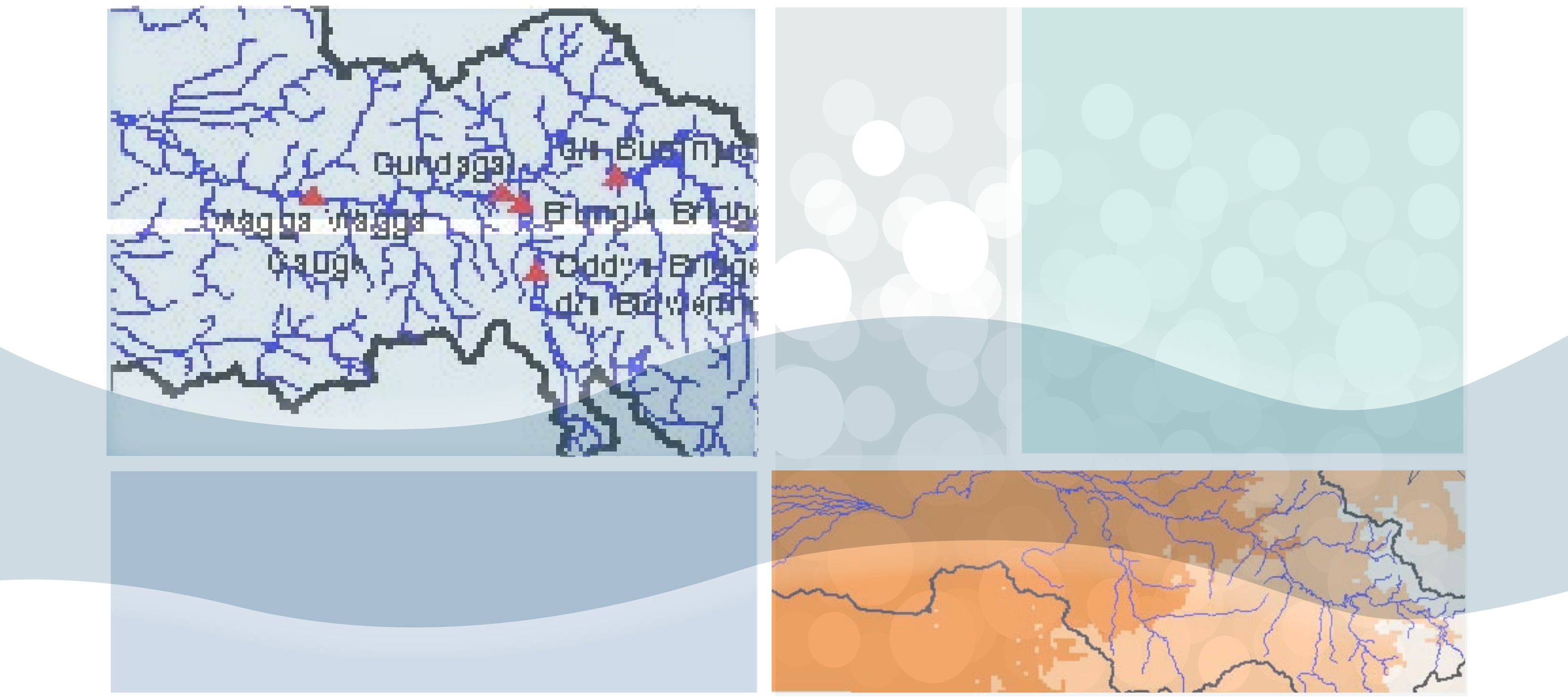
Instream salinity models of NSW tributaries in the Murray-Darling Basin

Volume 5 – Lachlan River Salinity Integrated Quantity and Quality Model



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Instream salinity models of NSW tributaries in the Murray-Darling Basin
Volume 5 – Lachlan 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 Lachlan 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 Lachlan 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 basinwide salinity management, which is discussed in Section 1.2. A number of basinwide and statewide natural resource management policies are relevant to salinity management and the need for this model. The modelling requirements are clearly set out in Schedule C of the Murray Darling Basin Agreement. The policies are discussed in Section 1.3, with a focus on Schedule C in Section 1.3.3. This model is one of a suite of models and decision support systems that have been developed for salinity management, and this is discussed in Section 1.4. The steps taken to develop this model are discussed in the final section of this chapter.

The processes affecting salinity behaviour in a catchment are influenced by many physical factors, and the most important of these are described in Chapter 2. Whereas the actual salinity behaviour is best described by data, and the data available to characterise this behaviour is described in Chapter 3. The salt transport model was developed using a daily water balance model as the platform. The Lachlan 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 Lachlan IQQM and software testing is described in Chapter 4.

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

1.1.2. Related reports

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

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

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

1.2. HISTORICAL BACKGROUND TO WORK

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

1.2.1. 1988 Salinity and Drainage Strategy

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

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

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

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

1.2.2. 1997 Salt trends

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

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

1.2.3. 1999 Salinity Audit

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

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

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

1.2.4. 2006 Salinity Audit

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

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

1.3. CURRENT POLICY FRAMEWORK

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

1.3.1. MDBC Integrated Catchment Management

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

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

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

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

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

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

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

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

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

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

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

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

1.3.3.1. Schedule C of the Murray-Darling Basin Agreement

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

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

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

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

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

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

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

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

1.3.4. Catchment Action Plans

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

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

1.3.5. NSW Water Sharing Plans

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

1.3.6. NSW Salinity Strategy

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

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

The salinity targets were developed and recommended through the Catchment Management Boards. To monitor the salinity targets and to assess the impacts of management options for land use changes on these salinity targets, numerical modelling tools to estimate salt load wash off and salt load transport became high priority. The modelling framework to meet these salinity strategies is described in Section **Error! Reference source not found.**.

1.3.7. NSW Environmental Services Scheme

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

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

1.3.8. CMA Incentive schemes

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

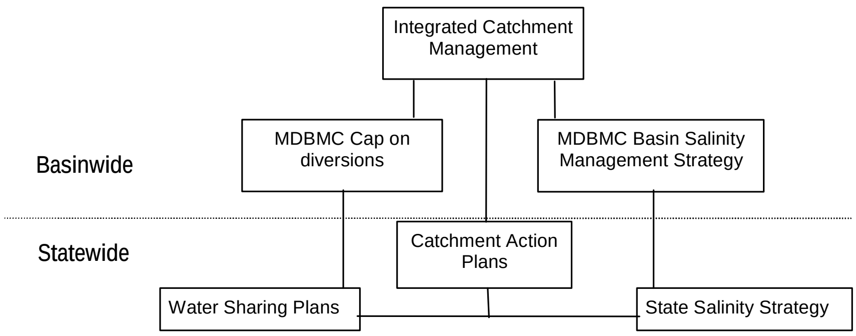


Figure 1.1. Relationship of Basinwide and Statewide policies and plans

1.4. DWE MODEL FRAMEWORK

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

1.4.1. Objectives of modelling

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

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

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

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

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

1.4.2. Modelling requirements

The modelling had the following requirements:

- Daily predictions

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

1.4.3. Strengths and Limitations

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

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

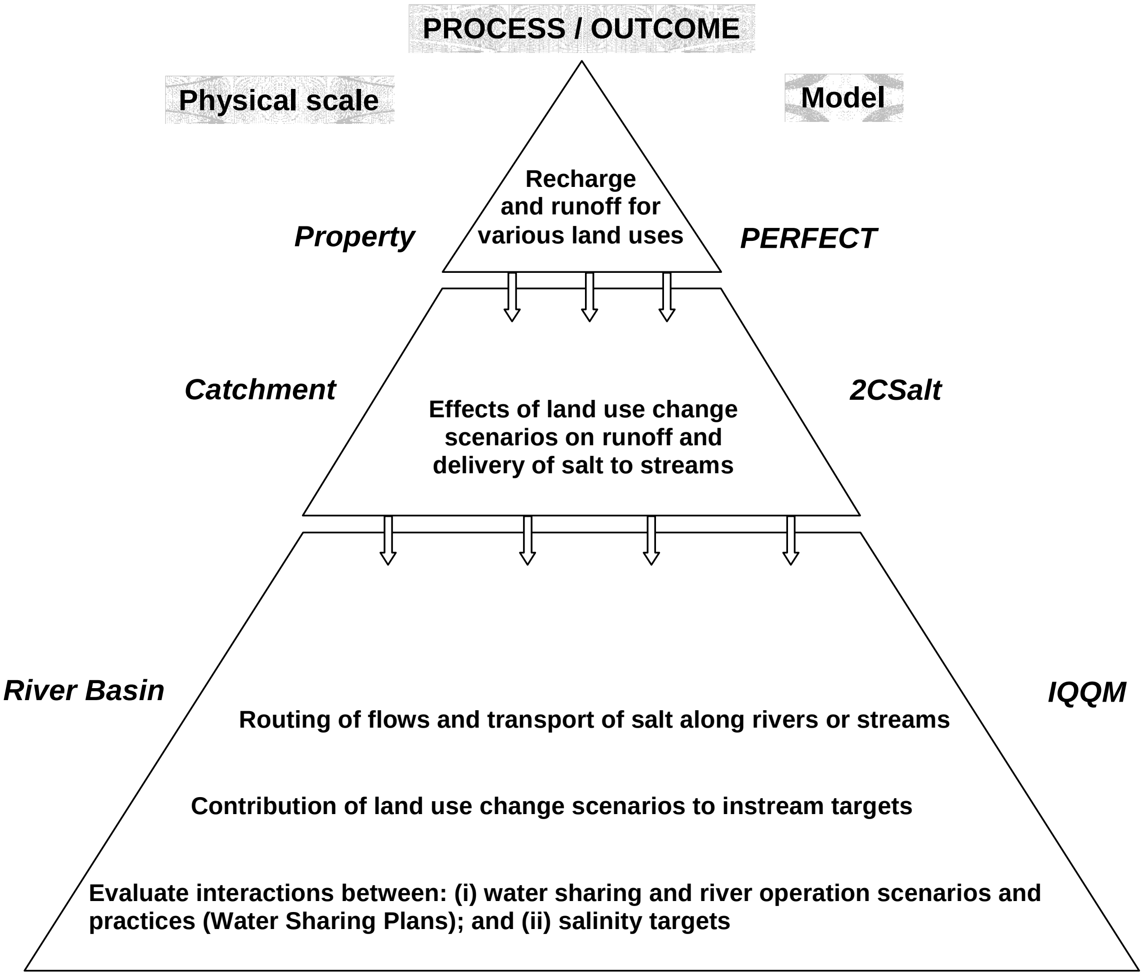


Figure 1.2. Applications and linkages of DECC and DWE models at different scales

1.5. STAGED MODEL DEVELOPMENT

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

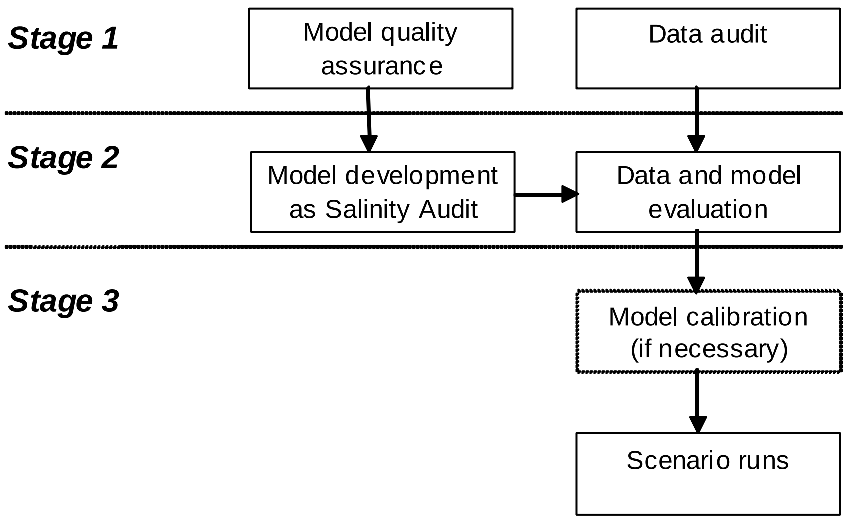


Figure 1.1. Stages of model development

1.5.1. Stage 1: Model QA and Data Audit

The existent IQQM that had been configured and calibrated for the Lachlan 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 Lachlan River System

2.1. PHYSICAL FEATURES OF THE CATCHMENT

2.1.1. General

The Lachlan River Valley is one of major NSW sub-catchments of the Murray-Darling Basin (Figure 2.1). It occupies an area of around 85,000 km^2 from the Great Dividing Range near Cowra to the Murrumbidgee River near Oxley, 600 km to the west. Normally, the Lachlan River is a terminal system ending at the Cumbung Swamp except during extreme floods where water flows into the Murrumbidgee River.

