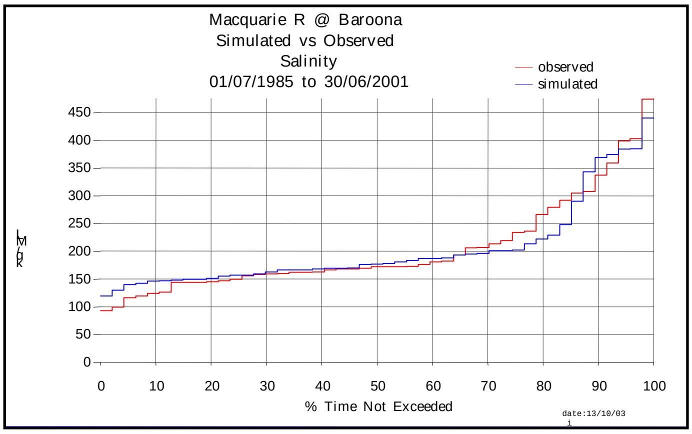


Figure 5.17. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421127: Macquarie River @ Baroona.

Table 5.42. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421127: Macquarie River @ Baroona

Flow range	Data set	Distributions				C_o v C_s		Mean load (t/d)
		Salinity (mg/L)						
		Mean	*S.D*	*Min*	*Max*	*Mean error (mg/L)*	R^2	
Low	*Observed*	306	101	166	474	81	0.22	153
	Simulated	334	84	201	440			327
Medium	*Observed*	207	79	124	399	36	0.60	583
	Simulated	196	45	146	343			554
High	*Observed*	157	37	93	234	30	0.07	3954
	Simulated	155	16	119	181			4275
All	*Observed*	204	87	93	474	42	0.58	1884
	Simulated	204	79	119	440			2035

5.4.8. Station 421090: Macquarie River @ Marebone Weir

The evaluation of the results from using the Salinity Audit relationships underestimated the observed data at the target percentiles. The calibration of the inflows upstream of the Baroona has improved these results. The only inflow in this reach is Ewenmar Creek. The Salinity Audit relationship was converted to a flow-concentration look-up table (Table 5.43). No adjustments were made to this table.

The results from the simulation are shown in Figure 5.42, and appear to match the observed data reasonably well. The over-estimate evident at Dubbo and Baroona in 1986 do not appear here. The distributions of simulated and observed data appear to match well for the median percentiles, however, overestimate at both the high and low non-exceedance probabilities. Some of this deviation can be attributed to the low amount of data at this site. The two low salinity observations apparent in 1989 and 2000 have pulled the observed non-exceedance curve down at this end. There is considerable doubt at least for the 1989 observation. The over estimate at the high non-exceedance probabilities may be because the reaches are drying out by evaporation. The statistics of the simulated versus observed match well overall, however, the model overestimates by 25% in the low flow range.

Table 5.43. Flow versus salinity LUT for Ewenmar Creek in the calibrated model

Flow (ML/d)	Concentration (mg/L)
0	0
1	1000
32	1000
60	610
120	400
220	300
600	235
2000	205
$1*10^{37}$	195

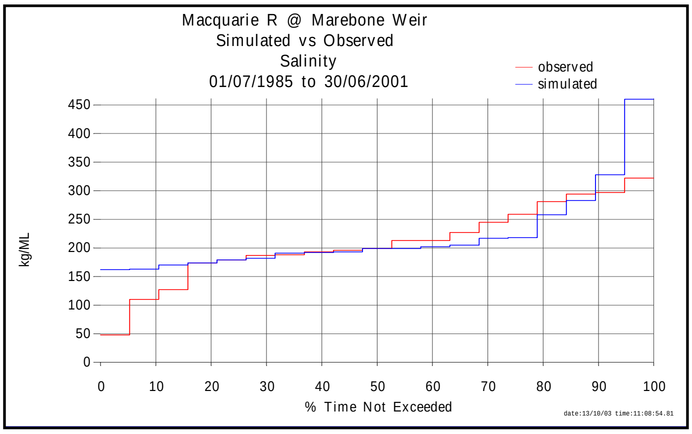


Figure 5.18. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421090: Macquarie River @ Marebone Weir

Table 5.44. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421090: Macquarie River @ Marebone Weir

Flow range	Data set	Distributions				C_o v C_s		Mean load (t/d)
		Salinity (mg/L)				*Mean error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	248	71	187	322	110	0.14	8
	Simulated	299	122	202	460			286
Medium	*Observed*	205	77	110	297	32	0.73	227
	Simulated	208	56	162	283			198
High	*Observed*	195	65	48	281	51	0.01	512
	Simulated	195	25	163	258			434
All	*Observed*	208	68	48	322	59	0.05	346
	Simulated	220	72	162	460			353

5.4.9. Station 421012: Macquarie River @ Carinda

The high concentrations at Carinda were caused by the way water quantity is modelled at the Macquarie Marshes. These were simulated in the quantity model as a very large storage with a high surface area, and were calibrated using data from three large events. This resulted in good results for flow calibration at Carinda, however, it turns out the surface area has been overestimated, thereby overestimating evaporation, and concentrating the salinity. Clearly, the evaporation had to be reduced, but this needed to be done without affecting the quantity results.

The method to fix this involved splitting the current evaporation loss into two loss components:

(i) loss through evaporation; and

(ii) loss to groundwater, with no concentration of salt.

The balance between these two components was adjusted so that the mean of the simulated concentration is approximately equal to the mean of the observed data. The best match was achieved with a ratio of evaporation loss to groundwater loss of approximately 58:42. The resultant calibration to the mean produced the result shown at Figure 5.43. The pattern match here is poor, especially when the storage is receding. A possible reason for this is that the increase is not dominated by evaporation, but by salt that has been precipitated on the ground surface when the volume in the Marshes is increasing. Methods to improve this will need to be developed.

The distributions of simulated versus observed salinities show a reasonable match Figure 5.19, with a slight overestimate at the 80th percentile non-exceedance. A direct comparison of the simulated versus observed shows that the statistics are close across all flow ranges, although the timing is not matched.

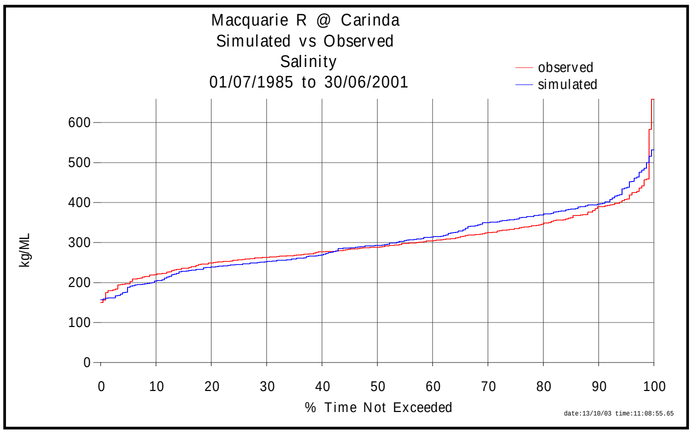


Figure 5.19. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 421090: Macquarie River @ Carinda

Table 5.45. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 421090: Macquarie River @ Carinda

Flow range	**Data set**	**Distributions**				**C_o v C_s**		**Mean load (t/d)**
		Salinity (mg/L)				*Mean error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	328	66	182	658	64	0.04	7
	Simulated	350	62	207	532			14
Medium	*Observed*	281	53	196	457	69	0.07	36
	Simulated	273	54	188	481			35
High	*Observed*	241	49	150	342	54	0.03	419
	Simulated	208	39	157	305			343
All	*Observed*	298	67	150	658	64	0.13	80
	Simulated	301	77	157	532			72

5.5. VALIDATION OF RESULTS

5.5.1. Continuous salinity records

The results for the calibration were further assessed by comparing the simulations with continuous data reported in Table 3.3. The full time series of simulated versus observed concentrations are shown at Figure 5.44 to Figure 5.51 for all evaluation sites, with the exception of Windamere Dam. A full statistical assessment is not possible at this stage, because (i) methods have not been developed yet; (iii) the continuous data record is short, and is not representative of the benchmark climate period; and (ii) there are discrepancies between discrete and continuous data (see Figure 3.4). Nevertheless, the data is useful to assess that the model is modelling the salinity behaviour correctly.

The results at the lower end of the Cudgegong system (Figure 5.40) from August 1997 to June 2001 show that the model is getting the patterns of salinity generally correct, but that the model produces more variable salinity than the observed data. This greater variability probably results from the multiple modelled ungauged catchments in the between Windamere Dam and Yamble Bridge. Another notable feature is that the observed salinity in 2001 is steadily increasing, whereas the simulation does not produce this result. This characteristic in the observed data has not been observed elsewhere, and is possibly an error.

The results at the Macquarie @ Bruinbun also appear to reproduce the general pattern of the observed data with greater variability. In this case the reduction in modelled salinity associated with events is greater than the observed. The results downstream of Burrendong Dam appear to broadly follow the pattern, but is not able to reproduce the rates of increase in salinity of the observed data. This is particularly noticeable with the rapid increases in mid-2000, and again in mid-2001. The cause of this mismatch may be the methods used to achieve water balance, or that there is some process not bein modelled, such as thermal stratification in the storage. The discrete data was checked again, and there appeared to be higher salinities in the winter than the summer.

Additional daily data sourced from Dubbo Council Town Water Supplies proved to be the best record within the Macquarie Valley, with over five years of record supplied. This data was consistent with the continuous data record extracted from DWE's HYDSYS database. The results at this location are very good, with the patterns of changes in salinity being consistently matched over the full five years (Figure 5.47), with what appears to be a good match also with the magnitude. The exception to this is that the model appears to be persistently underestimating salinity from mid-2000. The DWE continuous results are consistent with this conclusion (Figure 5.48).

Similar conclusions, ie matching patterns and magnitudes up to 2000, could also be drawn for the results at Baroona (Figure 5.49), and Marebone Weir (Figure 5.50). The simulated results at Carinda (Figure 5.51) only broadly match the pattern of the observed data. However, the rates of increase in the observed data are not reproduced in the simulated results, suggesting that the methods used to match the water balance in Carinda need to be reviewed.

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

Compared with the Salinity Audit, there is a range of differences in the annual salt load at the inflow and balance points (Table 5.46) as well as those used for the initial model evaluation (column 4 in Table B.8.1). The differences at the catchment as a percentage is in quite significant, although in real term only usually +/- a couple of thousand tons per year. The exception to this is the residual catchment R4, which is approximately twenty thousands ton per year higher. This change was necessary to get the matches in concentration at Station 421019: Cudgeong River @ Yamble Bridge.

The differences at the balance points were mostly minor, from 1% compared to the Audit for Station 421006: Macquarie River @ Narromine, the last balance point recorded in the Audit, to 5% up the river at Dubbo, less than 2% downstream of Burrendong Dam, and 4% at the lower end of the Upper Macquarie at Bruinbun. The only significant differences compared with the reported values in the Salinity Audit is the increase of 44% for the lower end of the Cudgegong River.

Table 5.46. 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**	Audit	Audit (modified)	Calibrated
421079	Cudgegong River @ Windamere Dam Site	9.5	9.1	12
421058	Wyaldra Creek @ Gulgong	10.0	6.2	4
R4	Ungauged Cudgegong River u/s Yamble Bridge	13.6	14.7	35
421019	**Cudgegong River @ Yamble Bridge**	34.0	**30.6**	**49**
421035	Fish River @ Tarana	5.1	4.9	4
421101	Campbells River u/s Ben Chifley Dam	12.4	10.5	13
R1	Ungauged Macquarie River u/s Bathurst	14.2	11.5	12
421072	Winburndale Rivulet @ Howards Bridge	11.5	9.4	6
R2	Ungauged Macquarie River between Bathurst and Bruinbun	12.0	9.8	8
421025	**Macquarie River @ Bruinbun**	45.3	**44.9**	**43**
421052	Lewis Ponds Creek @ Ophir	9.3	7.3	9
421041	Crudine River u/s Turon River junction	5.1	4.0	5
421026	Turon River @ Sofala	14.1	12.5	12
421073	Meroo Creek @ Yarrabin 2	12.1	10.7	10
R3	Ungauged Macquarie and Cudgegong Rivers u/s Burrendong Dam	38.7	23.3	26
421040	**Macquarie River d/s Burrendong Dam**	147.8	**129.6**	**146**
421018	Bell River @ Newrea	30.4	25.7	29
421059	Buckinbah Creek @ Yeoval	12.6	12.2	8
R5,6,7	Ungauged Macquarie River between Burrendong Dam and Dubbo	22.0	29.4	24
421001	**Macquarie River @ Dubbo**	212.9	**193.2**	**203**
421042	Talbragar River @ Elong Elong	15.5	15.5	9
R8-9	Ungauged Macquarie and Talbragar Rivers u/s Narromine	24.3	18.2	23
421055	Coolbaggie Creek @ Rawsonville	6.5	4.9	1
421006	**Macquarie River @ Narromine**	234.0	**224.1**	**232**
421023	Bogan River @ Gongolgon	34.0	N/A	N/A

5.6. MODEL SUITABILITY FOR PURPOSE

The salt transport models have two key purposes under the BSMS. The first is that it can produce a time series of flows, salinities, and salt loads for the Baseline Condition and the Benchmark Climate period. The second is that it can estimate the in-stream flow and salinity effects of land based salinity management actions, such as land-use change, 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 Macquarie IQQM is a robust and reliable water balance model of the Macquarie River. The model has been peer reviewed externally, and has been used for a number of years to provide information for developing water sharing policies. 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, particularly upstream of Burrendong Dam. These methods developed a model that was fit for the purpose of water sharing, but create difficulties in calibrating the salt balance. There are also some limitations in the methods and results of water balance through the Macquarie Marshes. This was not a limitation for the previous water sharing work, but may effect reliability of results for the salt balance at this site.

The result of the comparison for salinity and salt loads from the tables in Section 5.3 are summarised in Table 5.47. The quality of the results has been coded according to how close the simulated results match the mean observed concentrations or salt loads in the respective flow ranges.

The mean concentrations at all evaluation points in each flow range were matched within ±10% with three exceptions. These exceptions are the high flow range at the Cudgegong River @ Yamble Bridge, the low flow range at Macquarie River @ Marebone Weir, and the high flow range at Macquarie River @ Carinda.

The match of simulated salt loads to observed data was good for the total flow, with all evaluation points except Cudgegong River @ Yamble Bridge within ±10%. However, the salt load results within the respective low, medium, and high flow ranges are variable. The matches at Bruinbun, Dubbo and Baroona are within ±10% for the medium and high flow ranges, but not as close for the low flow range. All the evaluation points had matches in the low flow range greater than ± 20%, except for Dubbo, which was within ±20%. Cudgegong River @ Yamble Bridge, Macquarie River @ Marebone Weir, and Macquarie River @ Carinda had matches within ±20% or worse in more than one of the flow range categories.

In summary, the model appears to simulate the salinity behaviour in the river system well. The matches for the non-exceedance curves reported in Section 5.4, the corresponding consistency of behaviour of continuous and daily behaviour, and the close match of mean concentrations across all flow ranges at all evaluation sites gives us confidence in this. The exceptions to this may include Cudgeong River @ Yamble Bridge, and Macquarie River @ Carinda, which both have significant differences in the time-series results. The model appears to be able to reproduce the overall mean salt loads as well, except that there is more uncertainty about the distribution of these, especially in the low flow range.

Table 5.47. Summary of comparisons of simulated versus observed salt loads

Target Site		concentration match				salt load match			
Number	Name	*Low*	*Medium*	*High*	*All*	*Low*	*Medium*	*High*	*All*
		Legend: 1 < ±10%; 2 < ±20%; 3= > ±20%							
	Windamere Dam	-	-	-	1	-	-	-	1
421019	Cudgegong River @ Yamble Bridge	1	1	2	1	3	2	3	3
421025	Macquarie River @ Bruinbun	1	1	1	1	3	1	1	1
	Burrendong Dam	-	-	-	1	-	-	-	1
421001	Macquarie River @ Dubbo	1	1	1	1	2	1	1	1
421127	Macquarie River @ Baroona	1	1	1	1	3	1	1	1
421090	Macquarie River @ Marebone Weir	3	1	1	1	3	2	2	1
421012	Macquarie River @ Carinda	1	1	2	1	3	1	2	1

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 cover in a catchment. The resultant time series would then be substituted for the time series used for the Baseline Conditions, and routed through the river system. This would produce a different distribution of flow, salinity, and salt load compared with the Baseline Condition.

The model has some limitations with respect to this. The methods used to estimate the ungauged catchment inflows upstream of Burrendong Dam would remove nearly all the low flow salt load from the upper Macquarie, as well as a significant part of the medium and high flow range salt load. This would then underestimate the impact of land management of the catchments in the Upper Macquarie Region.

5.6.3. Water management scenarios

The impacts of various water sharing scenarios on salinity can be simulated with confidence.

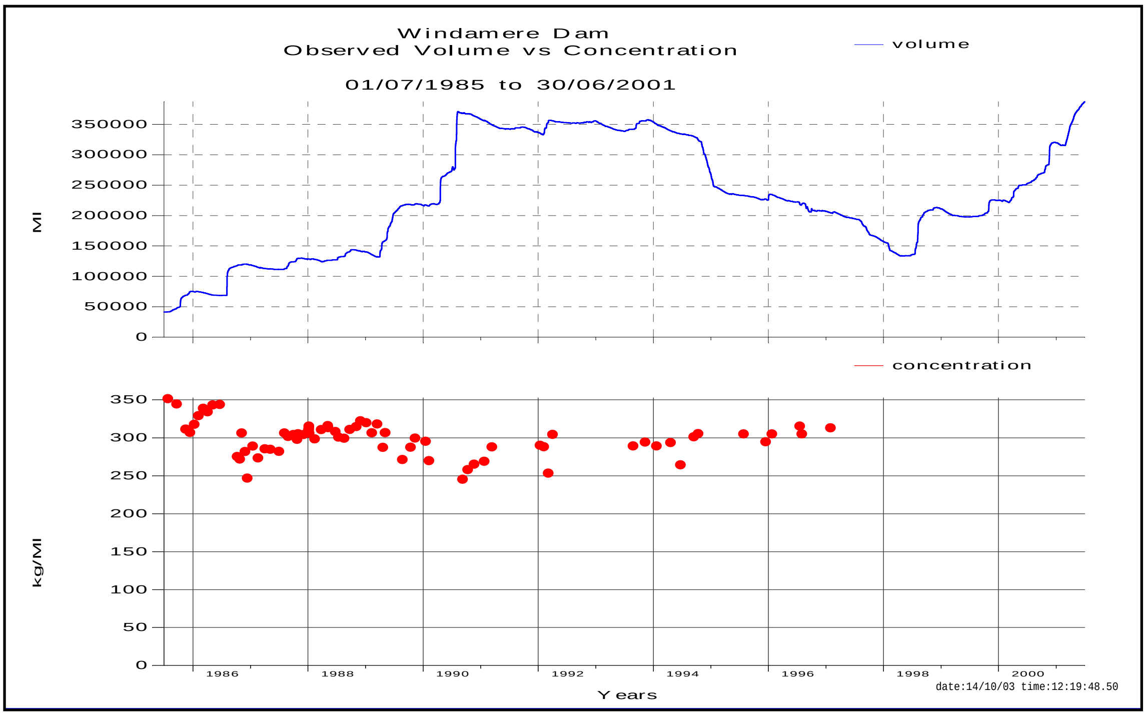


Figure 5.20. Windamere Dam storage volume and concentration data

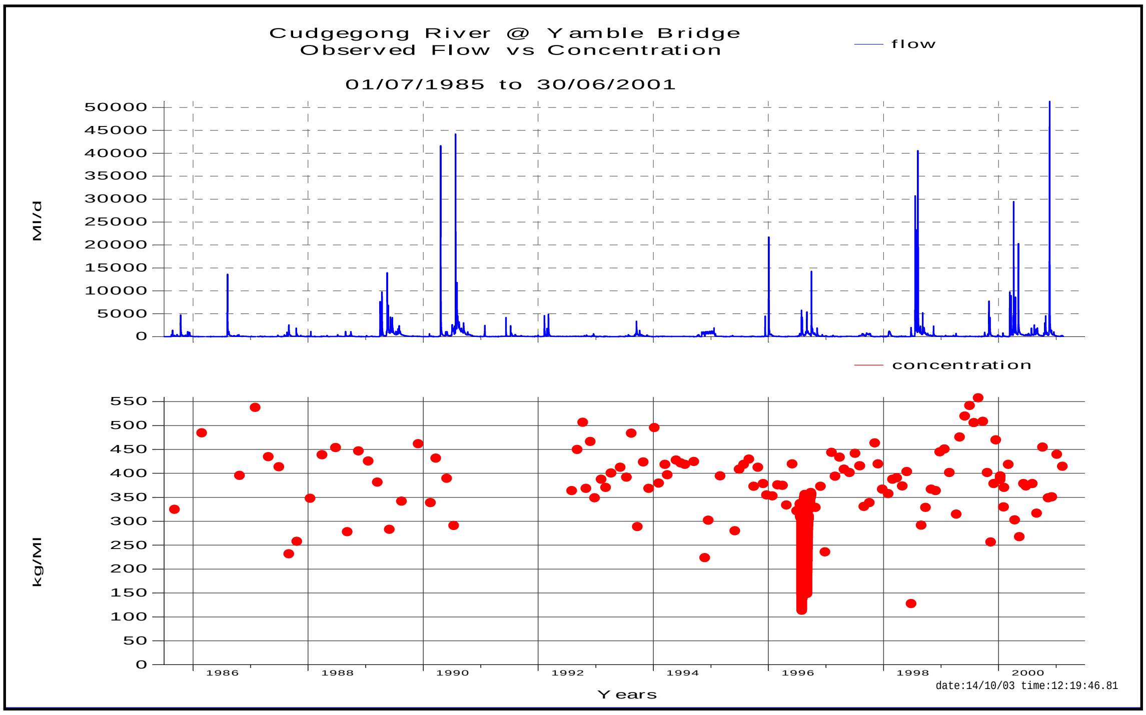


Figure 5.21. Station 421019: Cudgegong River @ Yamble Bridge flow and concentration data