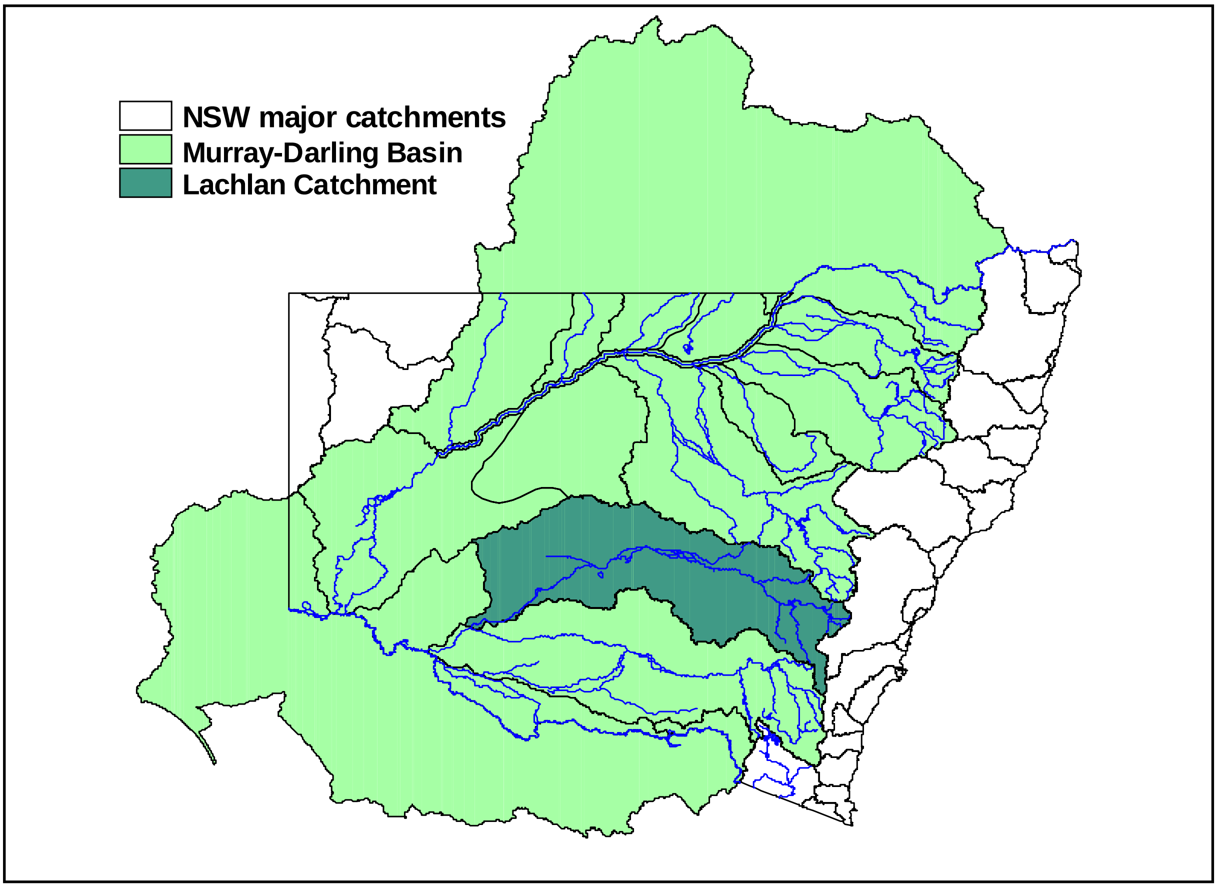


Figure 2.1. Relationship of Lachlan catchment to Murray-Darling Basin

The Lachlan catchment includes a number of regional centres, including Parkes, Cowra, and Forbes all with populations of up to 12,500 people in Cowra (includes surrounding district) (Figure 2.2). There are also a number of towns, with populations ranging from 500-3,500 people. The total urban population in the Lachlan catchment is about 50,000 people.

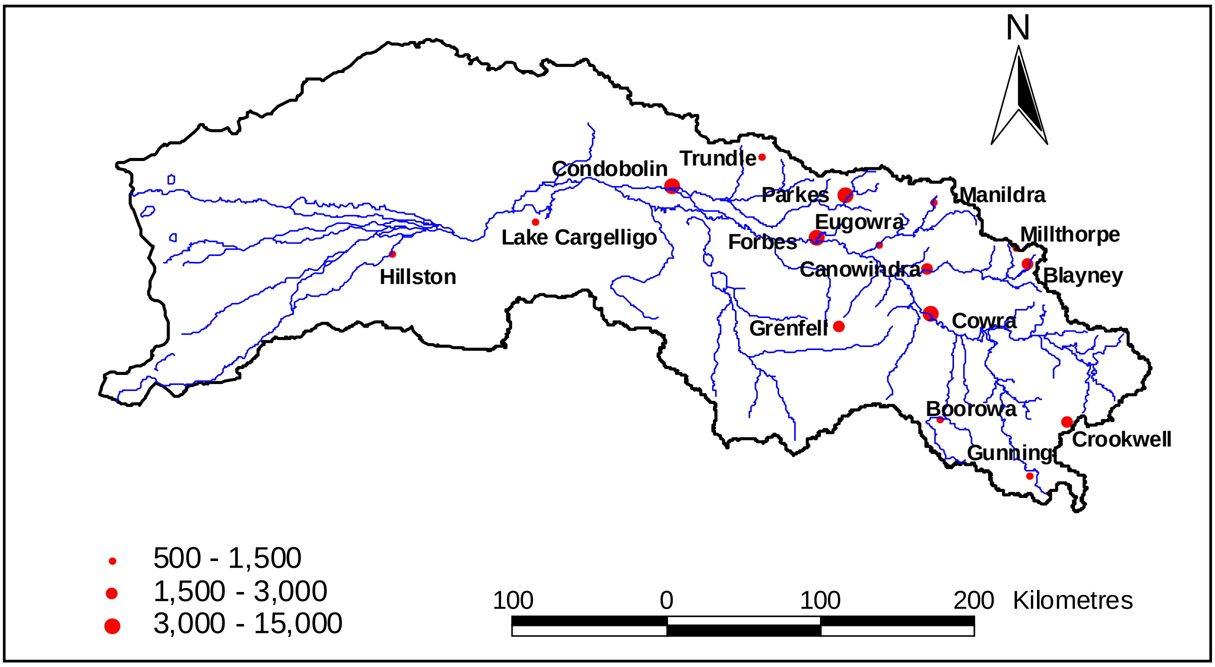


Figure 2.2. Cities and towns in Lachlan catchment

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

(i) Lachlan River Upstream of Wyangala (source region)

(ii) Belubula River (source and extraction region)

(iii) Lachlan River between Wyangala Dam and argelligo Weir (source and extraction region)

(iv) Lachlan Downstream of Cargelligo Weir (extraction region)

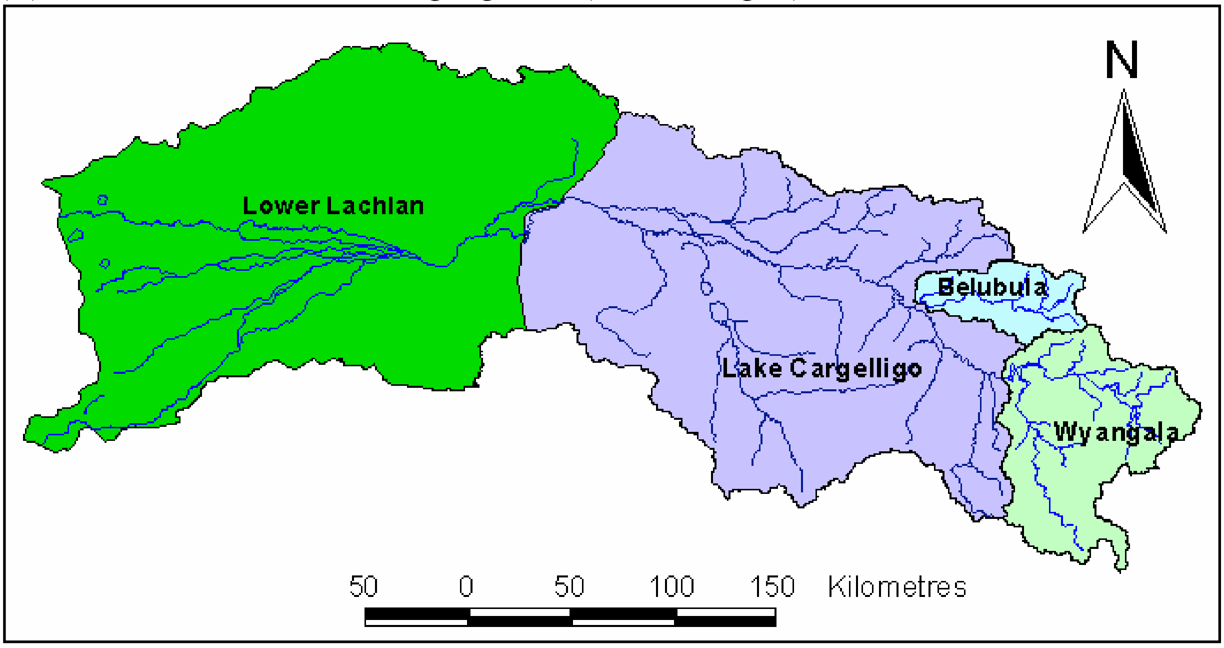


Figure 2.3 Major regions of Lachlan Catchment

2.1.2. Stream network

2.1.2.1. Lachlan River upstream of Wyangala Dam

The Lachlan River rises in the Great Dividing Range just north-west of Lake George and flows north-west into Wyangala Dam. Major tributaries in this reach include Crookwell and Abercrombie Rivers and Tuena Creek. There are also numerous small creeks contributing flows to the Lachlan River. The rivers in this reach flow within well-defined channels and have only limited floodplains.

2.1.2.2. Belubula River

The westerly flowing Belubula River system starts with a relatively small catchment upstream of Carcoar Dam and flows west ends approximately 60km to the west at the junction with the Lachlan River. There are also numerous creeks, including Flyers and Coombing Creeks, that contribute flows to the Belubula River

2.1.2.3. Lachlan River between Wyangala Dam and Cargelligo Weir

The Lachlan River flows north-west from Wyangala Dam collecting the major tributaries of Booroowa River, Back Creek, Belubula River, and Mandagery Creek before heading west between Forbes and Cargelligo Weir. About 40 km upstream of Condobolin, the river breaks up into numerous effluents from Island Creek before rejoining again near Condobolin.

2.1.2.4. Lachlan River downstream of Cargelligo Weir

The Lachlan River flows west interacting with the Cargelligo and Brewster storages. Downstream of Lake Brewster, the Lachlan splits into a number of effluents including Willandra, Moolbong, and Merrowie Creeks. Cargelligo and Brewster Lakes are used, in conjunction with Wyangala Dam, to supply the water requirements of users in this region.

2.1.3. Hydrometeorology

2.1.3.1. Rainfall

Average annual rainfall varies from 1200 mm along the elevated eastern part of the drainage basin to 250 mm in the lower western reaches. Annual rainfall varies over a range from about 0.5-2.0 times the average (600mm, Figure 2.4). Average monthly rainfall is generally uniform throughout the year, with slightly higher values in January and October (Figure 2.5). 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. During the benchmark climatic period (1975 and 2000), the annual rainfall at experienced droughts between 1979-1982, 1994 and 1997 (Figure 2.7).

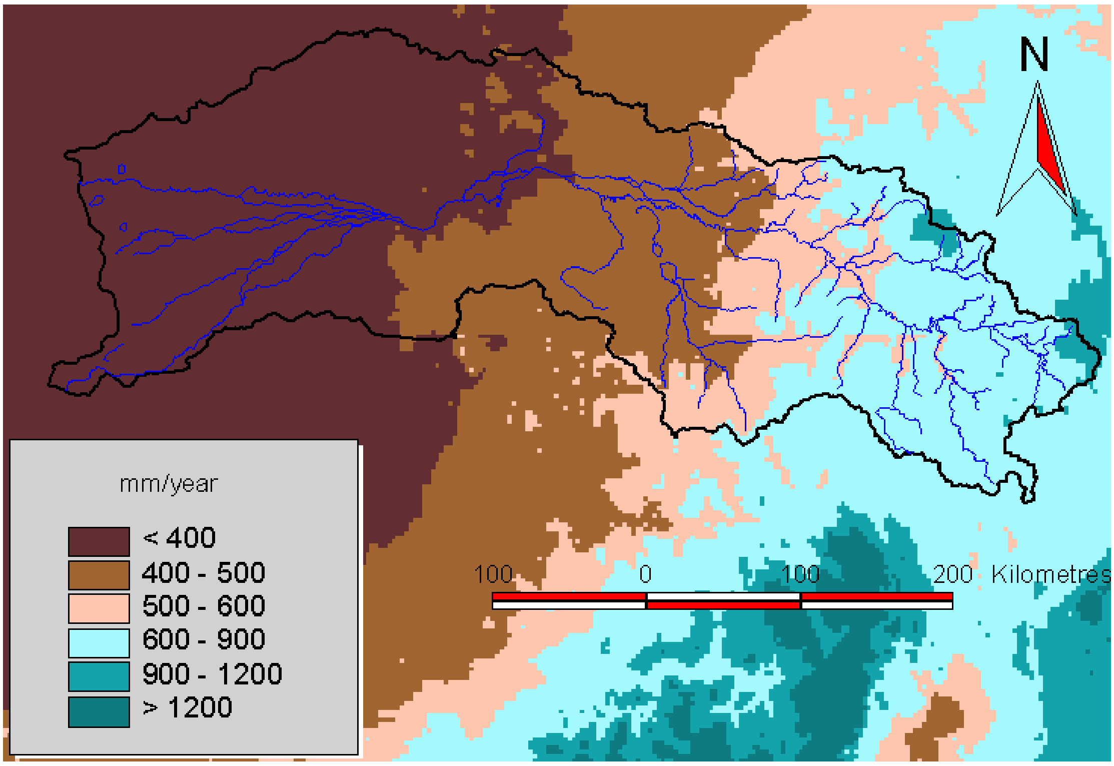


Figure 2.4. Average annual rainfall in Lachlan catchment

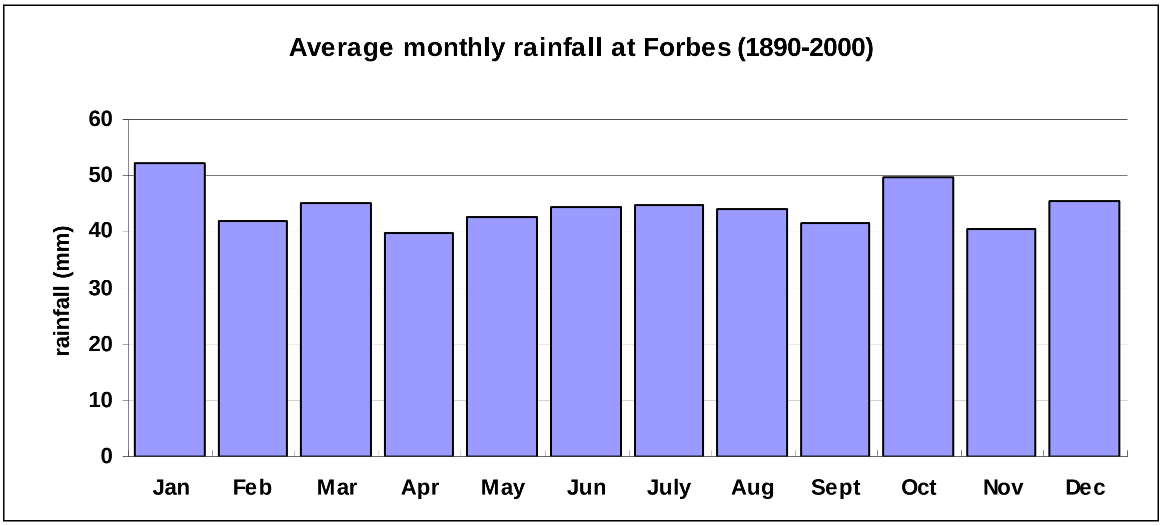


Figure 2.5. Average monthly rainfall at Forbes 1890-2000.