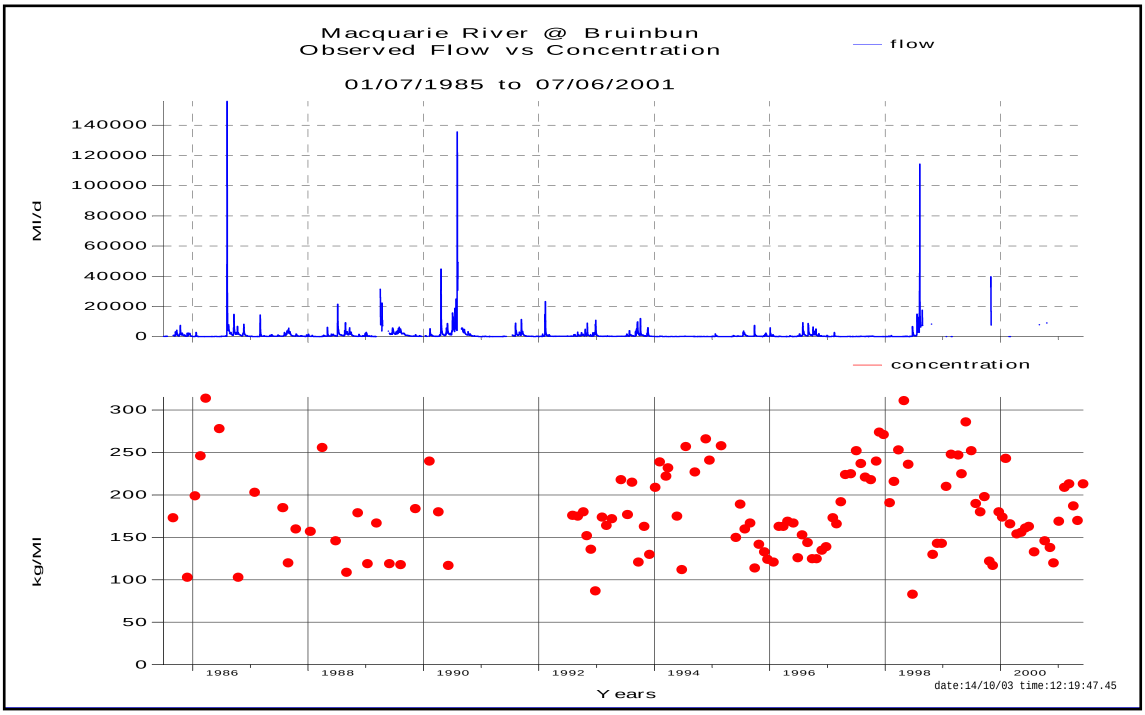


Figure 5.22. Station 421025: Macquarie River @ Bruinbun flow and concentration data

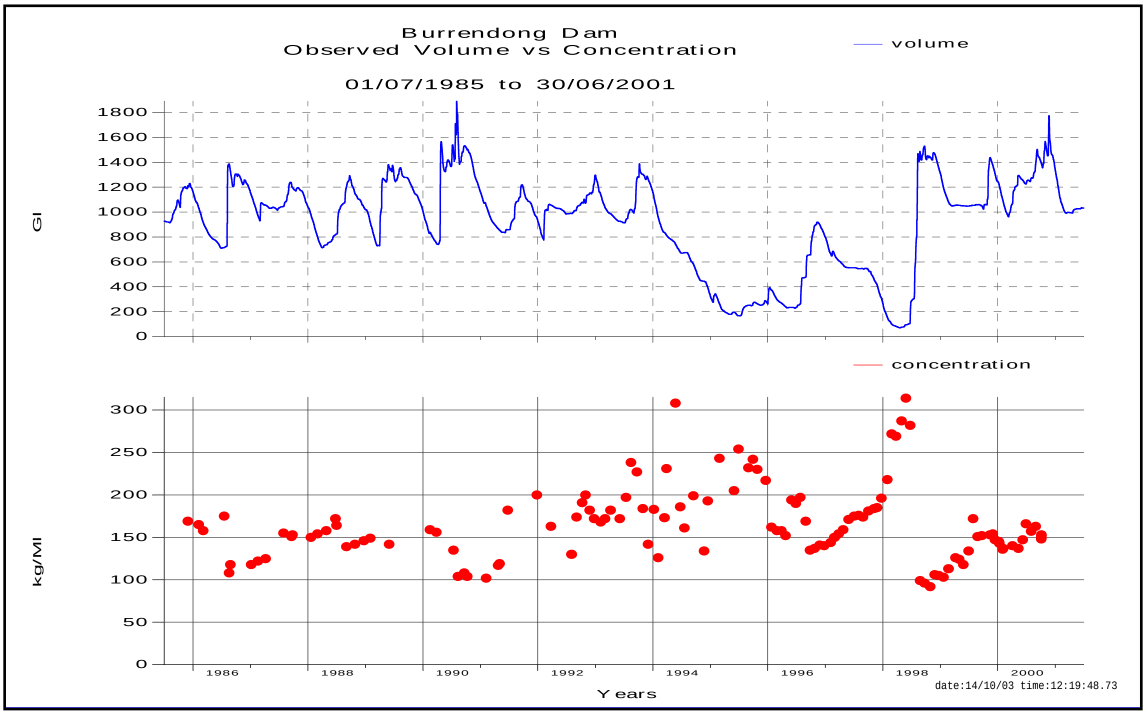


Figure 5.23. Burrendong Dam storage volume and concentration data

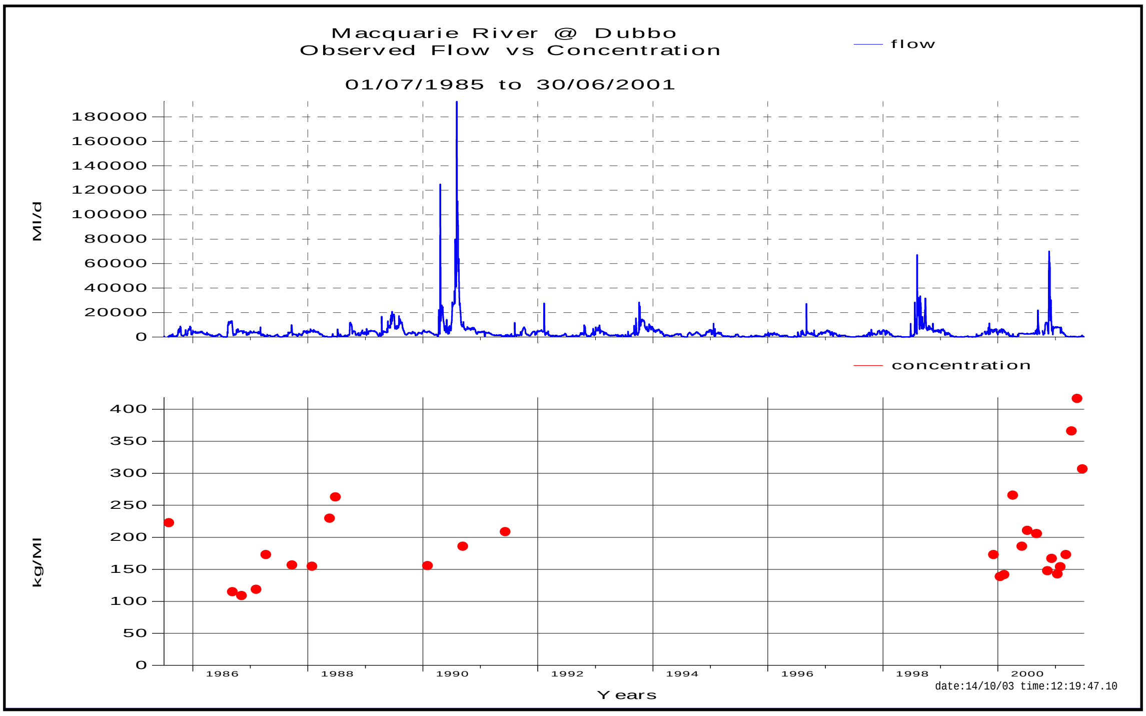


Figure 5.24. Station 421001: Macquarie River @ Dubbo, flow and concentration data

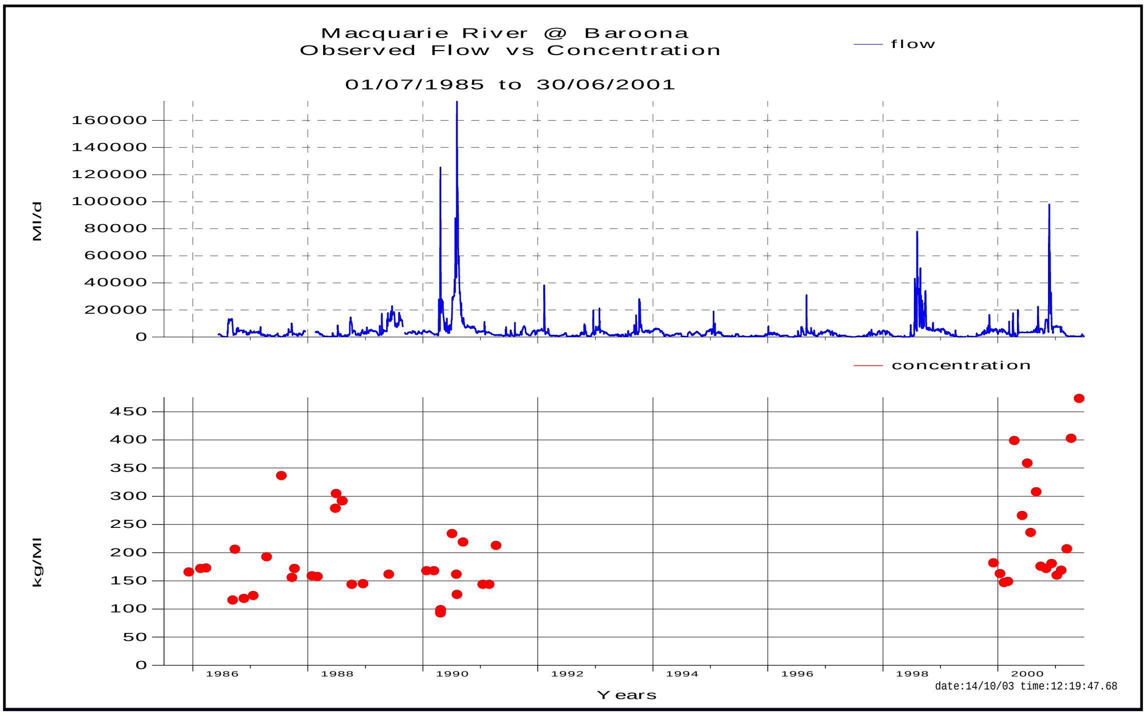


Figure 5.25. Station 421127: Macquarie River @ Baroona, flow and concentration data

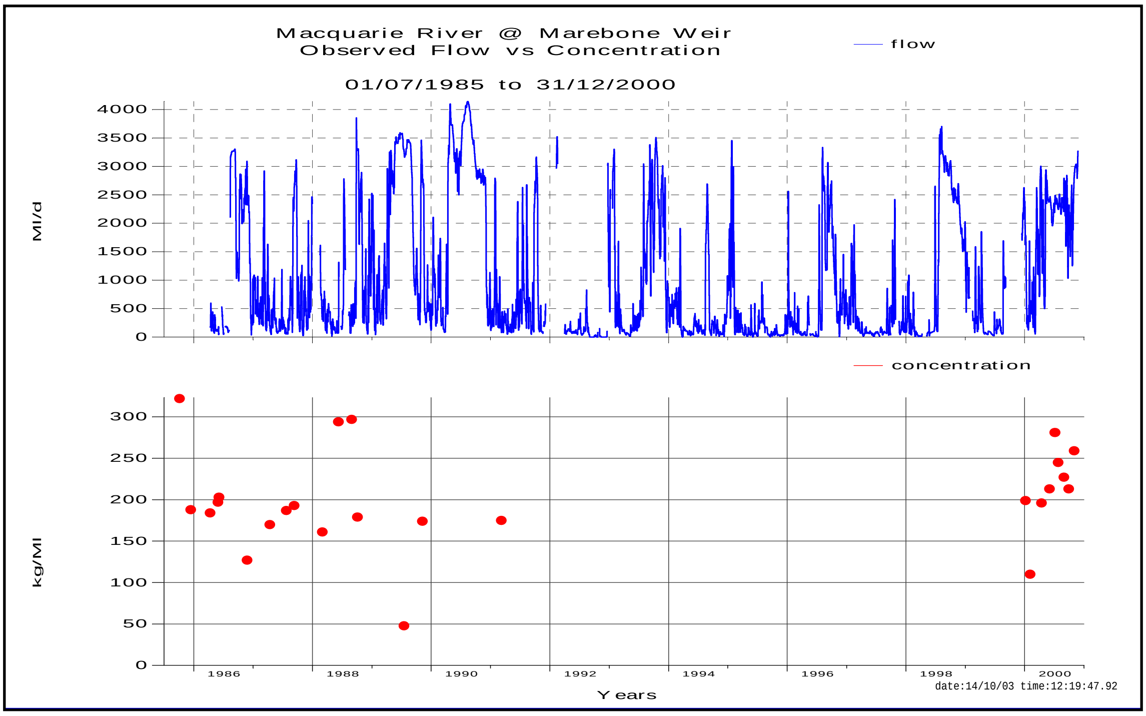


Figure 5.26. Station 421090: Macquarie River @ Marebone Weir

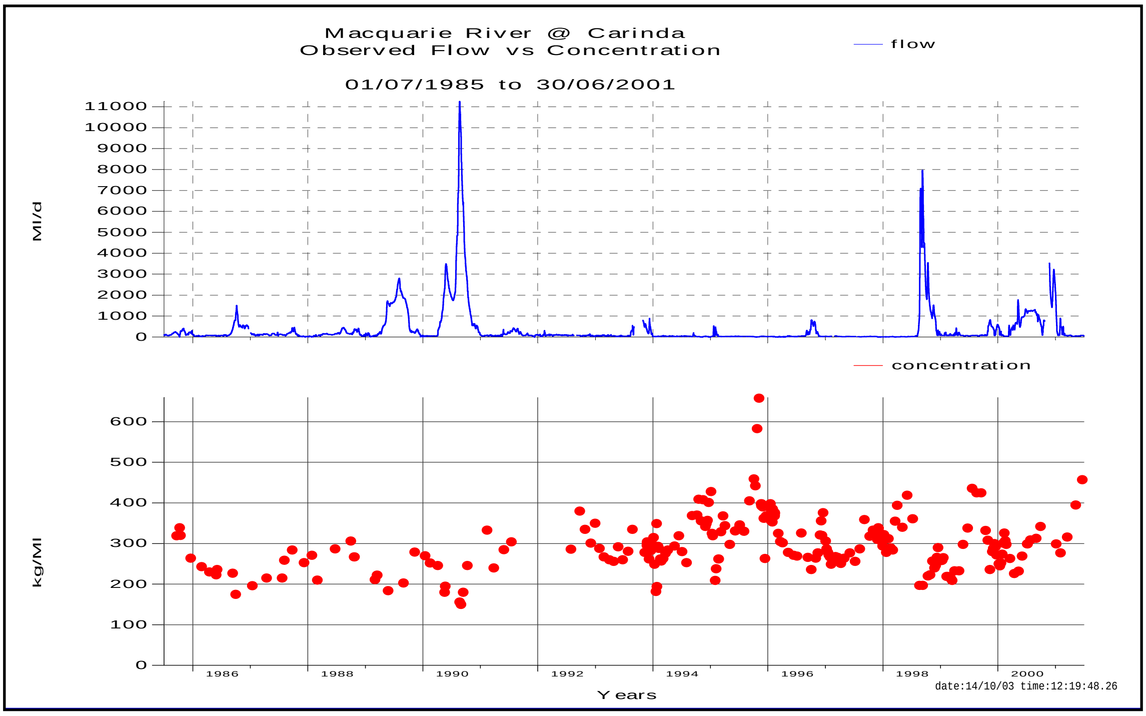


Figure 5.27. Station 421012: Macquarie River @ Carinda observed flow and concentration

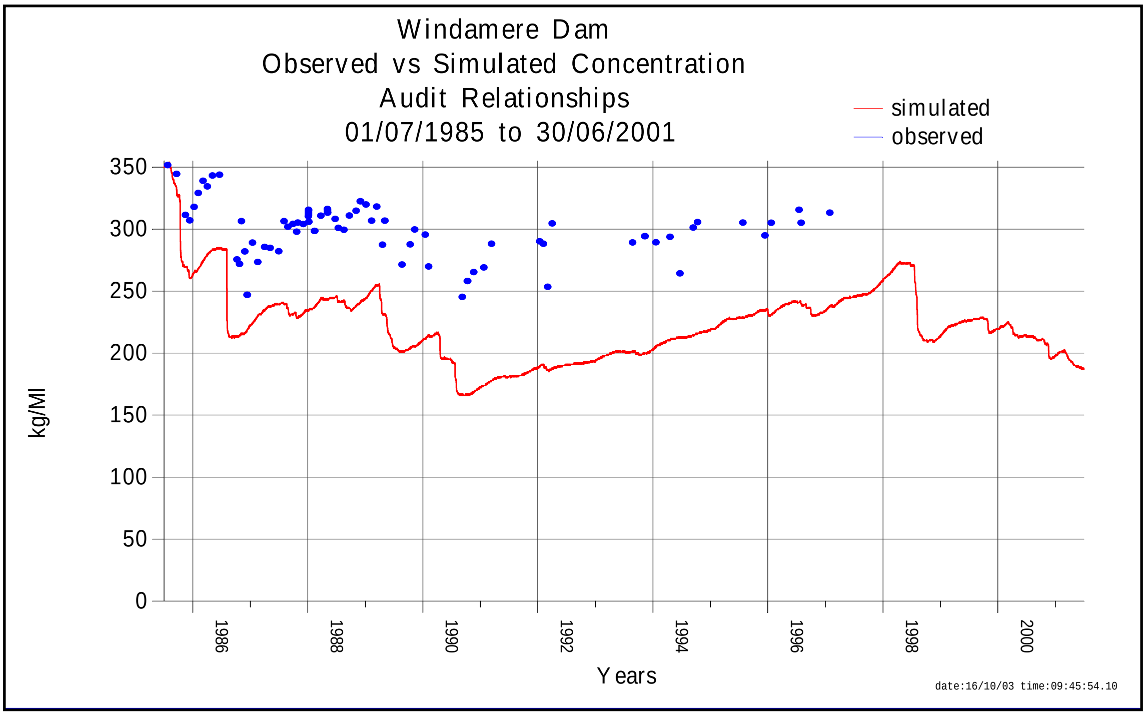


Figure 5.28. Simulated versus observed concentration at Windamere Dam, using Salinity Audit relationships.