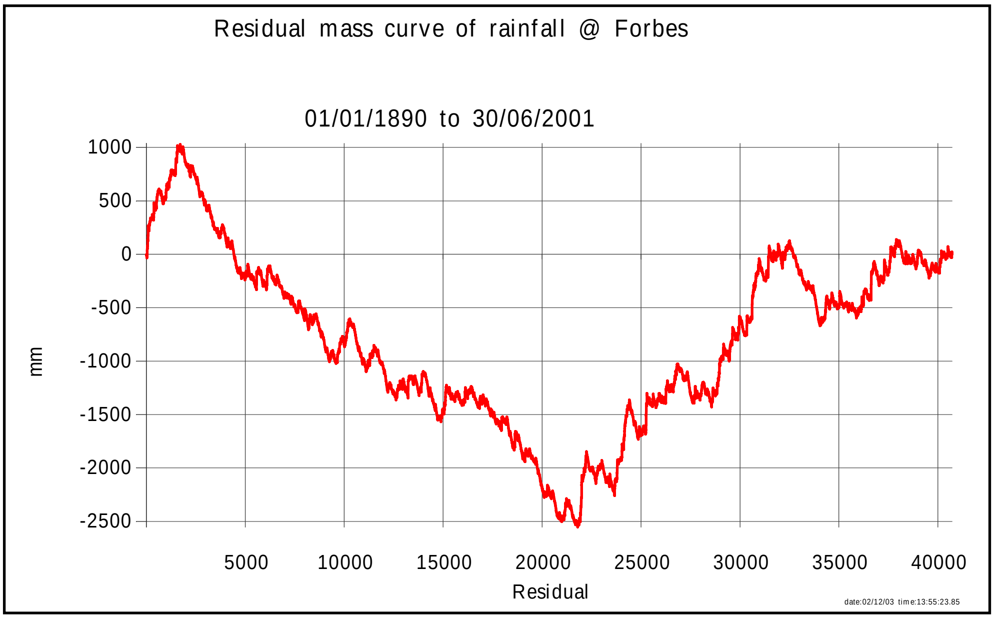


Figure 2.6. Residual mass curve of rainfall at Forbes

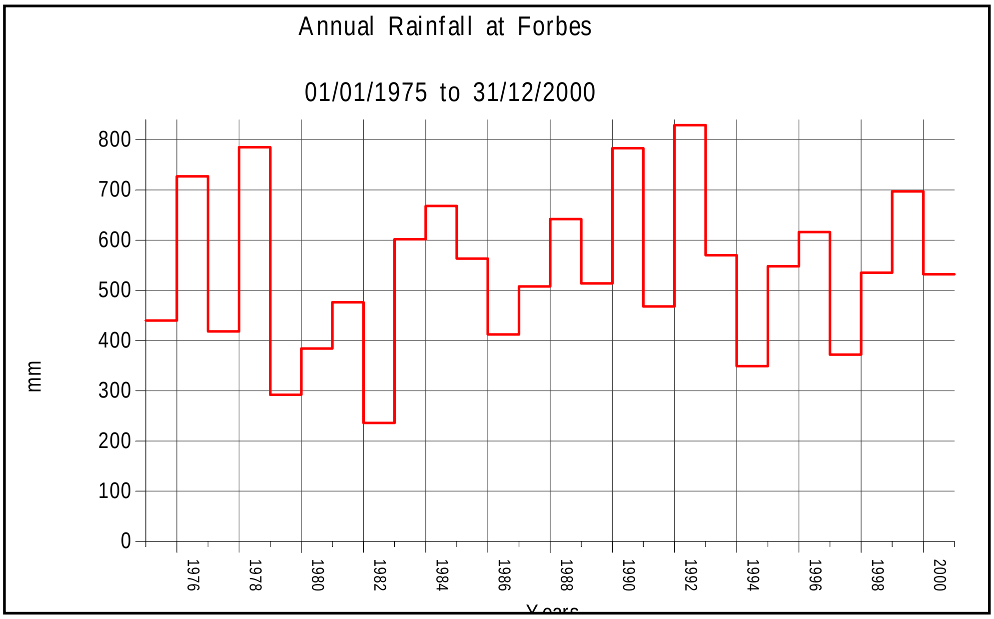


Figure 2.7. Annual rainfall at Forbes 1975-2000

2.1.3.2. Evaporation

Evaporation in the Lachlan catchment has a strong southeast to north-west gradient (Figure 2.8). Average Class A pan evaporation varies from around 1000 mm/year in the south-east, to over 2000 mm/year in the north west. Pan evaporation is also strongly seasonal, varying from less than 1 mm/d during June at Forbes, to 7.6 mm/d during December

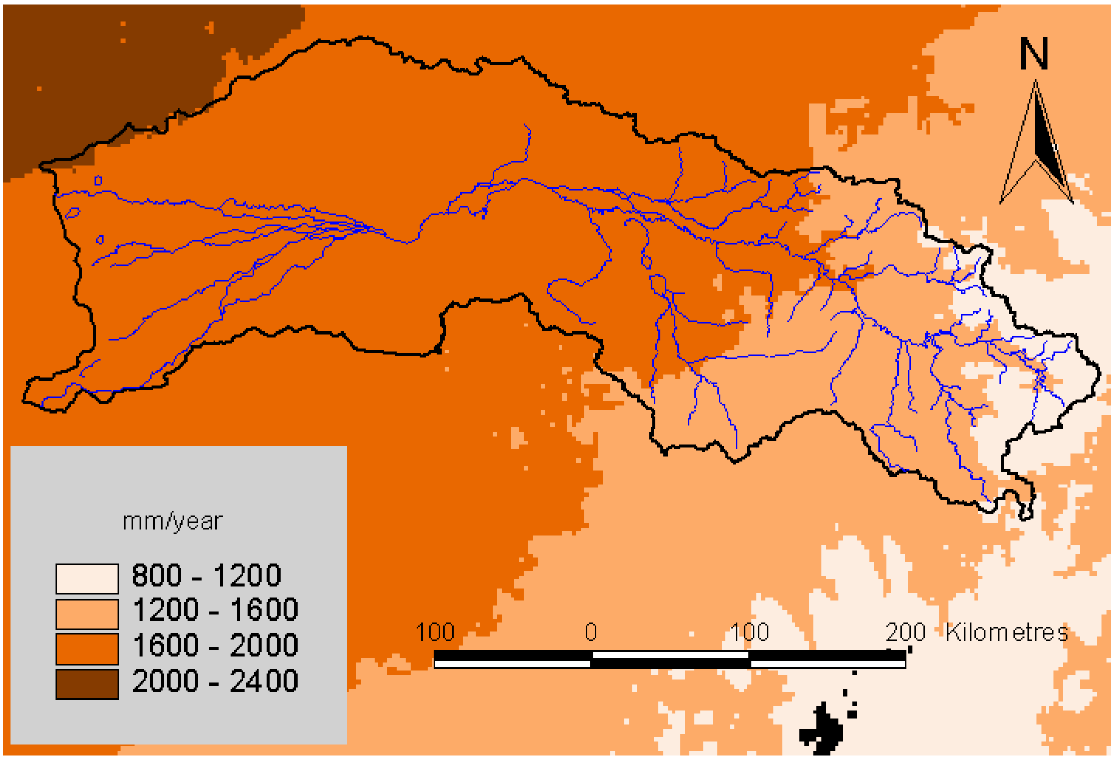


Figure 2.8. Average annual Class A Pan evaporation in Lachlan Valley (1973-1996)

2.1.3.3. flow

The principal flow contributing tributaries of the Lachlan River enter the river upstream of Forbes. Streams below Jemalong make little or no contribution to Lachlan River flow except in extremely wet years. The gauging stations on the tributaries are generally located some distance upstream from the confluence with the main river, resulting in large areas of ungauged catchment. There are also some ungauged contributions from smaller streams and local area runoff. Table 2.1 outlines the main tributary contribution to the Lachlan System.

Table 2.1.Average annual Lachlan inflows (Baseline period 1975 to 2000)

Region	Average annual inflow (GL/year)
Upstream of Wyangala	795
Belubula River	230
Lachlan River between Wyangala Dam and Condobolin	530
Lachlan River downstream of Condobolin	28

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 Lachlan River. 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.

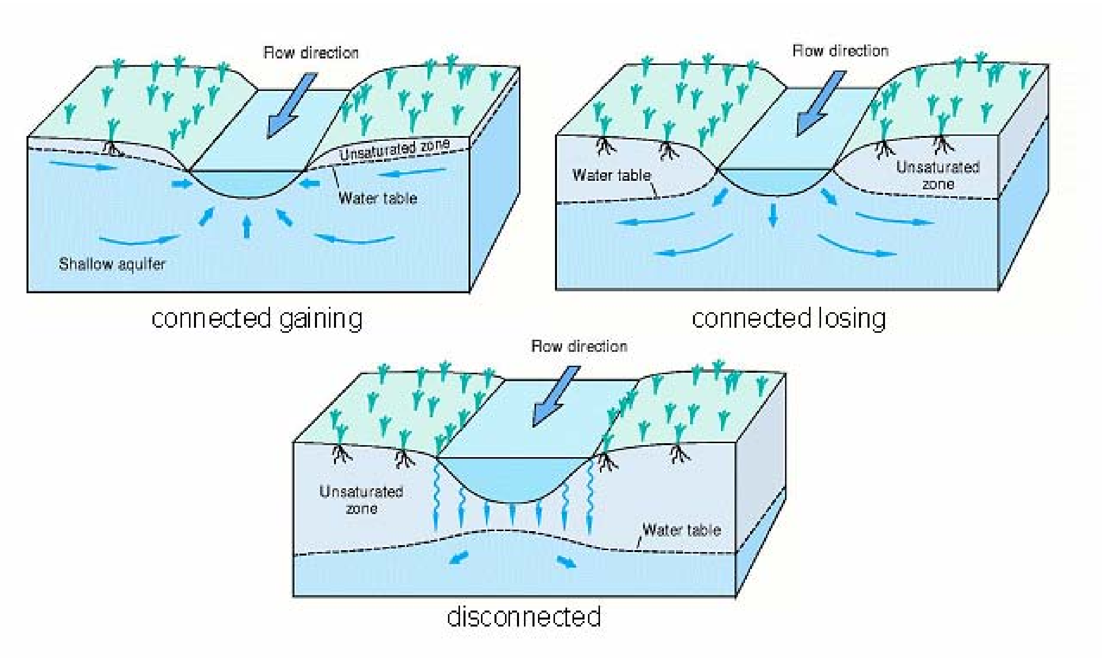


Figure 2.9. Types of river reach with respect to groundwater interaction (*after Gates and Braaten, 2002*)

Generally, whether a river section is hydraulically connected has a geographic distribution (Figure 2.10). Most upland streams are hydraulically connected, receiving flow from fractured rock aquifers. In the foothills of the ranges, narrow floodplains overlying bedrock and relatively high rainfall produce shallow alluvial water tables and strong hydraulic connections between river and aquifer. The direction of flux can vary over time. Water lost from the river during a flood, and during periods of 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 Lower Lachlan reaches, downstream of Lake Brewster. However, the lower reaches of this section, and upper reaches of the rivers in the other catchments are hydraulically connected, with the direction of flux varying over time.

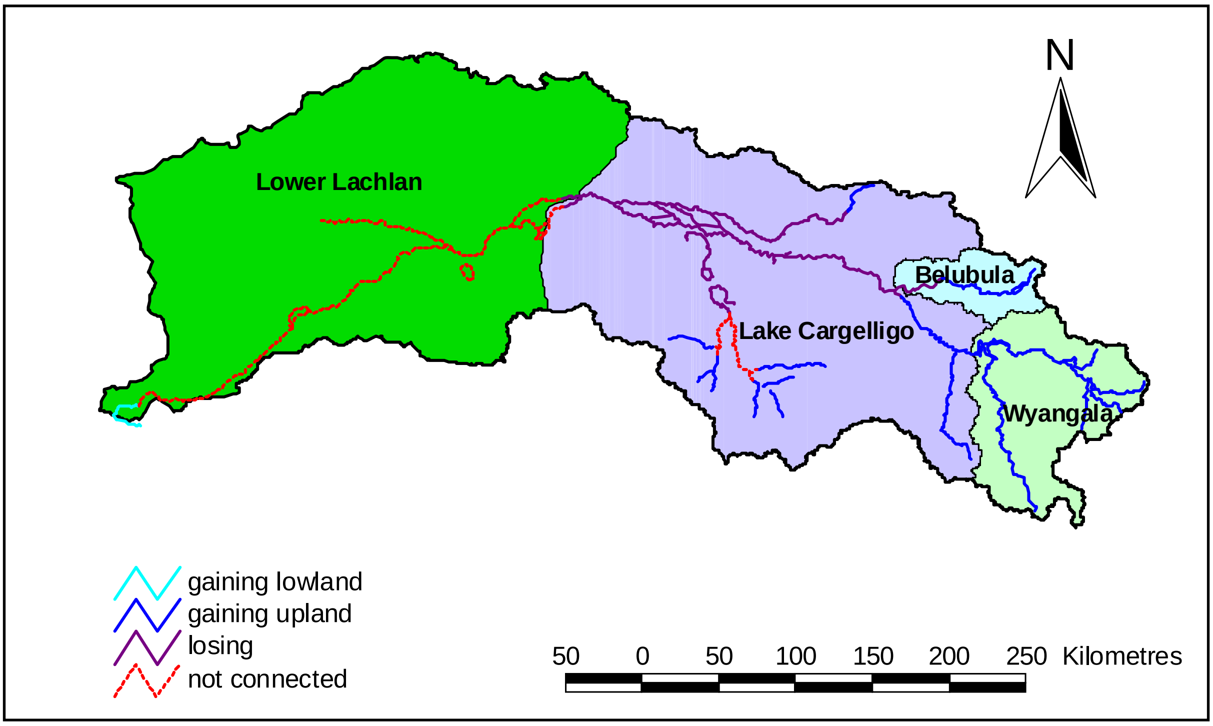


Figure 2.10. Hydraulic connection

2.1.5. Land Use

Land use in the Lachlan catchment is dominated by extensive agriculture (Table 2.2) with nearly three-quarters of the catchment used for livestock grazing, and 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 eight percent. Since the early 1960s, irrigation activities have increased rapidly and according to recent data, some 78,400 ha (Table 2.2) is currently used for planting crops such as cereals, lucerne (alfalfa), and cotton. Most of the summer crops need irrigation, whereas the winter crops get most of their required water from rain.

The grazing land is distributed throughout the catchment, and features heavily in Lower Lachlan and Wyangala regions (Figure 2.11). Dryland agriculture is mostly downstream of Wyangala Dam, with a heavy distribution through the mid-catchment. Forest areas are concentrated in the Abercrombie River Region, and a large area between Wyangala Dam and Cargelligo Weir.

Table 2.2. Vegetation and Land Use in Lachlan System (from Australian National Resource Atlas).

Land Use Description	Total Extent (`000 ha)	Extent (%)
Nature conservation / minimal Use	558	6
Livestock grazing	6239	69
Forestry	139	2
Dryland agriculture	1987	22
Irrigated agriculture	78	1
Built environment	11	< 1
Water bodies not otherwise classified	71	< 1