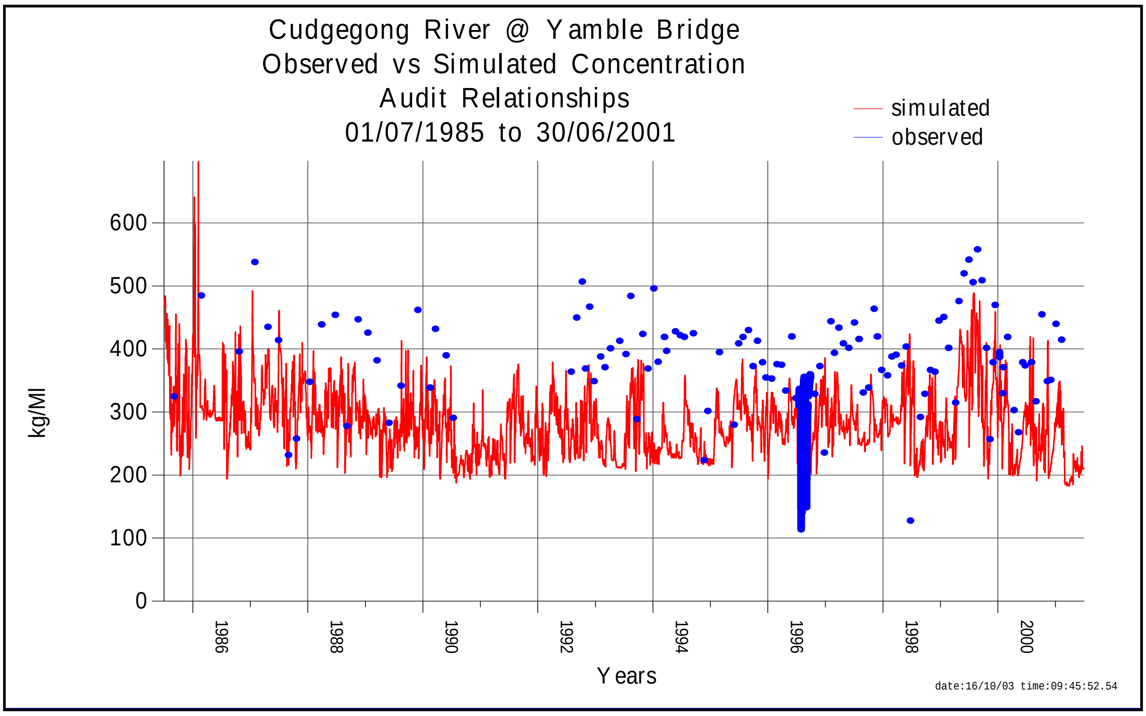


Figure 5.29. Simulated versus observed salinities at Station 421019: Cudgegong River @ Yamble Bridge, using Salinity Audit relationships.

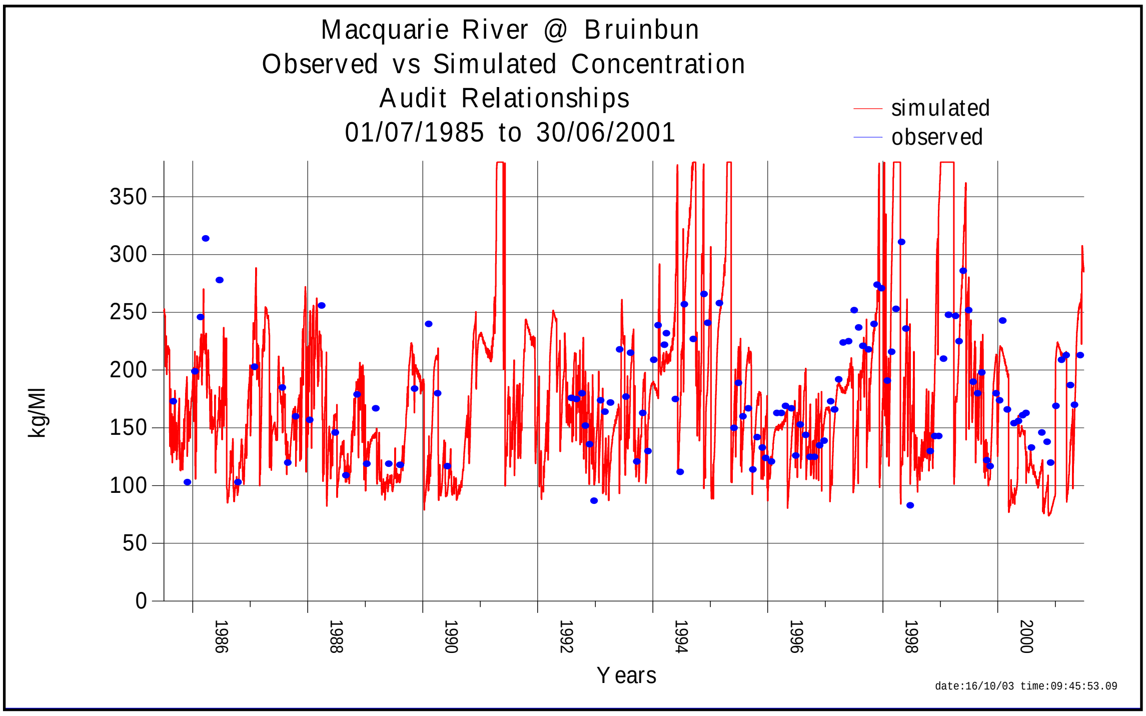


Figure 5.30. Simulated versus observed salinities at Station 421025: Macquarie River @ Bruinbun, using Salinity Audit relationships.

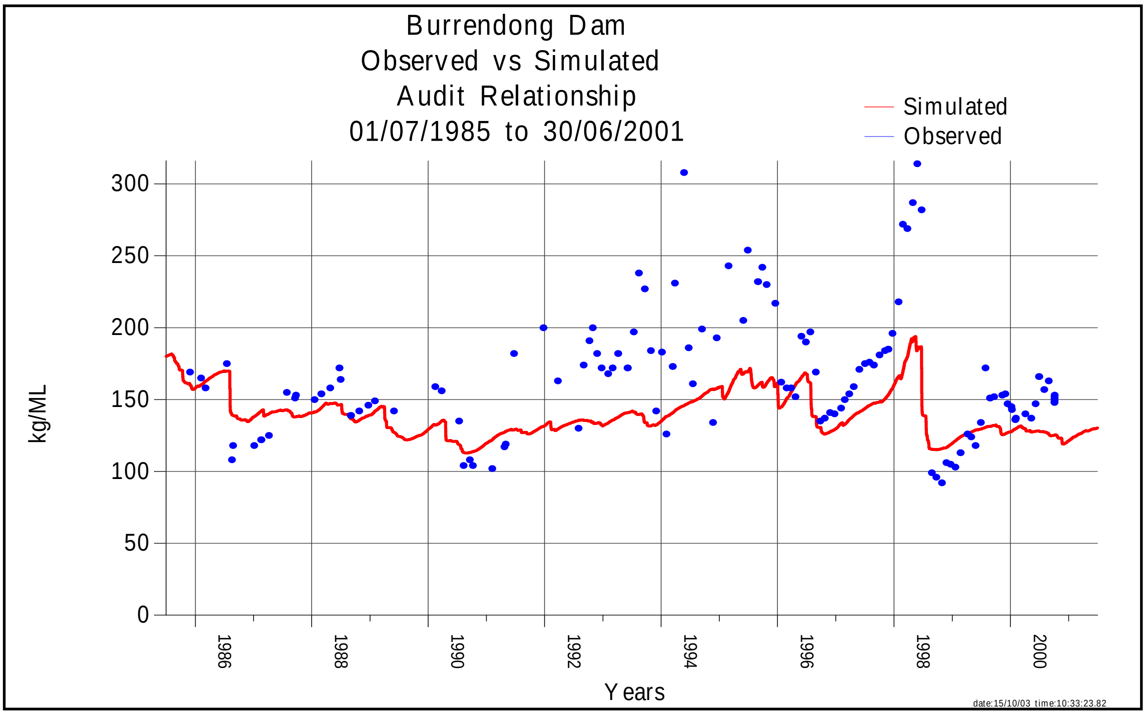


Figure 5.31. Simulated versus observed salinities at Burrendong Dam, using Salinity Audit relationships.

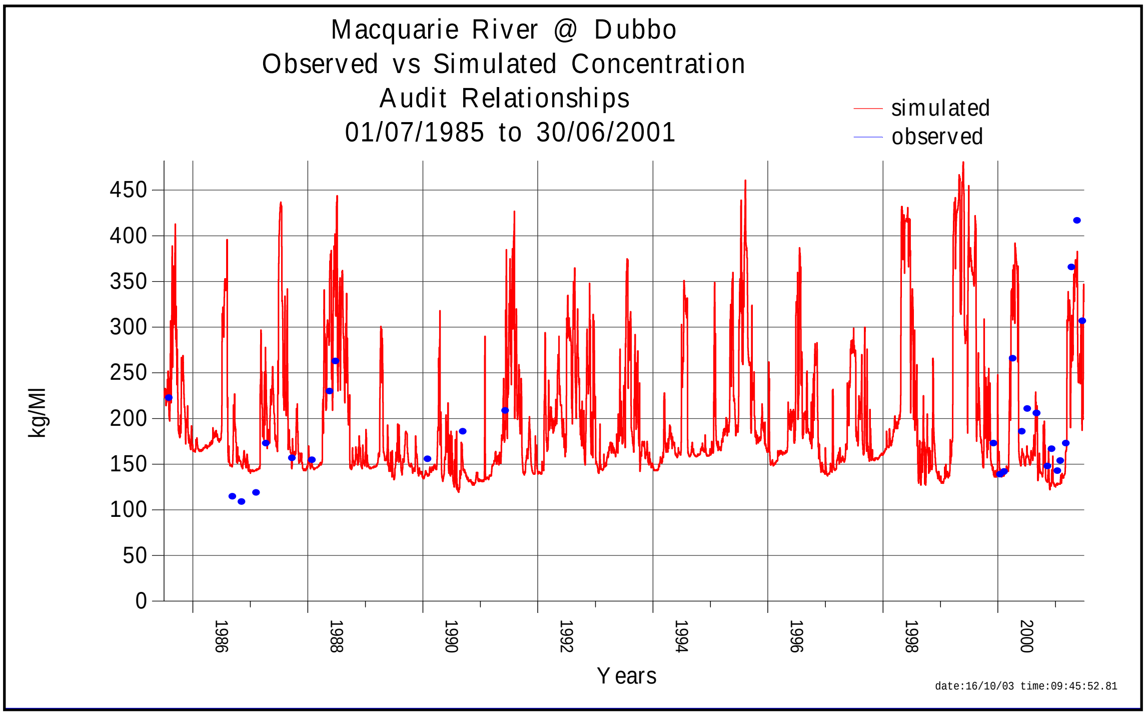


Figure 5.32. Simulated versus observed salinities at Station 421001: Macquarie River @ Dubbo, using Salinity Audit relationships.

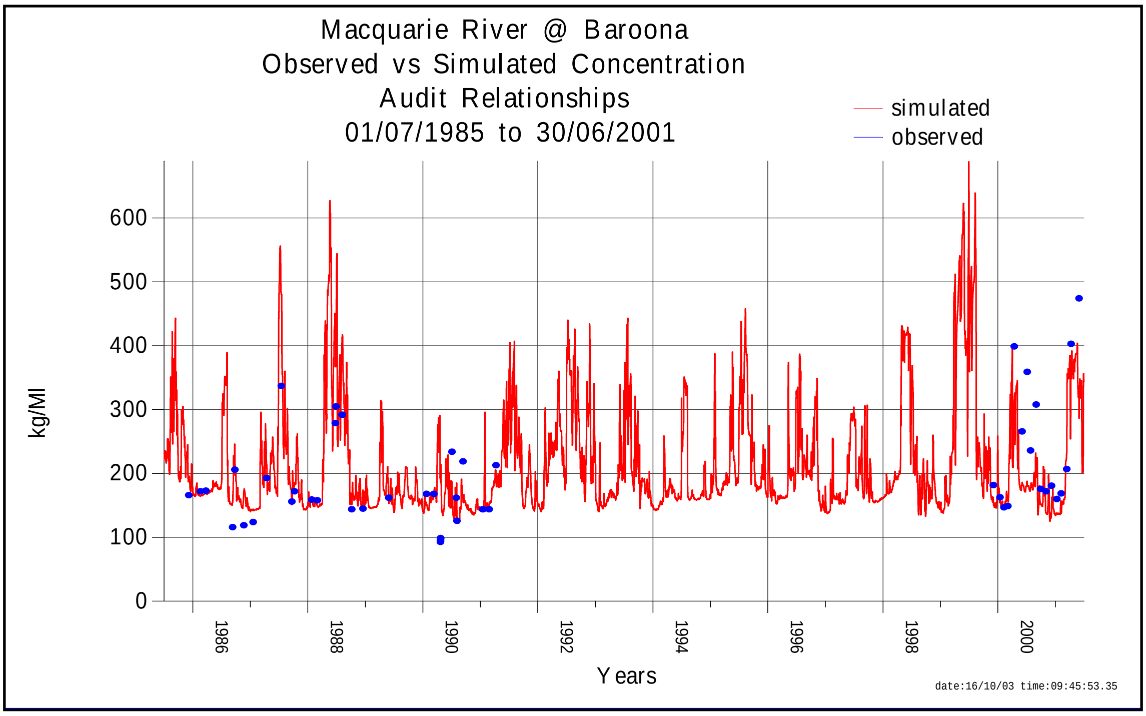


Figure 5.33. Simulated versus observed salinities at Station 421127: Macquarie River @ Baroona, using Salinity Audit relationships.

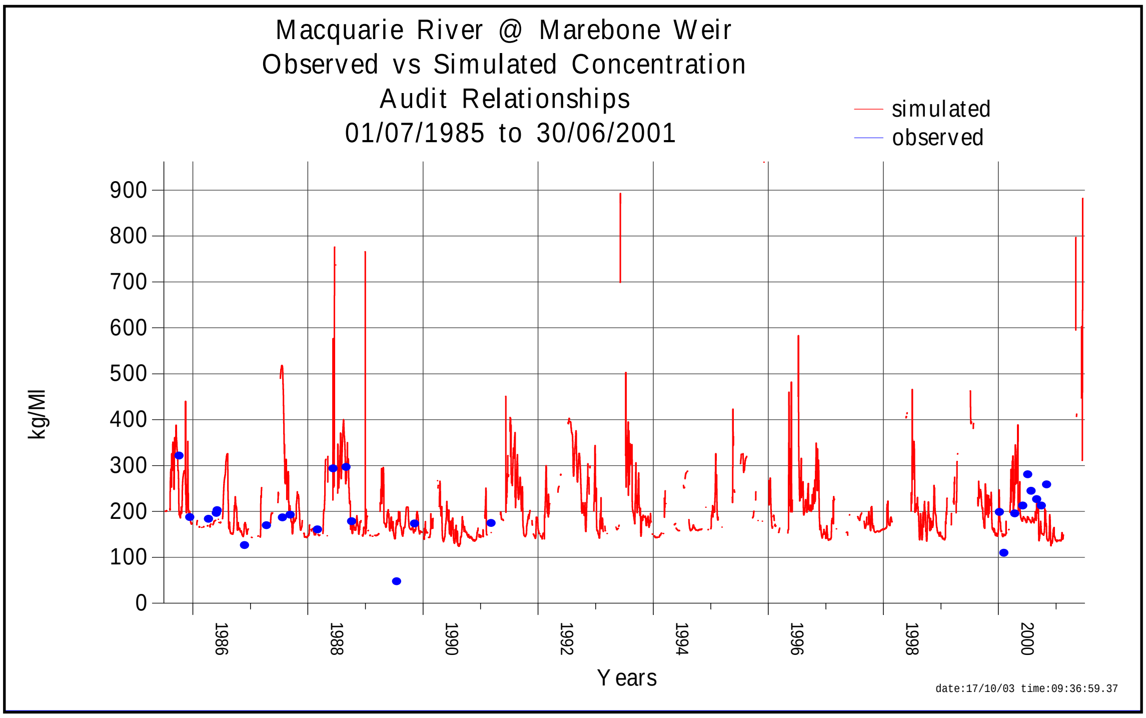


Figure 5.34. Simulated versus observed concentration at Station 421090: Macquarie River @ Marebone Weir, using Salinity Audit relationships.

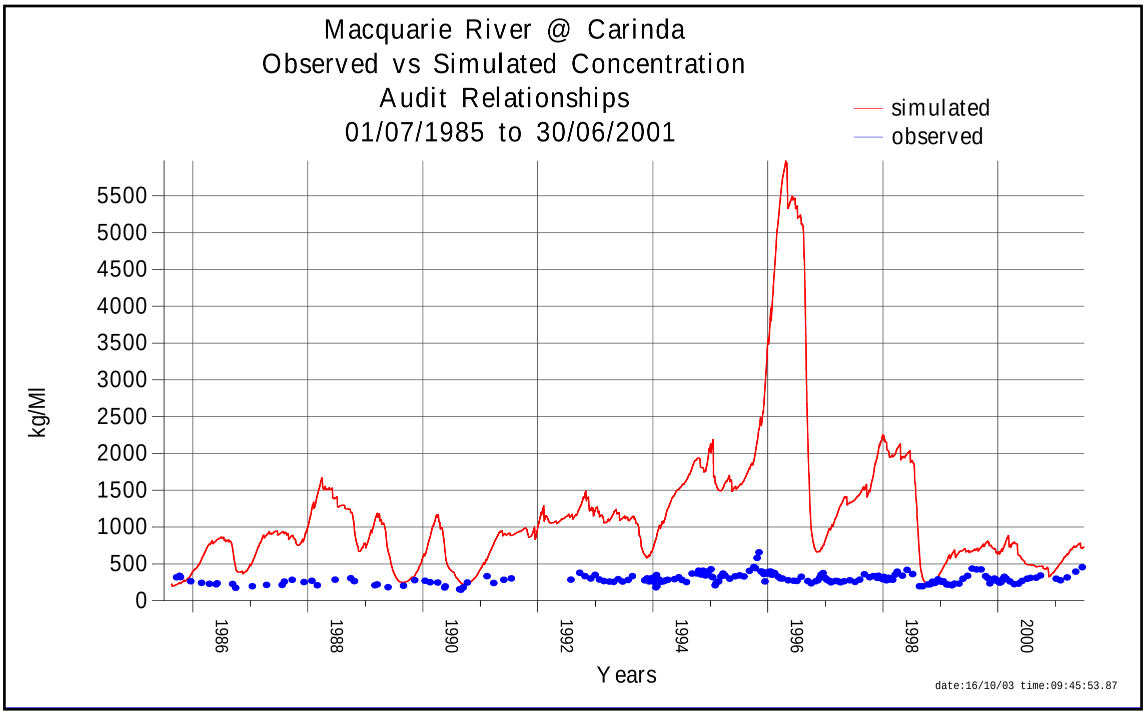


Figure 5.35. Simulated versus observed concentrations at Station 421012: Macquarie River @ Carinda, using Salinity Audit relationships.

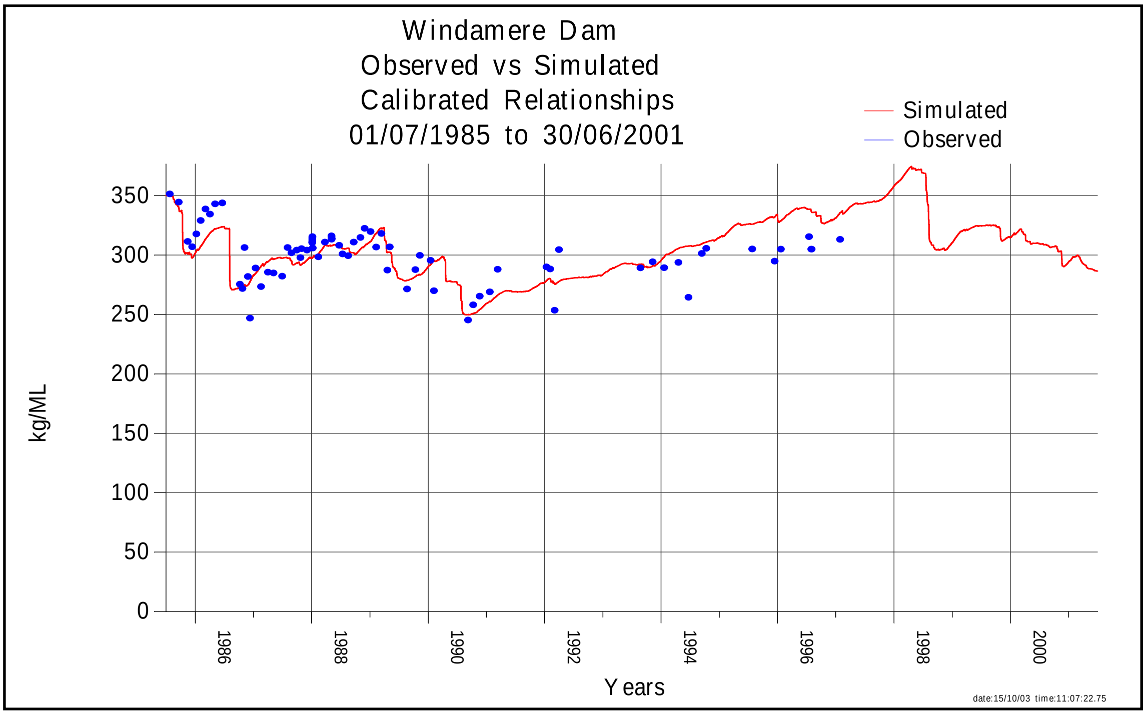


Figure 5.36. Simulated versus observed salinity at Windamere Dam, using calibrated relationship.