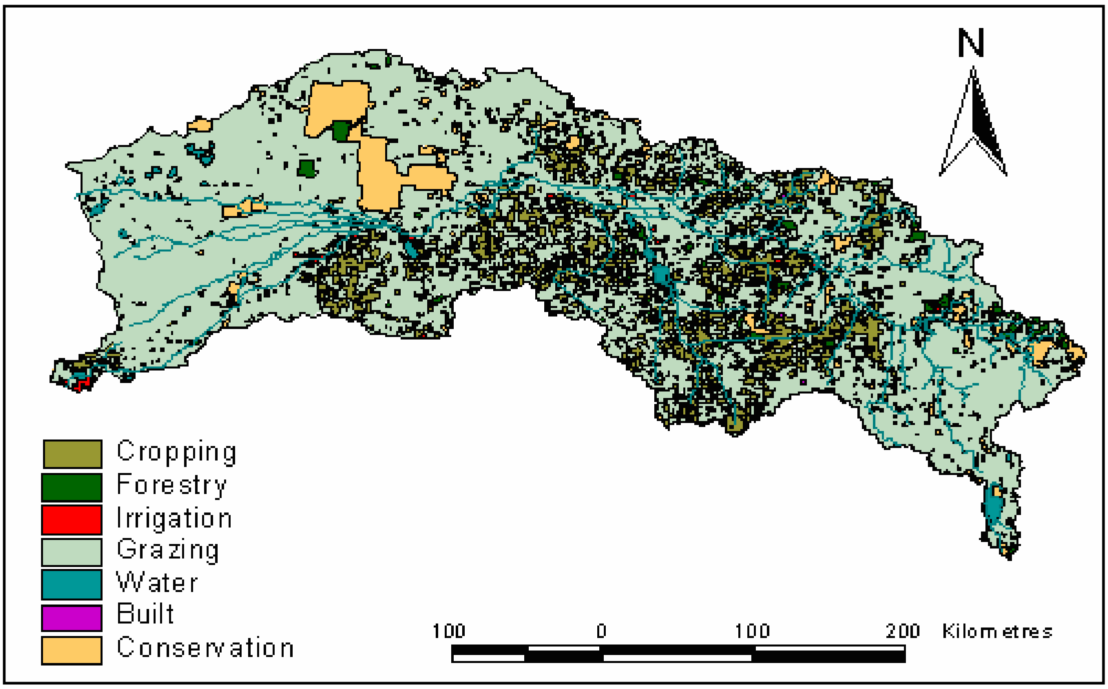


Figure 2.11. Land use in Lachlan Basin

2.2. WATER RESOURCE MANAGEMENT

Much of the water resources in the Lachlan catchment are regulated, with runoff from the Up-stream Wyangala and Belabula catchments stored in Wyangala Dam and Carcoar Dam respectively, and released from these storages for extractive and in-stream uses. Carcoar Dam supplies water for irrigators along the Belabula River, and Wyangala Dam supplies water to irrigators and towns as far as Lake Cargelligo. Lake Brewster and Lake Cargelligo are operated to supply all requirements from there downstream to the junction with the Murrumbidgee River. When the water levels in Lake Brewster and Lake Cargelligo are low, the demands downstream are met by releases from Wyangala Dam.

2.3. SALINITY IN CATCHMENT

Known occurrences of dryland salinity in the Lachlan catchment as identified by aerial photo interpretation are shown in Figure 2.12. These are heavily concentrated in the lower part of the Wyangala Region, in the south-west of Lake Cargelligo catchment, and throughout the Belubula River.

EC data showed several areas where salinity problems are severe. These include Boorowa River, Crookwell River, and other parts of the upper Lachlan catchment. Most salts from this area are believed to be cyclic salts stored in the landscape and remobilised by rising water tables or flushed into the groundwater and then discharged into streams as baseflow.

High vulnerability ranked groundwater resources are found predominantly in the upland to middle catchment along the Lachlan River about 50 kilometres downstream of Forbes as well as along major tributaries such as the Belubula River and Mandagery Creek. This classification has the characteristic of predominantly alluvial aquifers coupled with shallow water tables, high-moderate recharge potential and permeable soils. Small areas of high groundwater vulnerability in the western areas are associated with prior streams and permeable soils near Booligal and North of Lake Brewster.

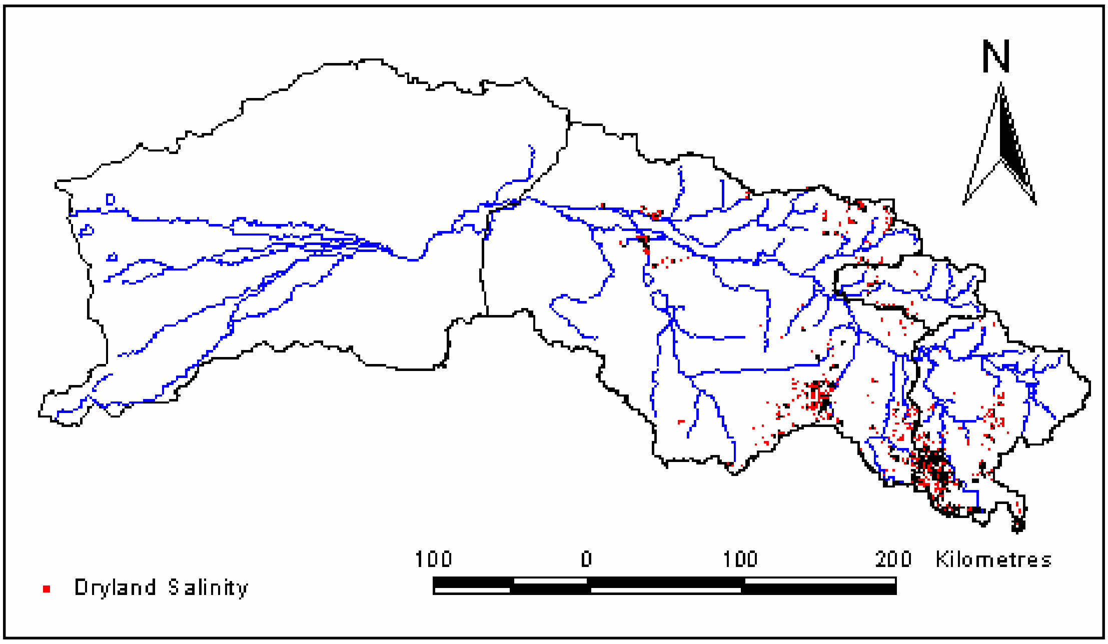


Figure 2.12. Dryland salinity occurrences in Lachlan catchment (mapped pre-1999)

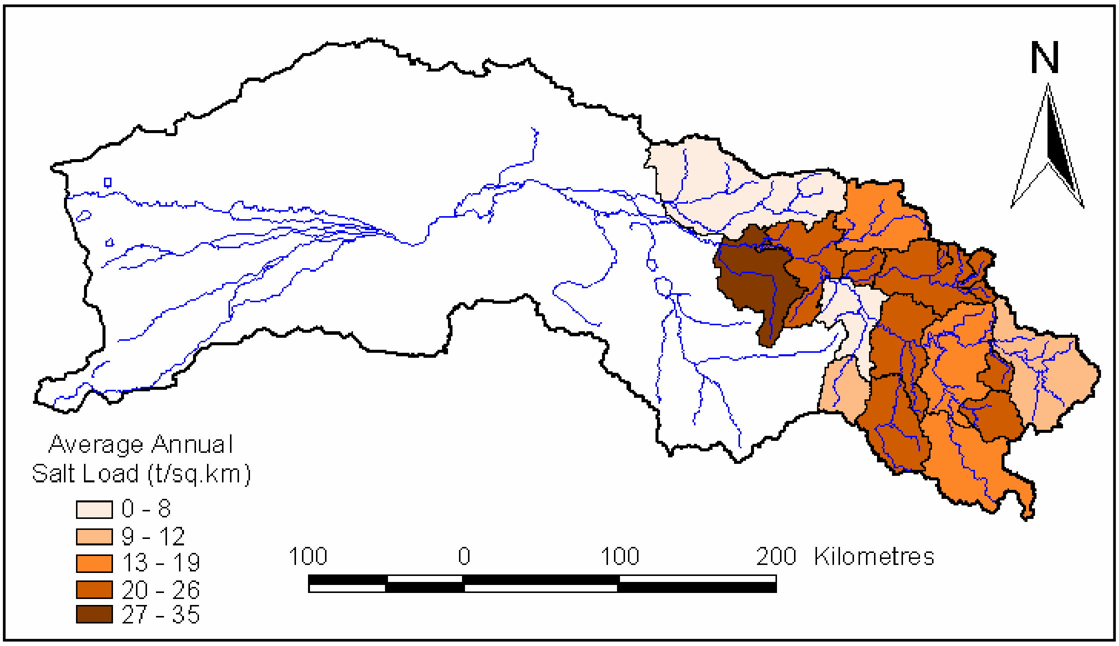


Figure 2.13. Modelled average annual salt export rates (tonnes/km2) from Lachlan catchments.