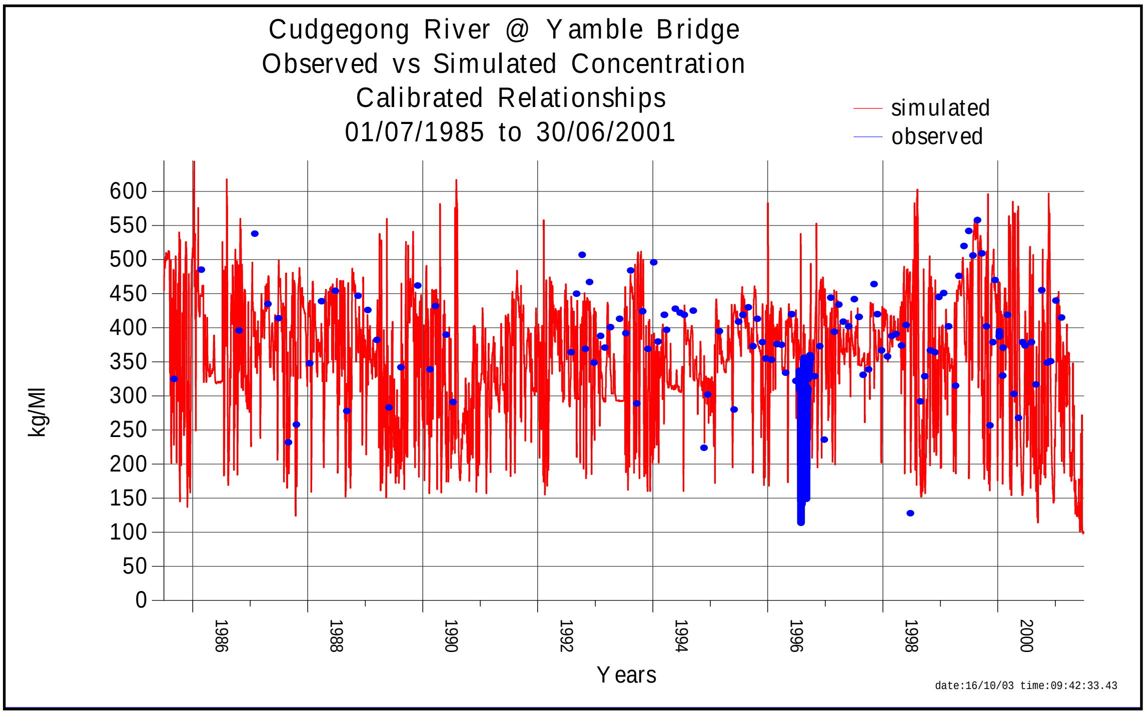


Figure 5.37. Simulated versus observed salinity for Station 421019: Cudgegong River @ Yamble Bridge, using calibrated relationships.

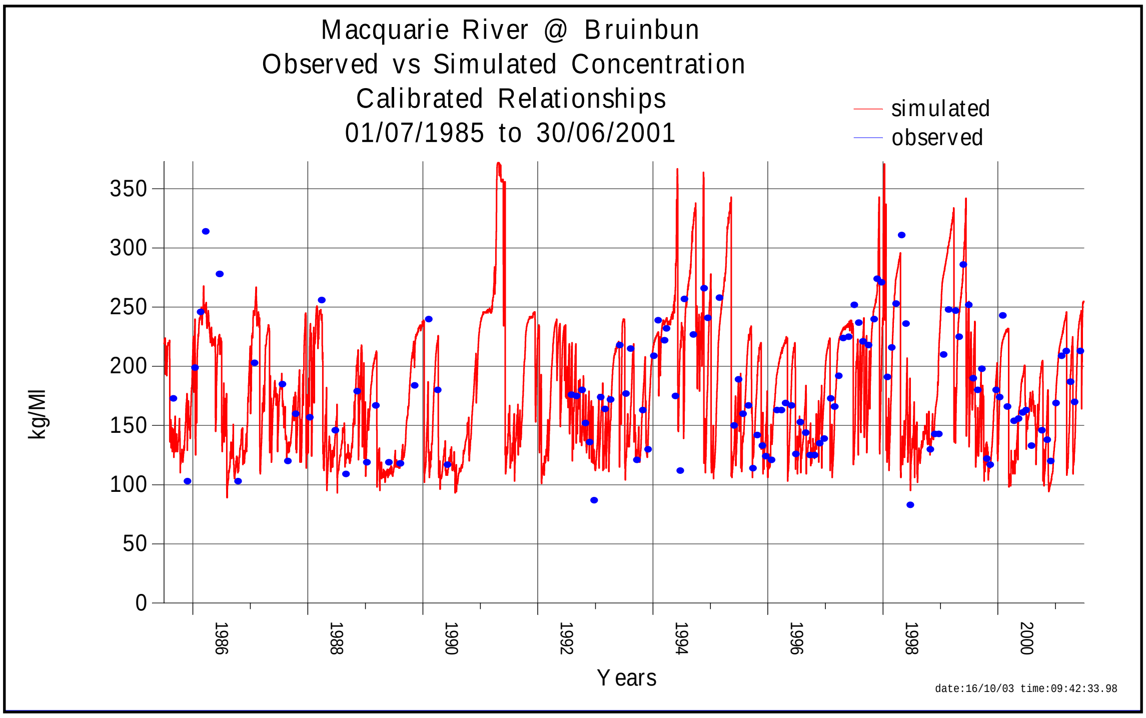


Figure 5.38. Simulated versus observed salinity for Station 421025: Macquarie River @ Bruinbun, using calibrated relationship.

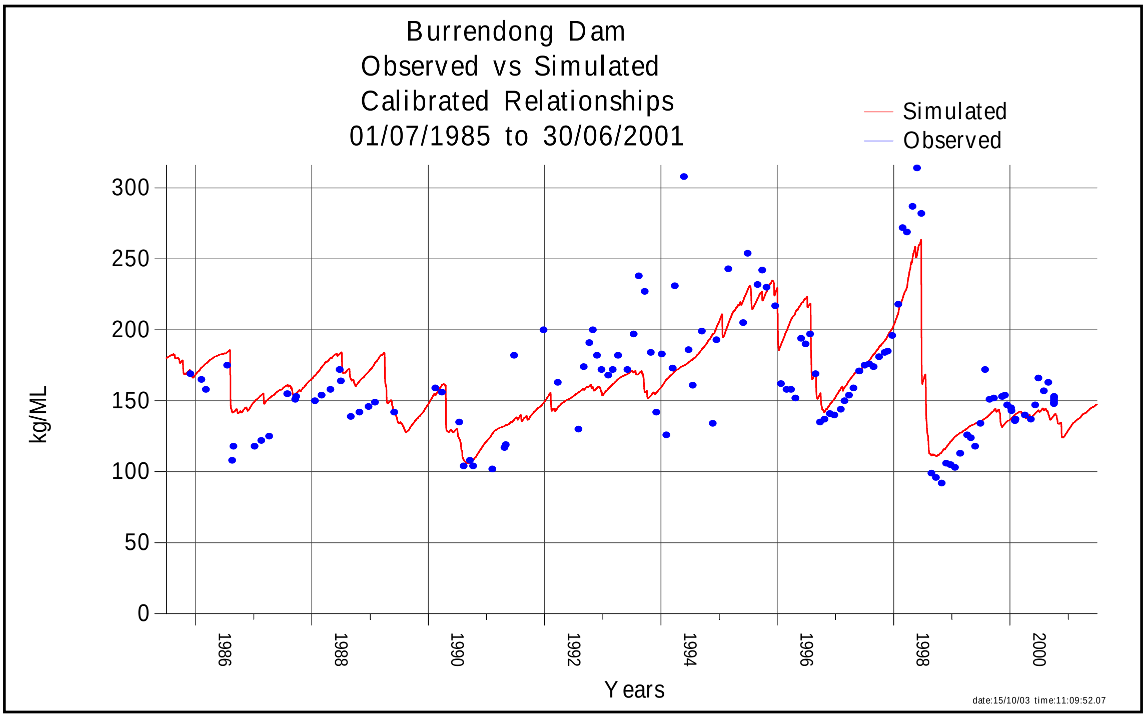


Figure 5.39. Simulated versus observed salinity for Burrendong Dam, using calibrated relationship.

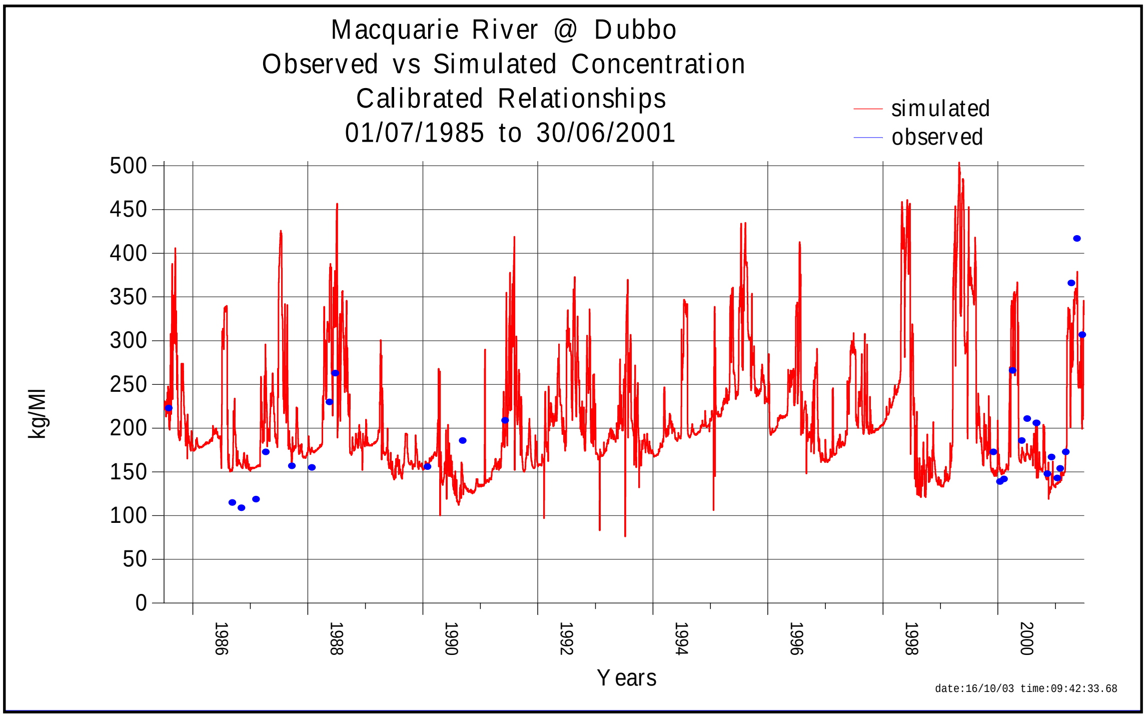


Figure 5.40. Observed versus simulated concentrations for Station 421001: Macquarie River @ Dubbo using calibrated relationship.

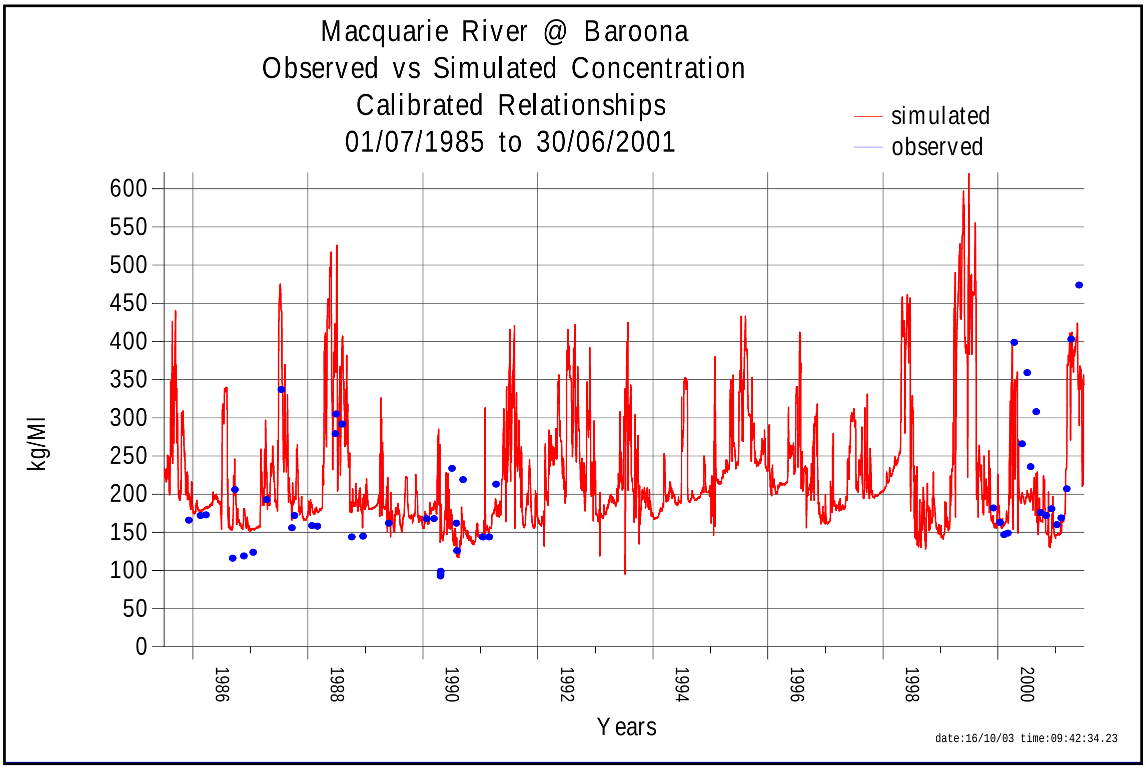


Figure 5.41. Observed versus simulated concentrations for Station 421127: Macquarie River @ Baroona, using calibrated relationships

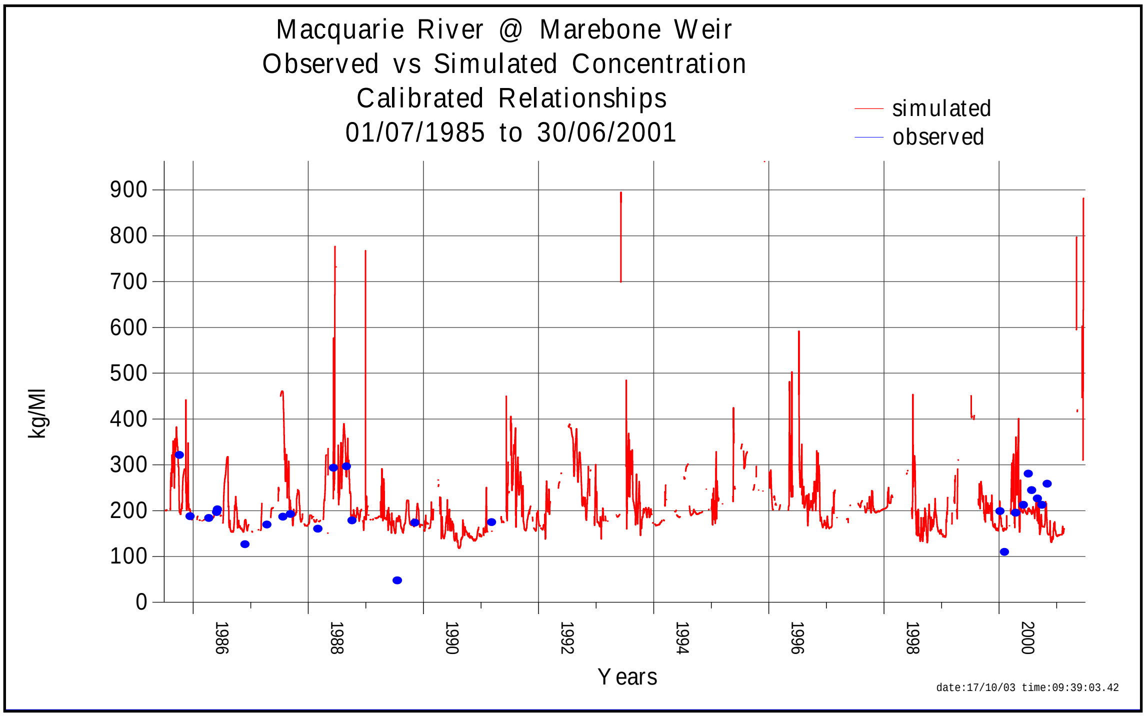


Figure 5.42. Observed versus simulated concentrations for Station 421090: Macquarie River @ Marebone Weir, using calibrated relationships.

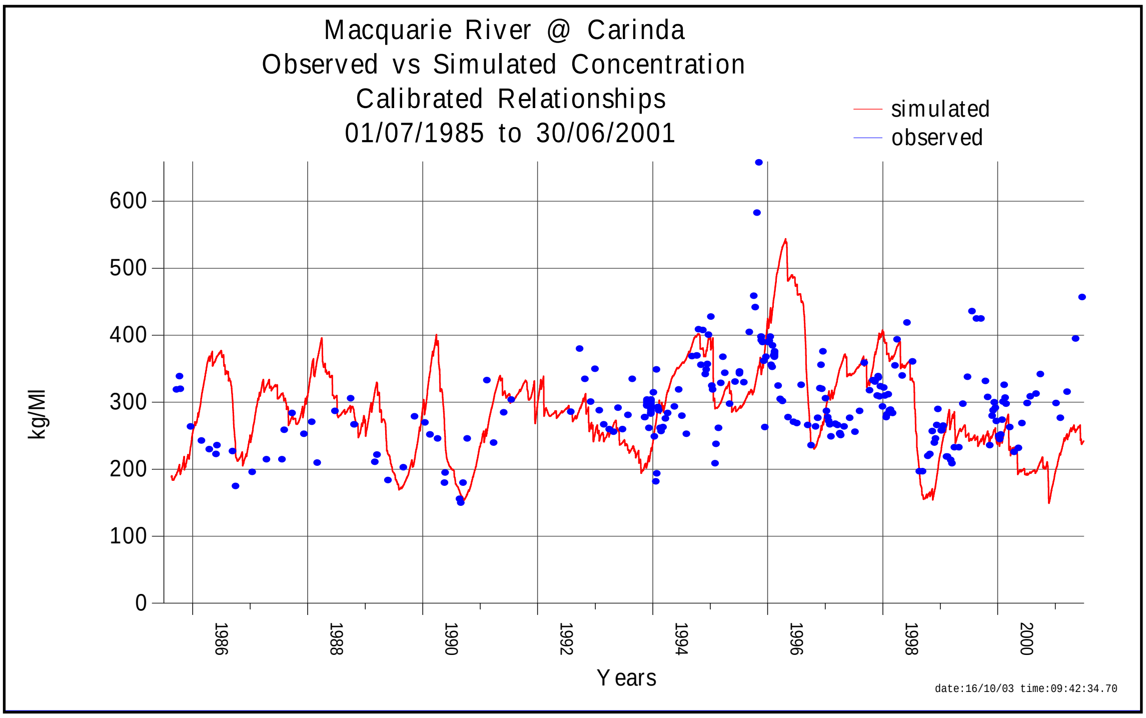


Figure 5.43. Observed versus simulated concentrations for Station 421012: Macquarie River @ Carinda using calibrated relationships.

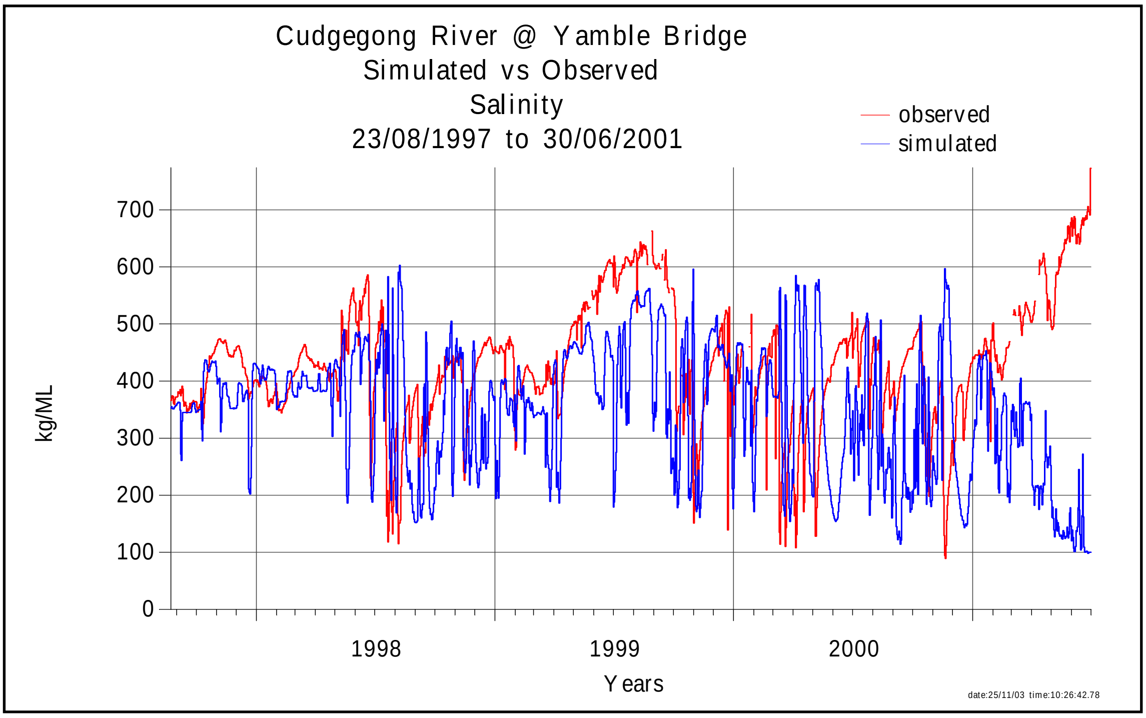


Figure 5.44. Continuous observed versus simulated salinities for station 421019: Macquarie River @ Carinda using calibrated relationships.

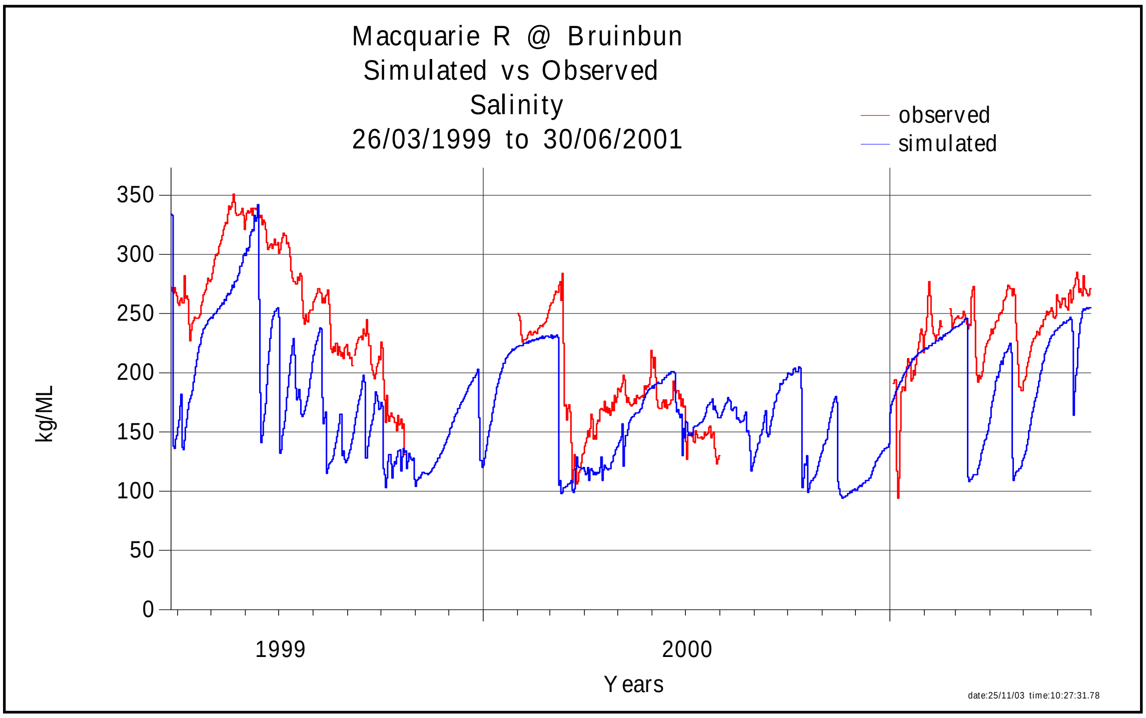


Figure 5.45. Continuous observed versus simulated salinities for station 421019: Macquarie River @ Bruinbun using calibrated relationships.

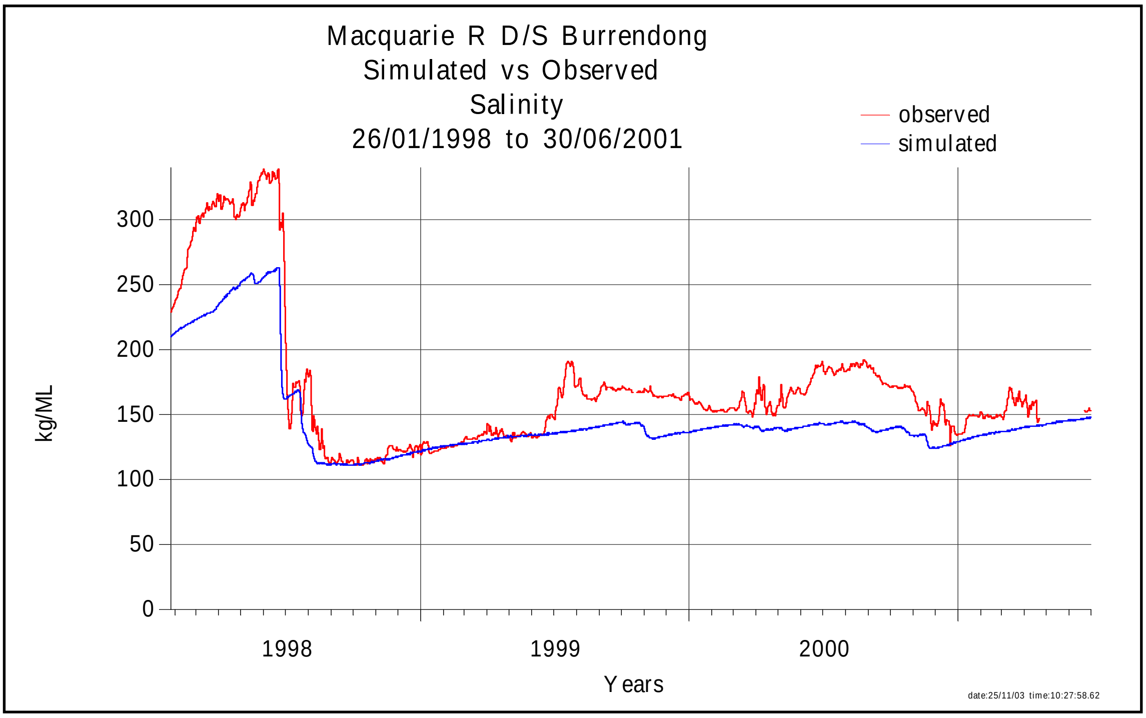


Figure 5.46. Continuous observed versus simulated salinities for Macquarie River downstream of Burrendong Dam using calibrated relationships.

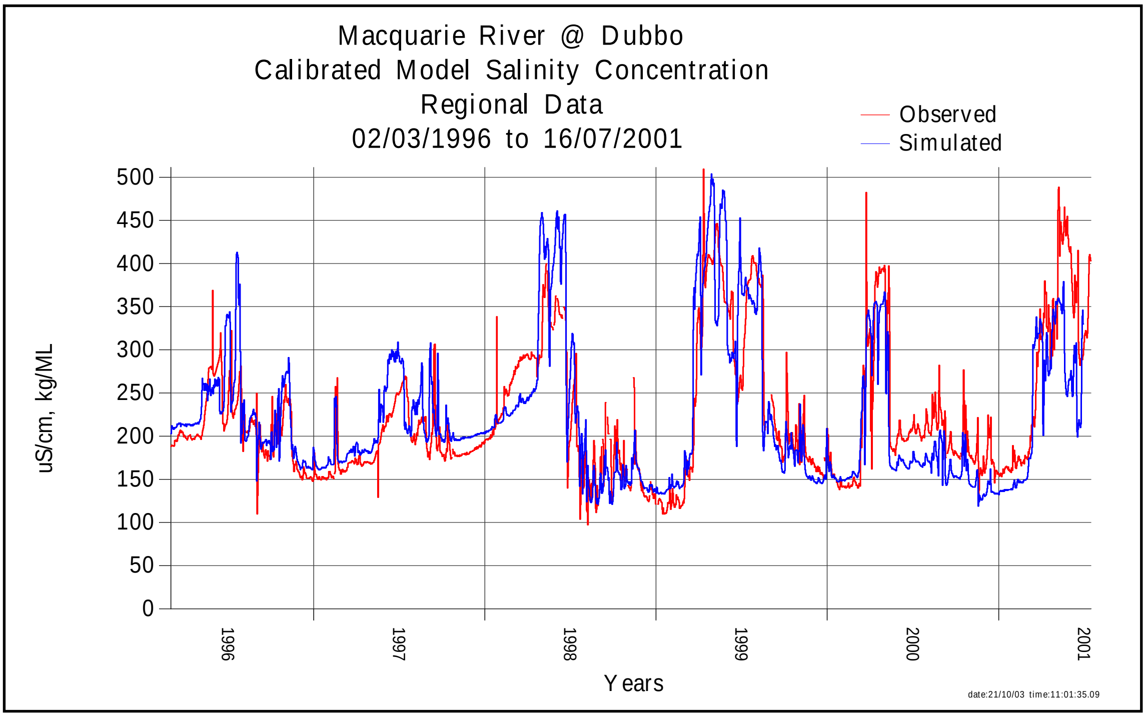


Figure 5.47. Daily read observed versus simulated salinities for Macquarie River @ Dubbo using calibrated relationships.

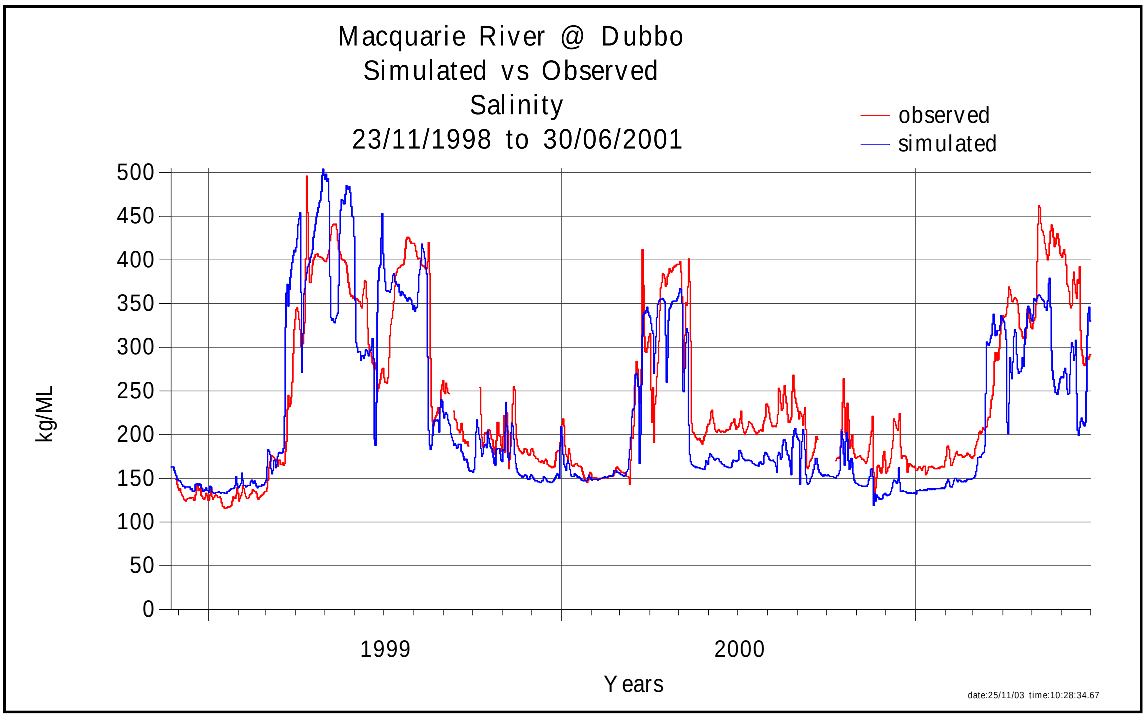


Figure 5.48. Continuous observed versus simulated salinities for station 421001: Macquarie River @ Dubbo using calibrated relationships.

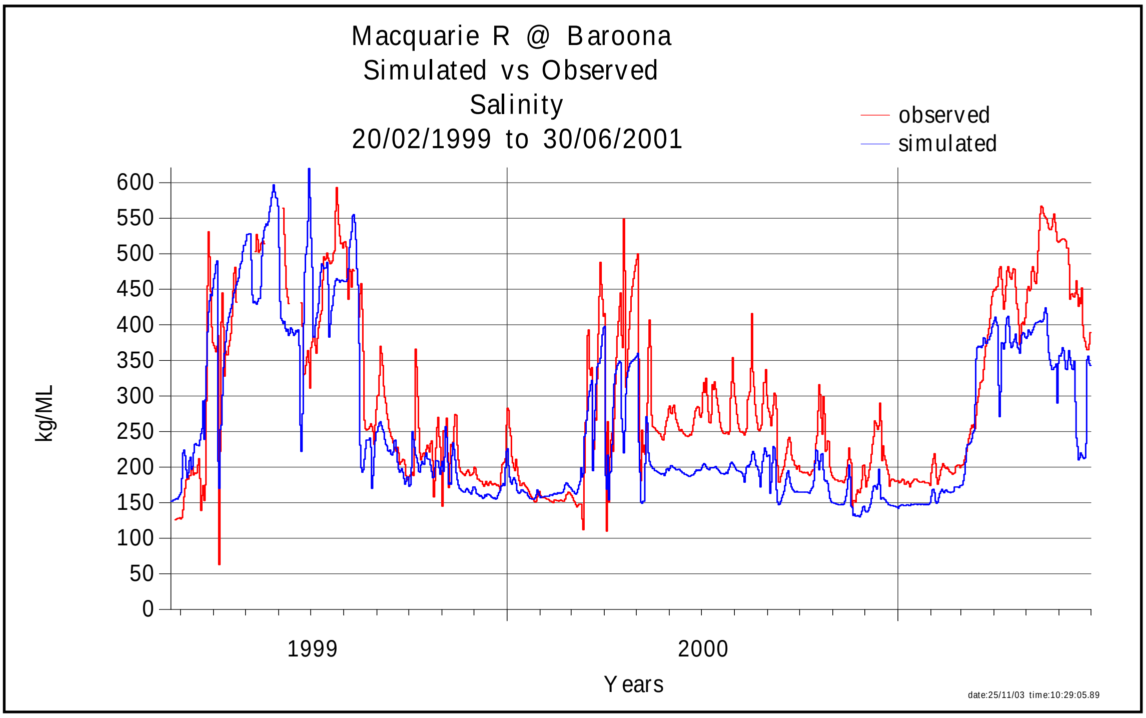


Figure 5.49. Continuous observed versus simulated salinities for station 421127: Macquarie River @ Baroona using calibrated relationships.

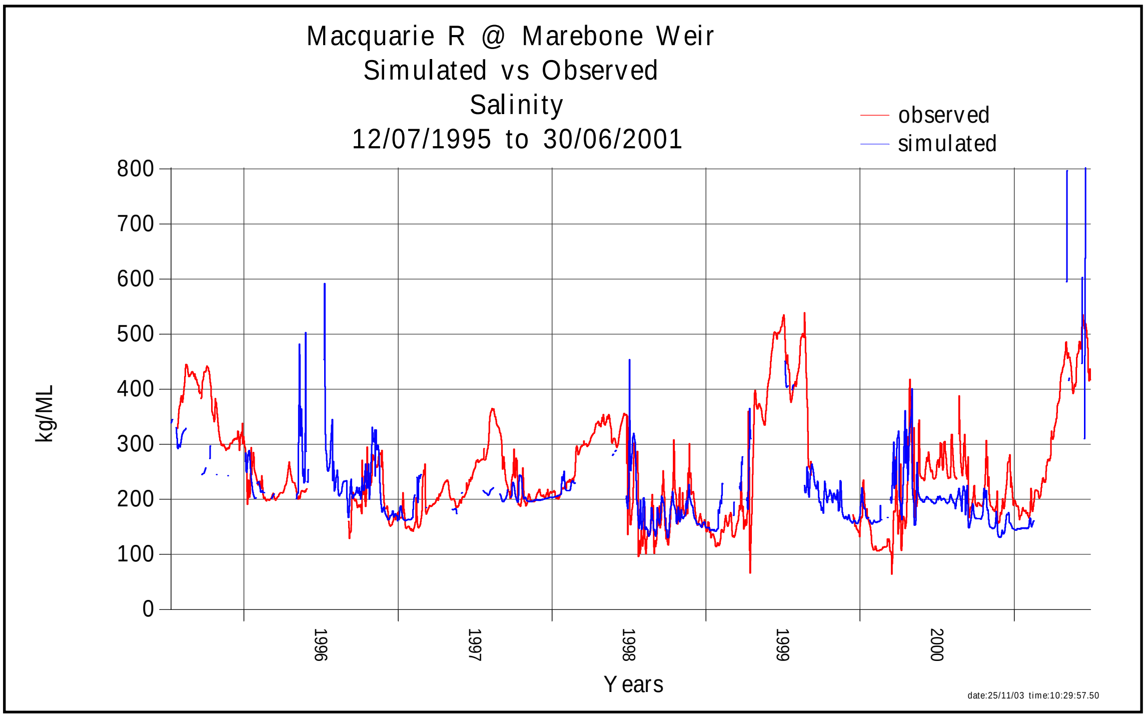


Figure 5.50. Continuous observed versus simulated salinities for station 421090: Macquarie River @ Marebone Weir using calibrated relationships.

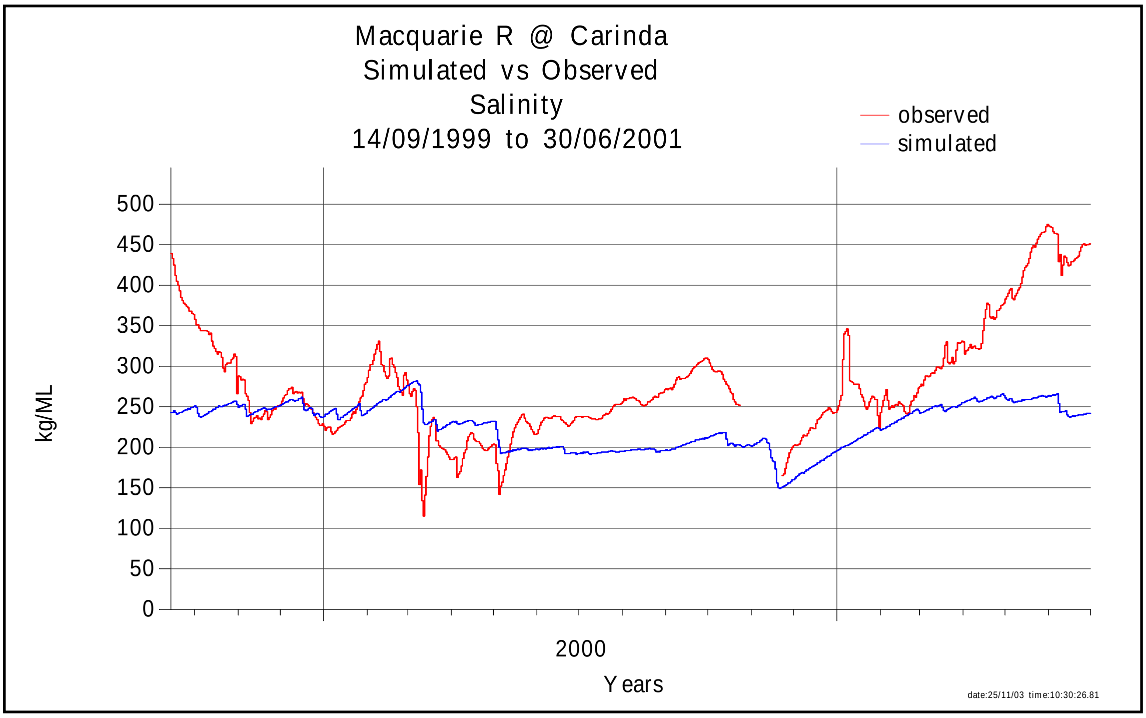


Figure 5.51. Continuous observed versus simulated salinities for station 421012: Macquarie River @ Carinda using calibrated relationships.

6. Baseline Conditions scenario

6.1. BASELINE CONDITIONS

The Basin Salinity Management Strategy (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 catchment 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, eg.; geology, topography, 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.

For reasons of lack 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.

More information is available to define water use and river operating regimes in the Macquarie River. This information has been collected, or developed in the process of setting up the IQQMs over the years. This information is summarised in Table 6.1 and Table 6.2.

The results from this simulation are reported in the following section.

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

Water Balance Component	Value	Units
Average annual inflows *(benchmark climatic period)*		
Cudgegong @ Yamble Bridge	117	GL/year
Upper Macquarie	922	GL/year
Macquarie below Burrendong	454	GL/year
Storages		
Chifley		
Active storage	15	GL
Storage reserve	0	GL
Transmission and operation losses	0	GL
Windamere		
Active storage	361	GL
Storage reserve	9	GL
Transmission and operation losses	0	GL
Burrendong		
Active storage	1,154	GL
Storage reserve	169	GL
Transmission and operation losses	180	GL
Irrigation		
General security licences	621	GL/year
High security licences	5	GL/year
Proportion licences active	97	%
Maximum allocation	100	%
Maximum irrigable area	76,000	Ha
Pump capacity	14	GL/day
On-farm storage capacity	65	GL
Crop types (See Table)		-
Surplus flow entitlement	50	GL/year
Town water supply		
Bathurst	8.0	GL/year
Wellington	2.2	GL/year
Dubbo	8.8	GL/year
Nyngan and Cobar	8.1	GL/year
In-stream water supply *(refer to Table 4.1 for details)*		
Windamere	11	GL/year
Ben Chifley	26	GL/year
Oxley	18	GL/year
Marebone Break	7	GL/year
Crooked Ck	12	GL/year
Duck Ck	19	GL/year
D/S Gunningbar Weir	19	GL/year
Marra Ck	15	GL/year
Lower Bogan	15	GL/year
Macquarie Marsh (HS)	50	GL/year
Macquarie Marsh (GS)	75	GL/year

Table 6.2. Crop types, proportions, and irrigation factor

Crop type	% of total	Irrig. factor	Average crop factor for month											
			J	F	M	A	M	J	J	A	S	O	N	D
Cotton	41	0.70	0.85	0.82	0.56	0.00	0.00	0.00	0.00	0.00	0.60	0.72	0.85	0.88
Lucerne	14	0.70	0.60	0.59	0.56	0.53	0.00	0.00	0.00	0.00	0.00	0.47	0.55	0.60
Pasture	10	0.80	0.60	0.59	0.58	0.56	0.54	0.52	0.46	0.50	0.54	0.58	0.59	0.60
Summer cereal	16	0.70	0.76	0.60	0.60	0.53	0.34	0.00	0.00	0.00	0.15	0.32	0.57	0.77
Winter cereal	19	0.65	0.00	0.00	0.00	0.73	0.73	0.73	0.71	0.71	0.64	0.00	0.00	0.00
Olives	<1	0.90	0.70	0.70	0.61	0.00	0.00	0.00	0.65	0.66	0.68	0.69	0.70	0.70
Grapes	<1	0.90	0.70	0.61	0.42	0.28	0.28	0.28	0.28	0.28	0.52	0.70	0.70	0.70
Vegetables	<1	0.75	1.15	1.09	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.87
Orchard	<1	0.90	0.90	0.90	0.83	0.66	0.00	0.00	0.00	0.00	0.57	0.69	0.84	0.90

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-excellences for daily concentration and daily salt load at all the evaluation points are reported in Table 6.3. The results for the mean and percentile non-exceedance annual salt load at all evaluation points are reported in Table 6.4.

The patterns of the concentration results are consistent with observed data (Figure 3.4) showing high concentrations in the Cudgegong River compared with the Macquarie River upstream of Burrendong Dam. Salinity decreases slightly immediately downstream of Burrendong Dam, and then increases to Dubbo, and then significantly higher again at Carinda. The concentration results for Carinda are consistent with the mean and distribution of observed salinities at Carinda (Table 6.5)

The results for salt loads show that the two major inflows to Burrendong Dam contribute similar amounts of salt at the respective measuring points, with higher flows from the Upper Macquarie compensating for the lower salinities. The salt load continues to increase past Dubbo and Baroona as they pick up more tributaries. The average annual salt load decreases downstream of Baroona as water and salt is removed from the river system by irrigation diversions (Figure 4.11) and also by groundwater losses (Figure 2.10 and Figure 4.6).

Table 6.3. 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 (mg/L)				Salt Load (Tonnes/day)			
Number	Name	*Mean*	*Percentile non exceedance*			*Mean*	*Percentile non exceedance*		
			20	*50*	*80*		*20*	*50*	*80*
421019	Cudgegong River @ Yamble Bridge	359	289	341	456	129	11	21	74
421025	Macquarie River @ Bruinbun	186	129	172	236	120	12	44	137
421040	Macquarie River d/s Burrendong Dam	171	136	157	208	396	60	277	677
421001	Macquarie River @ Dubbo	217	159	197	273	555	136	393	806
421127	Macquarie River @ Baroona	231	165	211	289	661	168	460	878
421090	Macquarie River @ Marebone Weir	226	166	211	280	164	15	64	404
421012	**Macquarie River @ Carinda**	**302**	**226**	**290**	**366**	**62**	**6**	**21**	**68**

- Note: In Bewsher (2004) it has been recommended that the Macquarie River 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. 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 ('000 tonnes/year)			
Number	Name	*Mean*	*Percentile non exceedance*		
			20	*50*	*80*
421019	Cudgegong River @ Yamble Bridge	47	15	36	77
421025	Macquarie River @ Bruninbun	43	27	36	70
421040	Macquarie River d/s Burrnendong Dam	145	90	132	183
421001	Macquarie River @ Dubbo	203	138	185	247
421127	Macquarie River @ Baroona	242	160	215	279
421090	Macquarie River @ Marebone Weir	60	37	60	82
421012	**Macquarie River @ Carinda**	**23**	**7**	**14**	**30**

- Note: In Bewsher (2004) it has been recommended that the Macquarie River 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 6.5. Statistics of observed data for flow, salinity and salt load (1975-2000) at Macquarie River @ Carinda

Parameter	Units	Mean	Percent non-exceedance		
			20	50	80
Flow	(ML/d)	834	37	107	307
Salinity	(mg/L)	290	239	284	335
Salt load	(tonnes/d)	66	7	16	64

Figure 6.1 to Figure 6.9 have been prepared to compare baseline conditions with observed salinity at Macquarie River at Carinda.

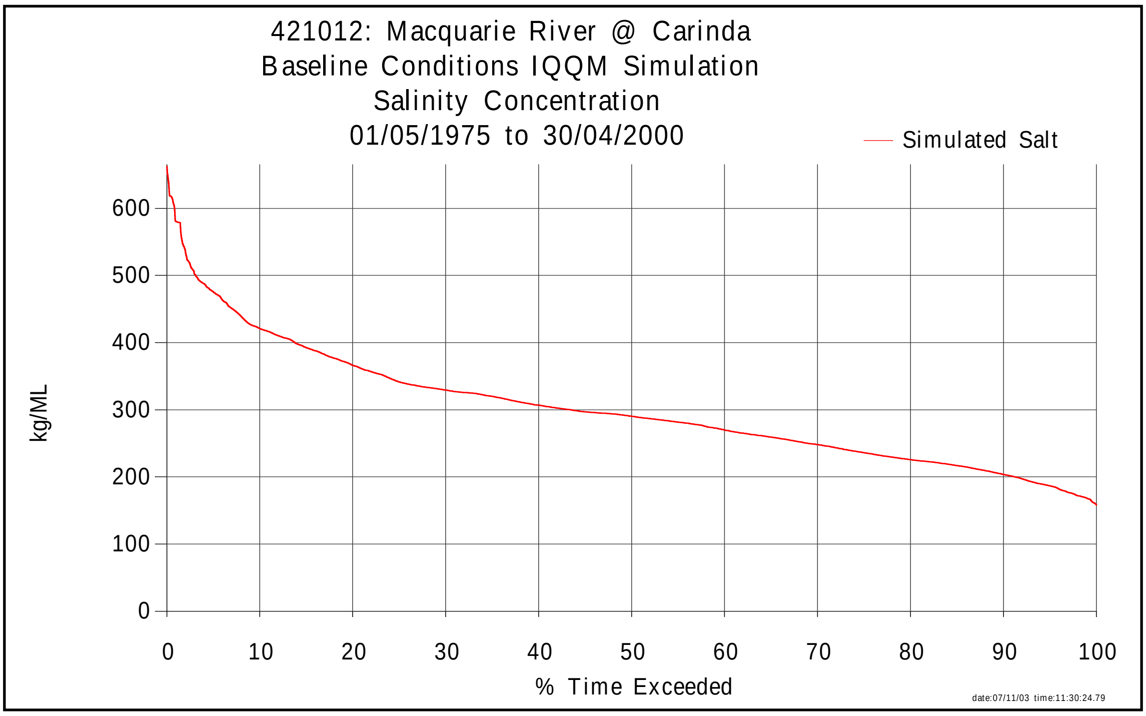


Figure 6.1. Frequency of exceedance of simulated salinity for Baseline Conditions scenario (1/5/1975-30/4/2000) for Macquarie River @ Carinda.

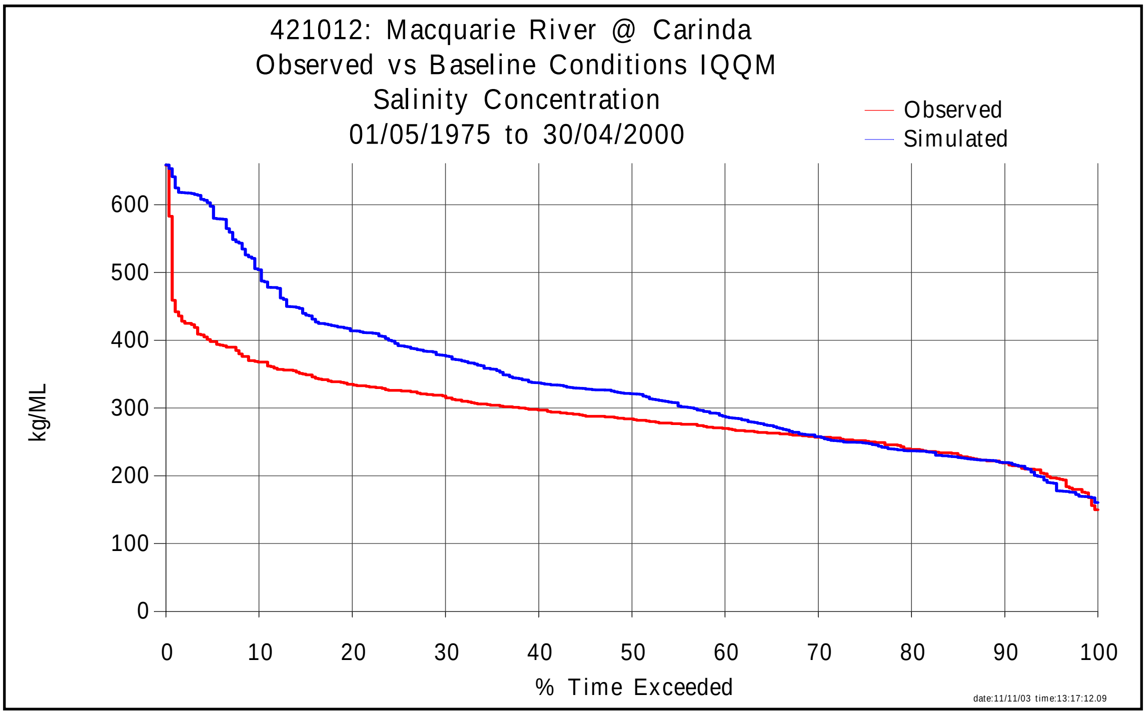


Figure 6.2. Frequency of exceedance of simulated salinity for Baseline Conditions scenario on days with salinity observations (1/5/1975-30/4/2000), compared with salinity observations for Macquarie River @ Carinda.

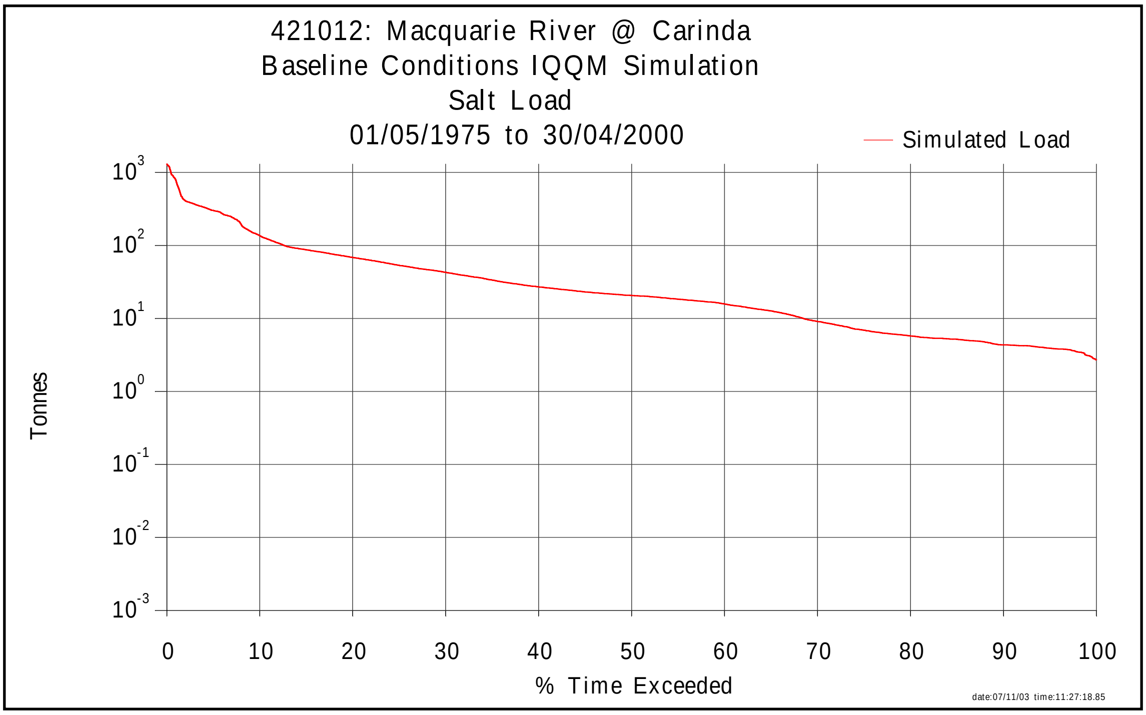


Figure 6.3. Frequency of exceedance of simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Macquarie River @ Carinda.

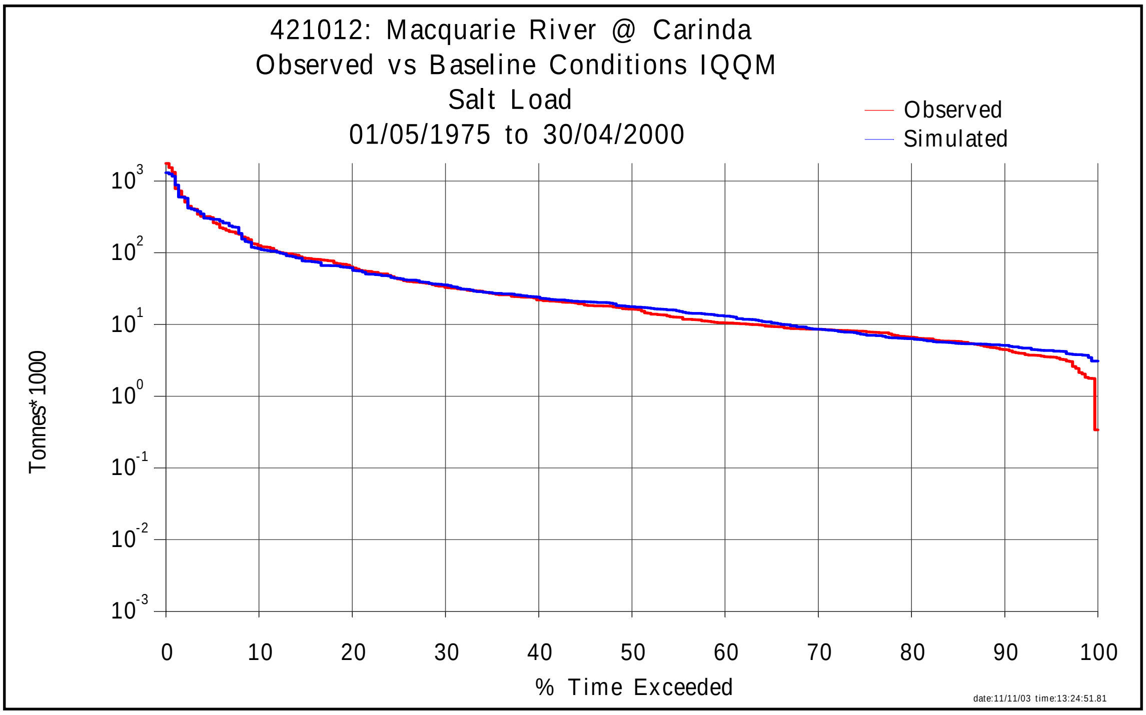


Figure 6.4. Frequency of exceedance of simulated salt load for Baseline Conditions scenario on days with salinity and flow observations (1/5/1975-30/4/2000), compared with salinity observations for Macquarie River @ Carinda.

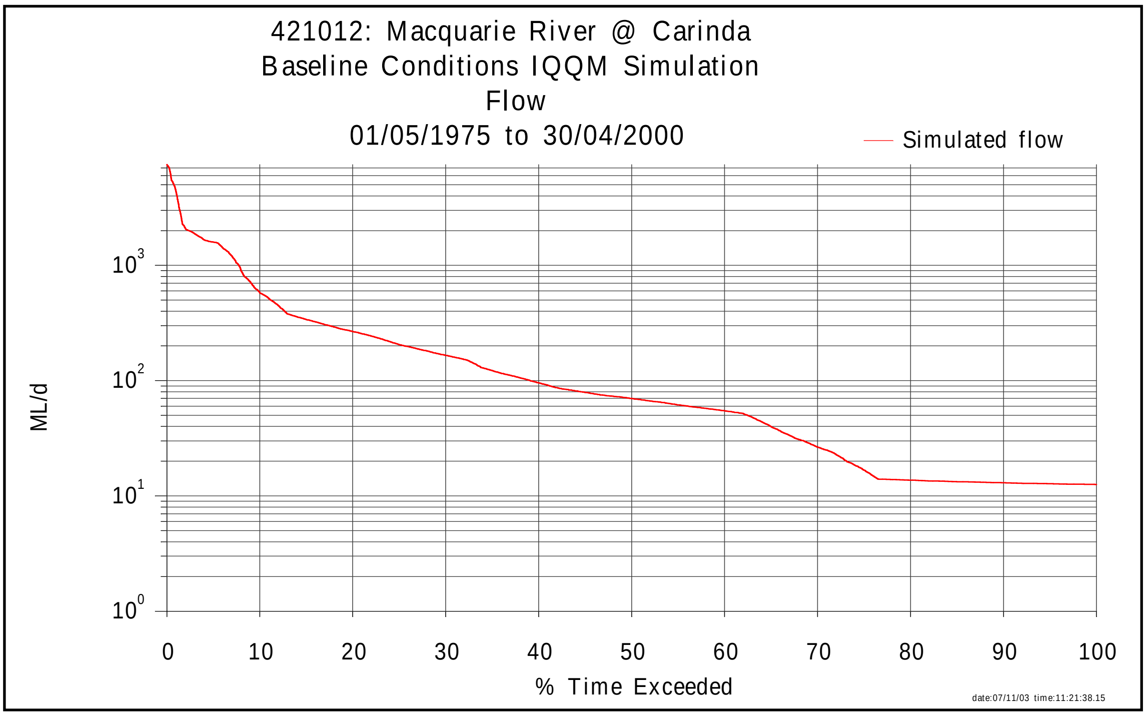


Figure 6.5. Frequency of exceedance of simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Macquarie River @ Carinda

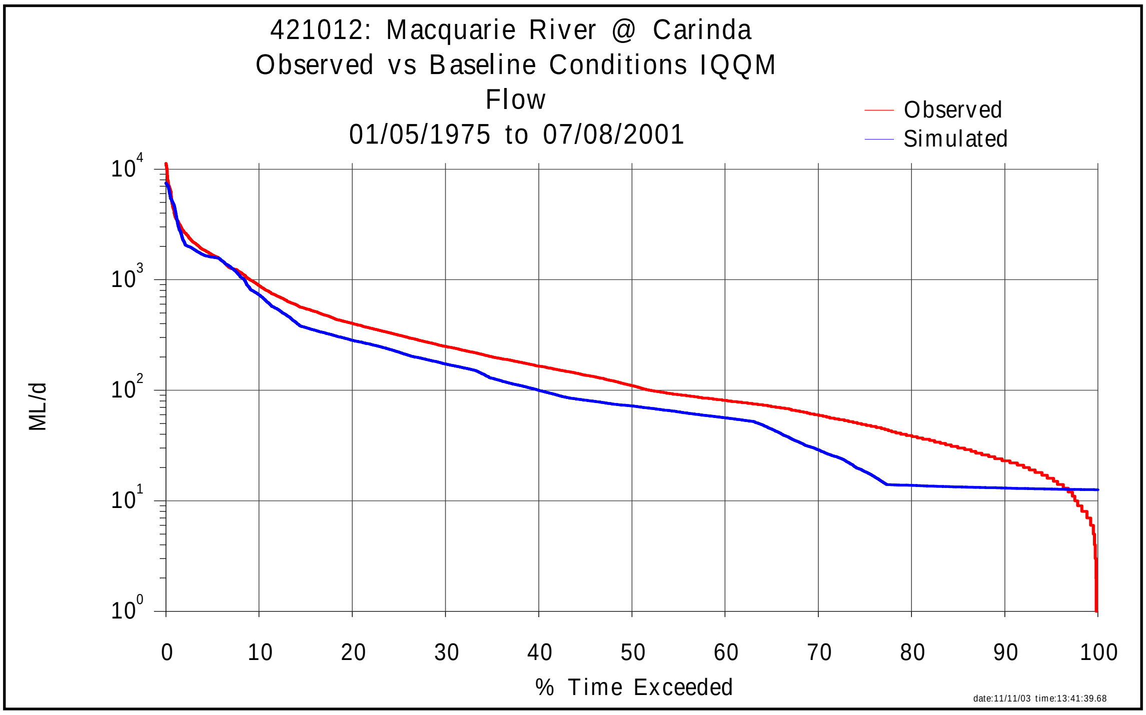


Figure 6.6. Frequency of exceedance of simulated flow for Baseline Conditions scenario on days with flow observations (1/5/1975-30/4/2000), compared with observed flow for Macquarie River @ Carinda.

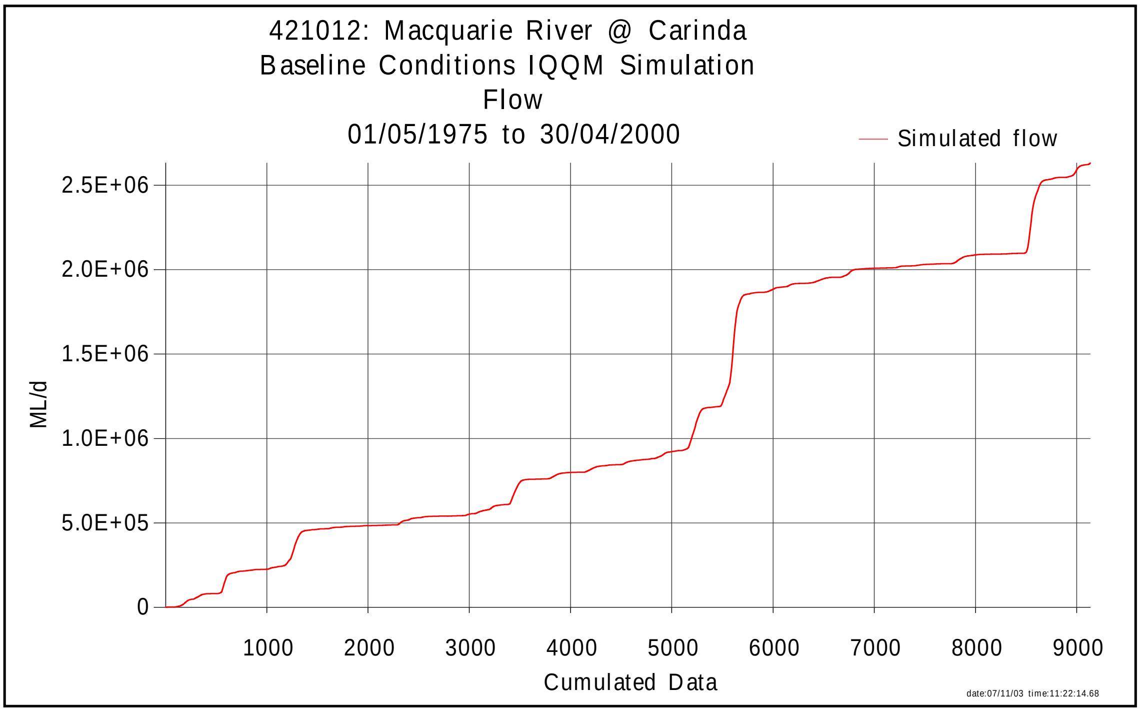


Figure 6.7. Cumulative simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Macquarie River @ Carinda.

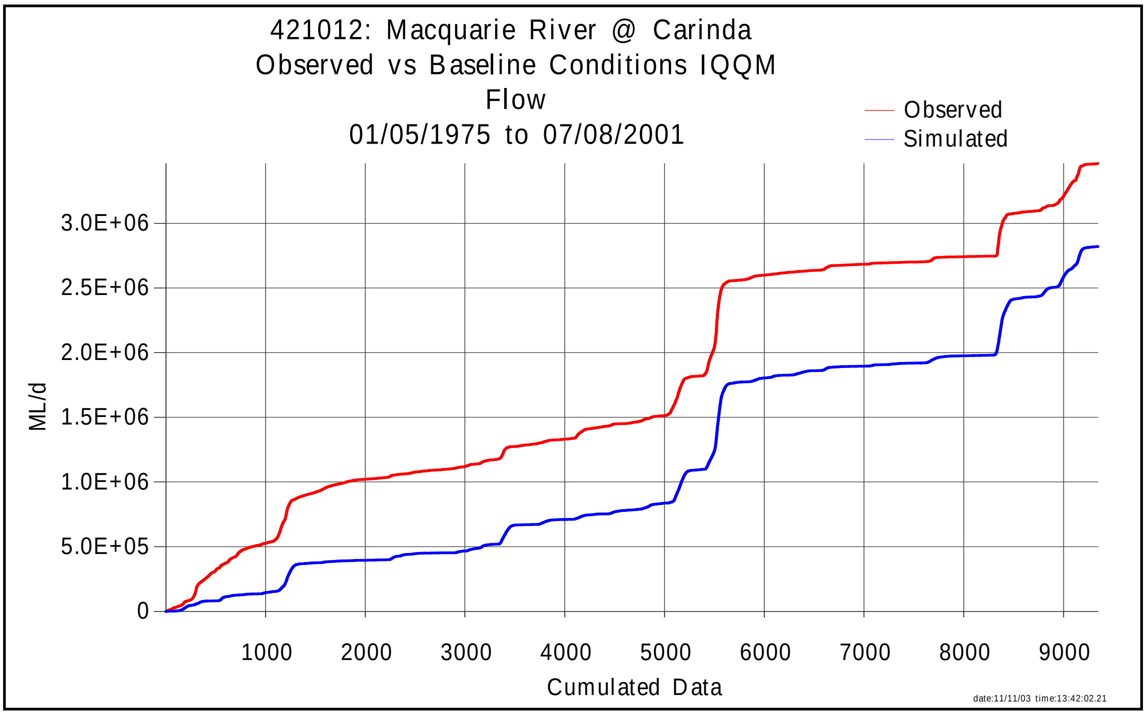


Figure 6.8. Cumulative simulated flow for Baseline Conditions scenario for days with observed flow, and observed flow (1/5/1975-30/4/2000) for Macquarie River @ Carinda.

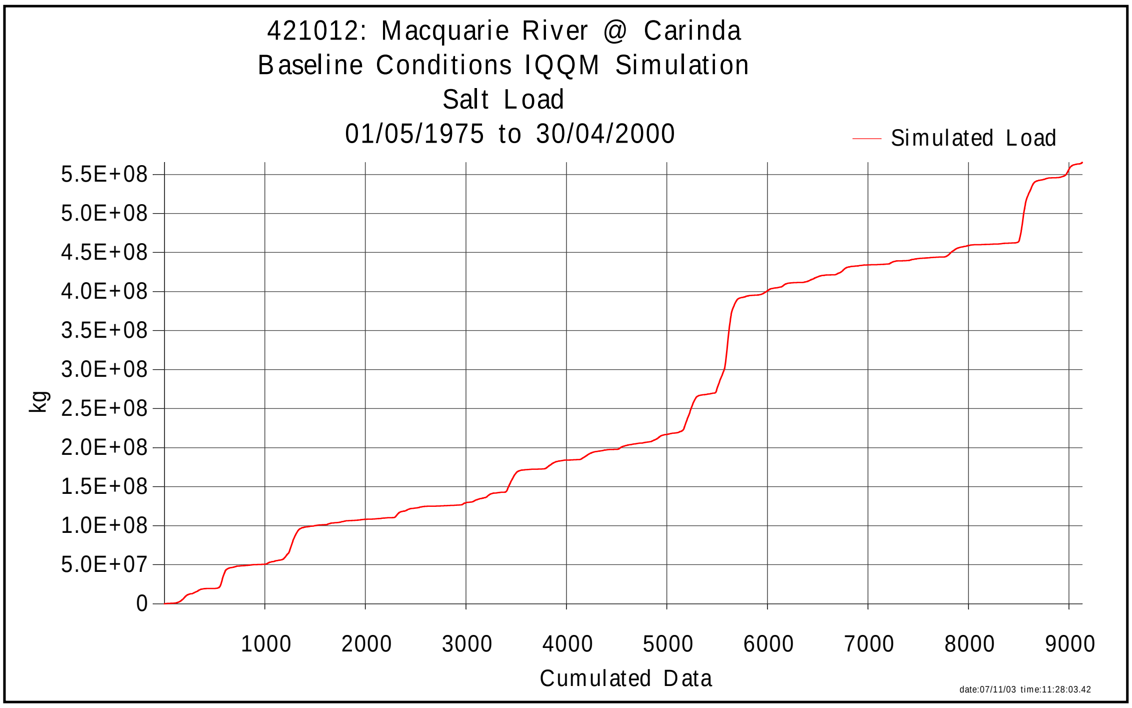


Figure 6.9. Cumulative simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Macquarie River @ Carinda.

7. Conclusion and recommendations

7.1. CONCLUSION

The Macquarie IQQM has produced a time series of flows and salt loads for the Benchmark Climatic Period under Baseline Conditions. The good match of flows, concentrations, and salt loads at Dubbo and Baroona signify that these Baseline Conditions results are quite reliable. The uncertainty in model results starts to increase at Marebone Weir and Carinda, largely because of uncertainties in modelling the water balance through irrigation areas and the Macquarie Marshes. The modelling through the Macquarie Marshes needs to be improved to get a better result of salt loads at Carinda.

The Macquarie IQQM, will at this stage of development, underestimate flow and salinity effects of land use changes in the Macquarie River upstream of Burrendong Dam. The modelling of ungauged catchments needs to be improved in this region to remove this limitation.

The Macquarie IQQM is capable of estimating the flow and salinity impacts of water sharing policies.

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 improvement.

- 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 do not on their own reproduce the variability in the salt load generation. Catchment process based modelling and continuous data should go some of the way to better salt export relationships.

- The methods to achieve water balance of inflows to Burrendong Dam be reviewed. This will enable the model to better estimate the effects of land use change in the Upper Macquarie Region. The simulated results of salinity are good overall over the period of record, but there are periods when the rate of change in salinity in Burrendong Dam is underestimated. The re-estimate of the inflows may address this also.

- The methods used to model the physical configuration and the water balance components of the Macquarie Marshes need to be reviewed to better represent the true components of the water balance. This will improve the match between both the simulated quantity and salinity behaviour at Carinda.

7.3. RECOMMENDED FUTURE DATA COLLECTION

7.3.1. Main stream salinity data

Sufficient continuous EC data at all gauging stations will improve estimates of salt balance in river reaches at all flow regimes, wet and dry periods, and summer and winter seasons. Both continuos and discrete data are required for quality checking the data. Priority should be given to the sites outlined in table.

Data coverage in the Macquarie catchment is excellent, with collection sites located at regular intervals along the mainstream channels. The modelling is somewhat limited by the length of the data sets, with the majority of continuous EC sites, having between 1 and 3 years of data (Figure 3.2), and discrete EC sites having between 1 and 30 days of data (Figure 3.1). Fortunately most of the discrete sites with low amounts of data are located on minor tributaries and watercourses and do not directly affect the quality of the modelling. Priority should be given to the sites outlined in Table 7.1.

Table 7.1: Main stream priority sites for discrete and continuous salinity data collection

Station Code	Station Name
421025	Macquarie River @ Bruinbun
421079	Cudgegong River D/S Windamere Dam
421019	Macquarie River @ Yamble Bridge
421040	Macquarie River D/S Wyangala Dam
421001	Macquarie River @ Dubbo
421127	Macquarie River @ Baroona
421004	Macquarie River @ Warren Weir
421090	Macquarie River @ Marebone
421012	Macquarie River @ Carinda

7.3.2. Inflow salinity data

Improved salinity inflow relationships will result from the continuation of salinity data collection at the sites listed in Table 7.2. Where it is possible continuous data probes should be installed. Flow data is required to support the salinity concentration data.

Table 7.2: Tributary stream priority sites for discrete and continuous salinity data collection

Station Code	Station Name
421058	Wyaldra Creek @ Gulgong
421073	Meroo Creek @ Yarrabin
421101	Cambells River U/S Ben Chiffley Dam
421035	Fish River @ Tarana
421053	Queen Charlottes Creek @ Georges Plains
421072	Winburndale Rivulet @ Howards Bridge

Station Code	Station Name
421026	Turon River @ Sofala
421041	Crudine Creek U/S Turon River Juction
421052	Lewis Ponds Creek @ Ophir
421067	Pyramul Creek @ Hill End
421066	Green Valley Creek @ Hill End
421018	Bell River @ Newrea
421048	Little River @ Obley
421059	Buckinbah Creek @ Yeoval
421042	Talbragar River @ Elong Elong
421055	Coolbaggie Creek @ Rawsonville

7.3.3. Storages and other supporting data

It is recommended to increase the salinity concentration sampling within the Windamere Dam storage. Data at this location is limited and the data 421079:Cudgegong River D/S Windamere Dam is not representative of concentrations in the storage due to the inflow from Swan Creek.

Sampling should also continue within the Burrendong storage, to gain a better understanding of the processes occurring within the storage. Continuous EC data together with storage inflow and outflows will assist in modelling salinity behaviour in the storage.

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 A1. EC data in the Mcquarie River valley

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
421001	Macquarie River @ Dubbo	32.270	148.600	Discrete	1976-2001	57
421001	Macquarie River @ Dubbo	32.270	148.600	Continuous	1998-2001	940
421002	Macquarie River @ Burrendong (Campbell's Dam)	32.676	149.117	Discrete	1977-1977	1
421003	Macquarie River @ Wellington	32.545	148.940	Discrete	1976-1977	7
421004	Macquarie River @ Warren Weir	31.736	147.865	Discrete	1976-2001	322
421004	Macquarie River @ Warren Weir	31.736	147.865	Continuous	1999-2001	954
421005	Gunningbar Creek @ Below Regulator	31.741	147.861	Discrete	1971-1991	83
421006	Macquarie River @ Narromine	32.220	148.238	Discrete	1976-1999	65
421007	Macquarie River @ Bathurst Post Q.Charlottes Div	33.418	149.590	Discrete	1976-1984	52
421008	Bell River @ Wellington	32.556	148.939	Discrete	1984-1990	2
421010	Bogan River @ Peak Hill No.1	32.723	148.127	Discrete	1976-1990	4
421011	Marthaguy Creek @ Carinda	30.466	147.683	Discrete	1976-2001	55
421012	Macquarie River @ Carinda	30.433	147.566	Discrete	1976-2001	316
421012	Macquarie River @ Carinda	30.433	147.566	Continuous	1999-2001	745
421013	Cudgegong River @ Guntawang	32.400	149.483	Discrete	1970-1978	9
421014	Macquarie River @ Warren Town	31.698	147.837	Discrete	1980-1988	2
421015	Duck Creek @ Offtake	31.658	147.755	Discrete	1970-1991	79
421016	Crooked Creek @ Profile	31.655	147.758	Discrete	1969-1991	74
421017	Gunningbar Creek At D/S Gunningbar Weir	31.676	147.755	Discrete	1971-1991	98
421018	Bell River @ Newrea	32.680	148.947	Discrete	1967-2001	140
421018	Bell River @ Newrea	32.680	148.947	Continuous	1999-2001	982
421019	Cudgegong River @ Yamble Bridge	32.400	149.333	Discrete	1968-2001	261
421019	Cudgegong River @ Yamble Bridge	32.400	149.333	Continuous	1997-2002	1588
421020	Nyngan Channel @ Offtake	31.677	147.763	Discrete	1977-1991	55
421022	Macquarie River @ Oxley Station	31.119	147.568	Discrete	1976-2000	266
421023	Bogan River @ Gongolgon	30.350	146.900	Discrete	1970-2001	197
421023	Bogan River @ Gongolgon	30.350	146.900	Continuous	2000-2001	324
421024	Marra Creek @ Yarrawin	30.266	147.216	Discrete	1971-1978	5
421025	Macquarie River @ Bruinbun	33.138	149.430	Discrete	1976-2001	165
421025	Macquarie River @ Bruinbun	33.138	149.430	Continuous	1999-2001	653
421026	Turon River @ Sofala	33.085	149.687	Discrete	1971-1990	123
421028	Talbragar River @ Cobborah	32.050	149.250	Discrete	1991-1991	1
421031	Macquarie River @ Gin Gin	31.916	148.100	Discrete	1976-1991	70

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
421032	Mckeons Creek @ Damsite	33.750	149.950	Discrete	1977-1977	3
421033	Bindo Creek @ Downstream Gum Valley	33.683	150.000	Discrete	1969-1977	36
421034	Slippery Creek @ Dam Site	33.673	149.910	Discrete	1969-1990	84
421035	Fish River @ U/S Tarana Road Bridge	33.566	149.916	Discrete	1969-1989	97
421036	Duckmaloi River @ Below Dam Site	33.753	149.936	Discrete	1969-1981	51
421037	Talbragar River @ Narranmore	32.119	149.140	Discrete	1969-1986	57
421038	Cudgegong River @ Rylstone Bridge	32.800	149.966	Discrete	1969-1988	54
421039	Bogan River @ Neurie Plains	31.775	147.125	Discrete	1968-2001	46
421039	Bogan River @ Neurie Plains	31.775	147.125	Continuous	2000-2001	101
421040	Macquarie River d/s Burrendong Dam	32.636	149.078	Discrete	1976-2001	199
421040	Macquarie River d/s Burrendong Dam	32.636	149.078	Continuous	1998-2001	1266
421041	Crudine Creek u/s Turon River Junction	33.050	149.666	Discrete	1968-1986	49
421042	Talbragar River @ Elong Elong	32.100	149.066	Discrete	1968-2001	187
421042	Talbragar River @ Elong Elong	32.100	149.066	Continuous	2000-2001	595
421043	Wisemans Creek @ Wisemans Creek	33.625	149.718	Discrete	1971-1981	41
421044	Sewells Creek u/s Wisemans Creek	33.658	149.707	Discrete	1976-1985	33
421045	Duck Creek u/s Bogan River Junction	31.100	147.133	Discrete	1969-1991	57
421046	Gunningbar Creek u/s Bogan River Junction	31.250	147.133	Discrete	1971-1991	59
421047	Talbragar River @ Meruthera	32.106	149.577	Discrete	1968-1991	78
421048	Little River @ Obley No.3	32.708	148.551	Discrete	1969-2001	136
421048	Little River @ Obley No.3	32.708	148.551	Continuous	1999-2001	924
421049	Molong River @ Molong	33.093	148.870	Discrete	1976-1990	38
421050	Bell River @ Molong	33.030	148.950	Discrete	1968-1991	123
421051	Blackmans Swamp Creek @ Near Orange	33.262	149.128	Discrete	1968-1978	46
421052	Lewis Ponds Creek @ Ophir	33.170	149.240	Discrete	1969-1978	54
421053	Queen Charlottes Creek @ Georges Plains	33.529	149.519	Discrete	1976-1982	24
421054	Campbells River @ Near Rockley	33.666	149.633	Discrete	1969-1981	55
421055	Coolbaggie Creek @ Rawsonville	32.145	148.454	Discrete	1969-2001	76
421055	Coolbaggie Creek @ Rawsonville	32.145	148.454	Continuous	1999-2001	805
421056	Coolaburragundy River @ Coolah	31.816	149.737	Discrete	1968-1991	125
421057	Campbells River @ Apsley	33.561	149.616	Discrete	1968-1978	50
421058	Wyaldra Creek @ Gulgong	32.338	149.472	Discrete	1971-1982	48

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
421059	Buckinbah Creek @ Yeoval	32.660	148.686	Discrete	1968-1990	76
421060	Marra Creek @ Marrabank	30.956	147.313	Discrete	1976-1978	5
421061	Merri Merri Creek @ Near Quambone	30.908	147.866	Discrete	1977-1989	20
421062	Marthaguy Creek @ Quambone	30.905	147.786	Discrete	1976-1991	30
421063	Ewenmar Creek @ Warren	31.676	147.852	Discrete	1971-1990	21
421064	Sandy Creek @ Medway No.2	32.150	149.204	Discrete	1971-1991	78
421065	Mitchell Creek @ Westella	32.290	148.901	Discrete	1976-1991	29
421066	Green Valley Creek @ Hill End	32.950	149.466	Discrete	1970-1990	60
421067	Pyramul Creek @ Hill End	32.933	149.466	Discrete	1976-1986	10
421068	Spicers Creek @ Saxa Crossing	32.200	149.016	Discrete	1976-1991	75
421069	Bogan River @ Broomfield	31.100	147.083	Discrete	1969-1990	71
421070	Crooked Creek @ Mumblebone	31.500	147.687	Discrete	1969-1991	47
421071	Duck Creek @ Colane	31.250	147.250	Discrete	1969-1980	42
421072	Winburndale Rivulet @ Howards Bridge	33.183	149.516	Discrete	1971-1978	42
421073	Meroo Creek @ Yarrabin No.2	32.630	149.336	Discrete	1976-2001	37
421074	Cudgegong River @ Apple Tree Flat	32.676	149.698	Discrete	1968-1981	33
421075	Evans Plains Creek @ Near Bathurst	33.483	149.450	Discrete	1970-1982	52
421076	Bogan River @ Peak Hill No.2	32.722	148.129	Discrete	1969-2001	41
421078	Macquarie River @ Burrendong Dam - Storage Gauge	32.668	149.110	Discrete	1979-1979	2
421079	Cudgegong River @ D/S Windamere Dam	32.708	149.753	Discrete	1970-2001	530
421079	Cudgegong River @ D/S Windamere Dam	32.708	149.753	Continuous	1997-2001	1385
421080	Macquarie River @ Dixons Long Point	33.027	149.280	Discrete	1976-2001	22
421081	Peppers Creek @ Rockley	33.704	149.555	Discrete	1971-1983	43
421082	Bell River @ Below Dam Site	32.883	148.966	Discrete	1972-1984	66
421083	Bogan River @ Dandaloo	32.276	147.616	Discrete	1973-1990	37
421084	Burrill Creek @ Mickibri	32.899	148.221	Discrete	1973-1991	58
421085	Beni Billa Creek @ Canonbar Road Bridge	31.366	147.300	Discrete	1974-1991	17
421087	Plum Pudding Creek @ Mirambee	32.350	148.683	Discrete	1976-1990	28
421088	Marebone Break @ Marebone Regulator	31.380	147.691	Discrete	1977-1991	65
421090	Macquarie River d/s Marebone Weir	31.386	147.691	Discrete	1976-2001	73
421090	Macquarie River d/s Marebone Weir	31.386	147.691	Continuous	1995-2001	2135
421091	Winburndale Rivulet @ Oakbrook	33.337	149.623	Discrete	1989-1989	1
421097	Marra Creek @ Carinda Road	31.366	147.655	Discrete	1977-1991	32
421099	Belaringar Creek @ Offtake (Regulator)	31.716	147.850	Discrete	1984-1990	7

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
421100	Pyramul Creeku/s Hill End Road	32.930	149.466	Discrete	1979-1985	19
421101	Campbells River u/s Ben Chifley Dam	33.612	149.697	Discrete	1978-1990	60
421103	Emu Swamp Creek @ Llewelyn	33.229	149.238	Discrete	1980-1990	36
421104	Brisbane Valley Creek @ Stromlo	33.687	149.725	Discrete	1979-1990	52
421106	Cheshire Creek @ Wiagdon	33.247	149.655	Discrete	1980-1990	46
421107	Marra Creek @ Billybingbone Bridge	30.375	147.188	Discrete	1980-2001	28
421108	Northern Bypass Channel @ Below Regulator	30.755	147.549	Discrete	1980-1991	20
421109	Monkey Creek @ Break	31.086	147.559	Discrete	1983-1989	6
421110	Monkey Creek @ Western Arm Return	31.005	147.506	Discrete	1980-1983	2
421111	Buckiinguy Creek @ Break	31.093	147.547	Discrete	1987-1989	4
421112	Buckinguy Creek @ Return	31.042	147.512	Discrete	1980-1988	5
421116	Macquarie River @ Gibson Way	30.913	147.505	Discrete	1980-1989	4
421118	Bulgeraga Creek @ Gibson Way	30.897	147.571	Discrete	1980-1991	21
421120	Macquarie River @ The Willows	30.767	147.521	Discrete	1980-1985	3
421121	Turee Creek @ Coolah-Cassilis Road Bridge	31.909	149.826	Discrete	1985-1988	4
421122	Macquarie River d/s Gibson Way	30.887	147.501	Discrete	1980-1980	2
421125	Jones Creek @ Tara	32.154	148.782	Discrete	1982-1991	37
421126	Cainbil Creek @ Loch Lomond	32.075	149.661	Discrete	1982-1991	22
421127	Macquarie River @ Baroona	32.213	148.375	Discrete	1981-2001	63
421127	Macquarie River @ Baroona	32.213	148.375	Continu ous	1999-2001	931
421128	Gunningbar Creek @ Box Culverts	31.386	145.175	Discrete	1984-1990	14
421129	Monkeygar Creek u/s Western Arm Monkey Creek	31.015	147.505	Discrete	1983-1989	7
421130	Macquarie River @ Bosses Crossing	30.981	147.431	Discrete	1988-1988	1
421132	Monkeygar Creek d/s Gibson Way	30.866	147.528	Discrete	1985-1989	6
421133	Bora Channel @ Return	30.595	147.570	Discrete	1983-1983	2
421134	Duck Swamp @ Return	30.567	147.595	Discrete	1985-1985	2
421135	Macquarie River @ Miltara	30.563	147.595	Discrete	1983-1991	26
421136	Bulgeraga Creek @ Oxley	31.059	147.797	Discrete	1983-1991	10
421138	Bogan River @ Nyngan	31.559	147.184	Discrete	1985-1986	5
421139	Redenville Break @	-	-	Discrete	1986-1989	2
421140	Northern Marshes Channel @ End	30.623	147.585	Discrete	1983-1985	4
421141	Nyngan Channel @ New Weir	31.686	147.333	Discrete	1985-1990	13
421142	Milmiland Creek @ Road Bridge	31.051	147.493	Discrete	1985-1989	4
421144	Oxley Break No. 3 @ Offtake	31.159	147.603	Discrete	1985-1985	1
421145	Bulgeraga Creek @ Bifurcation	31.179	147.668	Discrete	1984-1991	16
421145	Bulgeraga Creek @ Bifurcation	31.179	147.668	Continu ous	1998-2001	931

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
421146	Gum Cowal @ Bifurcation	31.180	147.669	Discrete	1984-1989	16
421147	Macquarie River @ Pilligawarrina	30.800	147.500	Discrete	1984-1991	23
421149	Cudgegong River @ Rocky Water Hole	32.622	149.640	Discrete	1985-2001	39
421149	Cudgegong River @ Rocky Water Hole	32.622	149.640	Continu ous	1998-2001	1018
421150	Cudgegong River @ Wilbertree Road	32.511	149.568	Discrete	1985-2001	40
421150	Cudgegong River @ Wilbertree Road	32.511	149.568	Continu ous	1997-2002	1759
421151	Bora Channel @ Offtake	30.760	147.523	Discrete	1987-1989	4
421152	Gum Cowal @ Oxley	31.038	147.748	Discrete	1987-1988	4
421153	Terrigal Creek u/s Marthaguy Ck	31.038	147.748	Discrete	1988-1988	2
421156	Terrigal Creek u/s Marthaguy Ck	32.700	149.041	Discrete	1991-1991	1
421174	Terrigal Creek u/s Marthaguy Ck	32.827	149.925	Continu ous	1999-2001	799
421902	Bogan River @ Mulgawarrina	30.666	146.916	Discrete	1970-1986	11
42110001	Burrendong Dam Station 1	32.672	149.106	Discrete	1977-1996	63
42110002	Burrendong Dam Station 2	32.721	149.176	Discrete	1990-1996	12
42110003	Burrendong Dam Station 3	32.819	149.243	Discrete	1990-1996	13
42110004	Burrendong Dam Station 4	32.880	149.226	Discrete	1981-1990	2
42110006	Burrendong Dam Station 6	32.601	149.195	Discrete	1990-1996	12
42110011	Burrendong Dam Station 6	32.842	149.907	Discrete	2001-2001	1
42110011	Burrendong Dam Station 6	32.842	149.907	Continu ous	1999-2001	902
42110017	Burrendong Dam Station 6	31.318	147.654	Discrete	1995-1999	27
42110019	Burrendong Dam Station 6	31.300	147.679	Discrete	1995-1999	26
42110021	Windamere Dam Station 1	32.732	149.767	Discrete	1984-1997	74
42110022	Windamere Dam (Limestone Ck) Station 2	32.758	149.780	Discrete	1984-1994	57
42110023	Windamere Dam (Ironstone Ck) Station 3	32.789	149.824	Discrete	1984-1991	52
42110024	Windamere Dam (Rec Area) Station 4	32.808	149.827	Discrete	1985-1994	55
42110025	Windamere Dam Station 5	32.810	149.873	Discrete	1990-1991	5
42110026	Windamere Dam Station 6	32.798	149.890	Discrete	1990-1995	15
42110028	Windamere Dam Station 6	32.791	149.984	Discrete	1992-1993	2
42110029	Windamere Dam Station 6	32.791	149.985	Discrete	1992-1993	2
42110030	Windamere Dam Station 6	32.835	150.203	Discrete	1992-1993	2
42110031	Windamere Dam Station 6	32.804	149.961	Discrete	1992-1993	2
42110040	Burrendong Dam Station 6	32.816	149.930	Continu ous	1999-2001	825
42110047	Burrendong Dam Station 6	32.811	150.034	Continu ous	1999-2001	712
42110085	Native Dog Creek @ Sewells Road	32.432	148.809	Discrete	1999-2001	21

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
42110101	Macquarie River @ Molong Rail Bridge	32.284	148.603	Discrete	1991-2000	150
42110102	Macquarie River @ Sandy Beach	-	-	Discrete	1991-1991	1
42110103	Macquarie River @ Dubbo Weir	-	-	Discrete	1991-1991	1
42110104	Macquarie River @ Emile Serisier Bridge	-	-	Discrete	1991-1991	2
42110105	Macquarie River @ Devils Hole	-	-	Discrete	1991-1991	2
42110106	Macquarie River @ Troy Bridge Road	-	-	Discrete	1991-1991	2
42110107	Macquarie River d/s Troy Junction	-	-	Discrete	1991-1991	2
42110108	Talbragar River @ Boothenba	-	-	Discrete	1991-1991	3
42110109	Macquarie River @ Terramungamine Reserve	32.170	148.583	Discrete	1991-2000	144
42110110	Talbagar River @ Newell Highway Road Bridge	-	-	Discrete	1991-1991	2
42110111	Bulgeraga Creek @ Oxley Road	31.060	147.628	Discrete	1991-1991	102
42110136	Bulgeraga Creek @ Oxley Road	30.436	147.568	Discrete	2000-2000	1
420001	Castlereagh River @ Gilgandra	31.730	148.667	Discrete	1969-1988	72
420002	Castlereagh River @ Coonabarabran No.1	31.266	149.283	Discrete	1968-1969	5
420003	Belar Creek @ Warkton (Blackburns)	31.386	149.201	Discrete	1968-1991	163
420004	Castlereagh River @ Mendooran	31.820	149.116	Discrete	1968-2002	276
420005	Castlereagh River @ Coonamble	30.955	148.386	Discrete	1970-1991	81
420007	Castlereagh River @ Binnaway	31.526	149.351	Discrete	1968-1981	65
420008	Binnia Creek @ Ulinda	31.575	149.452	Discrete	1969-1990	30
420009	Merrygoen Creek @ Mendooran	31.841	149.158	Discrete	1976-1981	10
420010	Wallumburrawang Creek @ Bearbung	31.666	148.867	Discrete	1970-1991	53
420011	Baronne Creek @ Near Gulargambone	31.286	148.731	Discrete	1981-1990	8
420012	Butheroo Creek @ Neilrex	31.735	149.348	Discrete	1969-1991	94
420013	Castlereagh River @ Coonabarabran No.2	31.268	149.266	Discrete	1970-1984	90
420014	Magometon Creek (Site 3) @ Near Coonamble	30.997	148.477	Discrete	1983-1991	9
420015	Warrena Creek @ Warrana	30.994	148.433	Discrete	1970-1991	65
420016	Jack Halls Creek @ Near Coonabarabran	31.331	149.231	Discrete	1975-1991	60
420017	Castlereagh River @ Hidden Valley	31.419	149.313	Discrete	1980-1991	82
420019	Castlereagh River @ Merryula	31.358	149.327	Discrete	1988-1988	2
420020	Castlereagh River @ Gungalman Bridge	30.310	147.998	Continu ous	2001-2001	196

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 5.9 of the Salinity Audit (DECC, 2007). This test for consistency is necessary for confidence in the Macquarie 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, 2000).

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 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., Cudgegong River @ Windamere Dam site, 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 4.3-Figure 4.6), were subtracted to produce net flow and salt load for that catchment.

These results are summarised in Table B.8.1. The shaded rows in the Table B.8.1 represent Salinity Audit balance points, and the other rows represent inflow points.

Table B.8.1. 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*
421079	Cudgegong River @ Windamere Dam Site	*45.7*	50.5	52.0	*9.5*	10.5	10.7	10.0	9.1
421058	Wyaldra Creek @ Gulgong	*21.4*	19.9	24.5	*10.0*	10.0	11.2	10.5	6.2
R4	Ungauged Cudgegong River u/s Yamble Bridge	*54.2*	53.0	63.0	*13.6*	14.0	16.2	15.2	14.7
421019	**Cudgegong River @ Yamble Bridge**	***101.2***	**114.5**	**124.2**	***34.0***	**35.5**	**37.4**	**35.3**	**30.6**
421035	Fish River @ Tarana	*91.2*	93.3	87.4	*5.1*	5.2	4.9	4.6	4.9
421101	Campbells River u/s Ben Chifley Dam	*84.6*	81.8	82.2	*12.4*	12.2	12.2	11.4	10.5
R1	Ungauged Macquarie River u/s Bathurst	*87.8*	81.0	74.6	*14.2*	13.7	12.9	12.1	11.5
421072	Winburndale Rivulet @ Howards Bridge	*67.0*	70.1	71.8	*11.5*	11.8	12.1	11.3	9.4
R2	Ungauged Macquarie River between Bathurst and Bruinbun	*39.1*	40.6	43.6	*12.0*	14.4	14.9	13.9	9.8
421025	**Macquarie River @ Bruinbun**	***389.3***	**358.7**	**351.5**	***45.3***	**55.5**	**55.2**	**51.8**	**44.9**
421052	Lewis Ponds Creek @ Ophir	*73.3*	69.3	66.1	*9.3*	9.0	8.8	8.3	7.3
421041	Crudine River u/s Turon River junction	*27.7*	28.3	29.7	*5.1*	5.1	5.3	4.9	4.0
421026	Turon River @ Sofala	*90.0*	89.5	95.7	*14.1*	14.0	14.7	13.8	12.5
421073	Meroo Creek @ Yarrabin 2	*79.2*	71.2	84.2	*12.1*	11.2	12.7	11.9	10.7
R3	Ungauged Macquarie and Cudgegong Rivers u/s Burrendong Dam	*281.7*	261.8	296.6	*38.7*	13.0	16.1	15.1	23.3
421040	**Macquarie River d/s Burrendong Dam**	***1048.5***	**983.2**	**973.0**	***147.8***	**148.1**	**145.9**	**137.2**	**129.6**
421018	Bell River @ Newrea	*108.5*	107.6	109.4	*30.4*	30.2	30.6	28.7	25.7
421059	Buckinbah Creek @ Yeoval	*22.2*	21.8	24.3	*12.6*	12.7	13.7	12.9	12.2
R5,6,7	Ungauged Macquarie River between Burrendong Dam and Dubbo	*N/A*	104.8	108.4	*22.0*	35.0	35.8	33.6	29.4
421001	**Macquarie River @ Dubbo**	***N/A***	**1196.5**	**1194.0**	***212.9***	**221.3**	**221.3**	**207.9**	**193.2**
421042	Talbragar River @ Elong Elong	*82.4*	43.0	53.6	*15.5*	15.2	17.4	16.3	15.5
R8-9	Ungauged Macquarie and Talbragar Rivers u/s Narromine	*51.2*	41.1	64.0	*24.3*	14.8	20.1	18.9	18.2
421055	Coolbaggie Creek @ Rawsonville	*18.2*	16.5	20.9	*6.5*	5.7	6.8	6.4	4.9
421006	**Macquarie River @ Narromine**	***1279.2***	**1262.4**	**1294.3**	***234.0***	**248.2**	**255.9**	**240.2**	**224.1**
421023	Bogan River @ Gongolgon	*223.8*	N/A	N/A	*34.0*	N/A	N/A	N/A	N/A

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
421079 = Inflows (001, 300) – Losses (301).
R3 = Inflows (024, 025, 242, 243, 244) – Losses (030)
R4 = Inflows (350, 302, 304, 306, 307, 352, 309, 310, 312, 354, 314, 318, 356, 358) – Losses (351, 303, 305, 308, 353, 311, 224, 313, 355, 315, 319, 357, 359, 238).
421058 = Inflows (316) – Losses (317)
R1 = Inflows (016, 029) – Losses (403)
R2 = Inflows (401) – Losses (406)
R5,6 and 7 in the audit have been grouped = Inflows(261, 038, 264, 286) – Losses(262, 265, 287, 123)
R8,9 = Inflows(268, 270, 271,) – Losses (269, 271, 124)

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 show that there are differences in nearly all the inflow balance points. Of the nineteen inflow points, ten are within 5% of the reported Salinity Audit results, seven within 10%, and two are over 10%. There is some bias toward IQQM results underestimating the comparable Salinity Audit results, particularly where differences are greater than 5%.

These results are not what were expected, as the flows should have been the same. Possible explanations for some inflows include:

(i) Windamere Dam outflows were used in the Salinity Audit, whereas inflows are reported here. Part of the difference would be because of net evaporation from the storage.

(ii) Some of the residual catchment inflows were revised compared with the model version used for the Salinity Audit.

The reasons for discrepancies for the gauged inflows are not apparent. Possible explanations for these would include:

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

(iv) 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).

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

(vi) Typographic error for the case of 421042, Talbragar River @ Elong Elong.

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, partially 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 sixteen of the nineteen 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 Dubbo (Figure 2.7). The three inflows that were lower on average were from catchments in the Upper Macquarie region. The catchments downstream of Burrendong Dam appear to have had the biggest percentage increases. The overall modelled difference in water at the end of the system is approximately 2%.

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 flows shows that there are differences for many the inflows and balance points. However, these differences are relatively minor with some notable exceptions. Of the nineteen IQQM inflow points, twelve are within 5% of the reported Salinity Audit results, with eight of these less than 2%. A further two are within 10%, and the remaining five are over 10% different.

The two salt load inflow points with 5-10% difference are the Cudgegong River @ Windamere Dam, and Meroo Creek @ Yarrabin 2. The difference for the Cudgegong River salt load inflow could be attributed to applying the Salinity Audit relationship to a different flow time series. The Salinity Audit appears to have used Windamere Dam outflows, whereas the relationship is applied to the inflows in the Macquarie System IQQM. The inflows are greater than the outflows as discussed in Section B.1.1.1. The difference for the Meroo Creek salt load inflow seem to be because the flow time series at this site is significantly different.

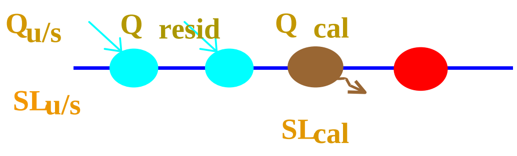
The five salt load inflow points with greater than 10% difference are all residual catchments, with the exception of Coolbaggie Creek @ Rawsonville. The 12% difference in this case is probably because of the comparable flow difference for this stream. The differences for the residual catchments are all 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.8.1, 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, it is also includes salt load from upstream. These differences in structure between the Salinity Audit and IQQM makes it difficult to directly compare salt load inflows for residual catchments.

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

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

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



Where: η, λ are salt load relationship parameters $SL\_\_$, $Q\_\_$ are shown in Figure B.8.1.

Figure B.8.1. Schematic for calculating net salt load inflow from residual catchments in IQQM

The salt loads at the balance points in IQQM are therefore generally higher than those reported in the Salinity Audit. This is in part because of the incompatible configurations of the residual catchments and calibration nodes. The net effect at Macquarie River @ Narromine is a 4% increase in salt loads compared with that reported in the Salinity Audit.

B.1.2.2. Climatic period

The mean annual salt loads for the BSMS climatic period (01/05/1975-30/04/2000) are higher for sixteen of the nineteen inflow points than the mean annual salt loads for the Salinity Audit climatic period (01/01/1975-31/12/1995). The salt load inflows that increased are for the same catchments where flows increased. While the range of differences varies from 0-24%, the net difference at Narromine is a 3% increase compared with that reported in the previous section.

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.8.1 a constant ratio of 0.9375 (or 0.60/0.64) lower than those in Column 2 of Table B.8.1.

B.1.2.4. Concentration cap

Capping the concentration has had quite a significant effect on the total salt loads for most of the inflow points, with reductions compared with column 3. These changes are mostly within the range of 10-20% lower than those in Column 3. One major exception to this is the result for catchment R3, where unexpectedly the average annual salt load increased. This latter result was investigated, and was found to be caused by the method used to calculate the net residual. The calibration node at the inflow from the Upper Macquarie into Burrendong Dam removes nearly all the modelled inflow below 300 ML/d, and 40% of total modelled inflows from the Upper Macquarie in order to achieve mass balance. This result highlights an area that needs attention when reporting results.

B.2. CONCLUSION

The direct comparison (same climate period, same EC→Salinity conversion factor, and no concentration cap) of mean annual flow results reported in the Salinity Audit and those from IQQM showed some differences. The net difference at Macquarie River @ Narromine is approximately -2%. Some possible reasons for this were put forward, and can be confirmed by reviewing the data and calculations used to report the Salinity Audit results.

The direct comparison of mean annual salt loads reported in the Salinity Audit (Beale et al. 1999) and those from IQQM showed some differences. The net difference at Macquarie River @ Narromine is approximately +6%. 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 for the BSMS Benchmark climate period were 2% higher than that used in the Salinity Audit. These higher flows resulted in a 3% increase in mean annual salt loads compared with the IQQM results used in the direct comparison. These mean annual salt loads were then reduced by 6% using the lower EC→ Salinity conversion factor and a further 7% by adopting a realistic maximum concentration for the salinity inflows.

The net difference in mean annual salt loads of all the modifications is -10% compared with the IQQM used for the direct comparison, and –4% compared with those reported in the Salinity Audit.

Appendix C. Model Details

The following details the IQQM used for the Macquarie River Baseline conditions scenario run.

- IQQM version = 6.76.1
- System file = MacqBL01.sqq (all other files are detailed in this system file).