3. Salinity data

3.1. AVAILABLE DATA

All data for the Lachlan catchment (in the DWE databases) was extracted and tabulated in Appendix A. The distribution and relative length of the tabulated stations is shown in Figure 3.1 for discrete EC data stations, and Figure 3.2 for continuous EC data stations.

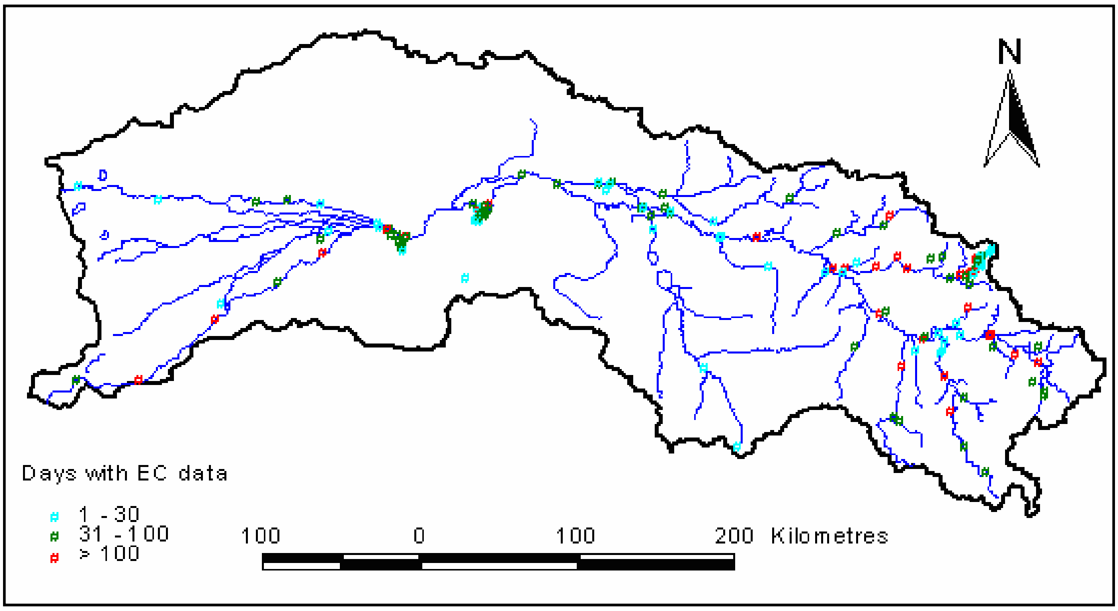


Figure 3.1. Location and record length for continuous EC data stations

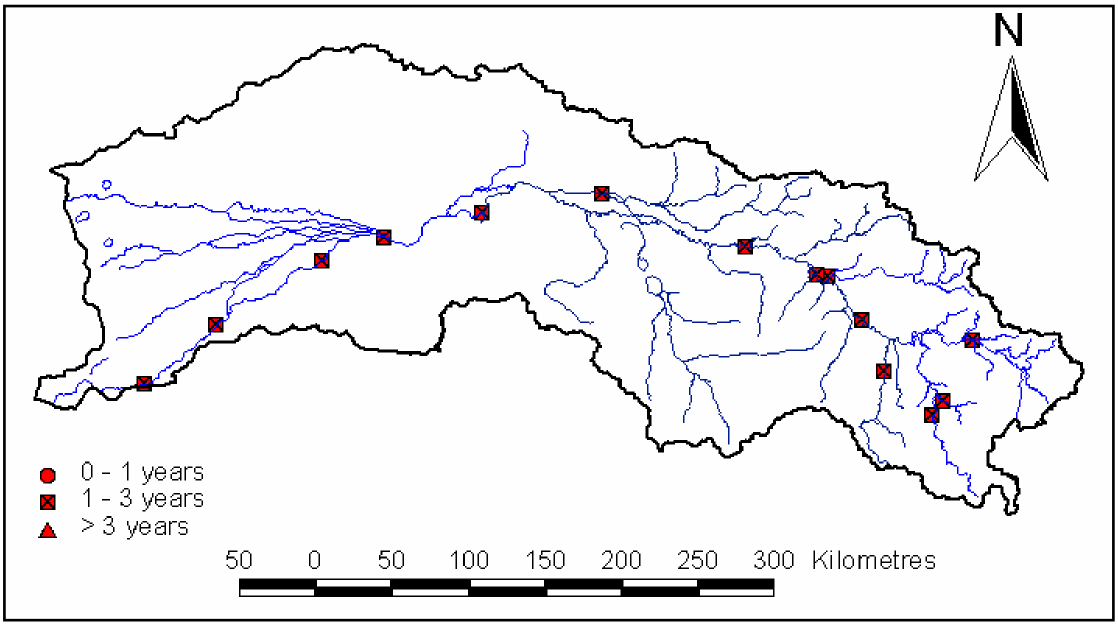


Figure 3.2. Location and record length for continuous EC data stations

The legend used in Figure 3.1 and Figure 3.2 is indicative of the usefulness of the data for modelling purposes. 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 nineteen totals reported in Appendix A, thirteen have more than a hundred data points. Ten of these stations are on the Lachlan River, with six of them at or downstream of Condobolin.

The Lachlan River System has a better coverage of continuous stations compared with most other NSW MDB valleys, and reflects on the level of salinity management activity in the catchment. The fourteen continuous stations all have between 1.5 and 2.5 years of data. However, several of the stations have data that has not been quality coded.

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. All of the 36 stations with discrete EC data and 14 stations with continuous EC data were 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 nine stations with discrete EC data in this list (Table 3.1), and five 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 14 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 Mandagery Creek (412030), Lachlan River at Narrawa (412065) and Boorowa River (412029) contribute moderate quantities of high salinity water. Belubula River produces significant amounts of moderate salinity water, and that Abercrombie River (412028) contributes large amounts of low salinity water.

The longitudinal overview of median salinities (Figure 3.3) shows that the Lachlan River tributaries downstream of Wyangala Dam have higher median salinities than the catchments upstream Wyangala Dam. The storage effects of Wyangala reduce these inflow median salinities as water mixes with low salinity inflows. The catchment with the highest salinity is the Back Creek, but with zero inflows to Lachlan River in half of the time prevent huge salt inflows.

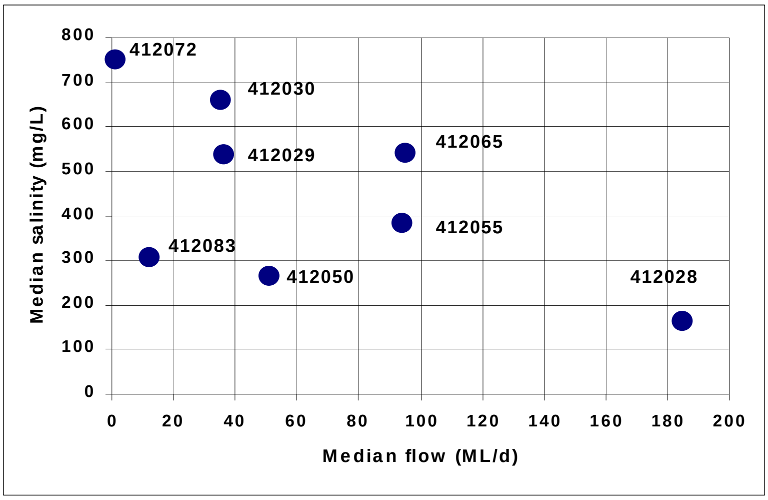


Figure 3.3 Median salinity versus median flow for inflow sites with discrete EC data

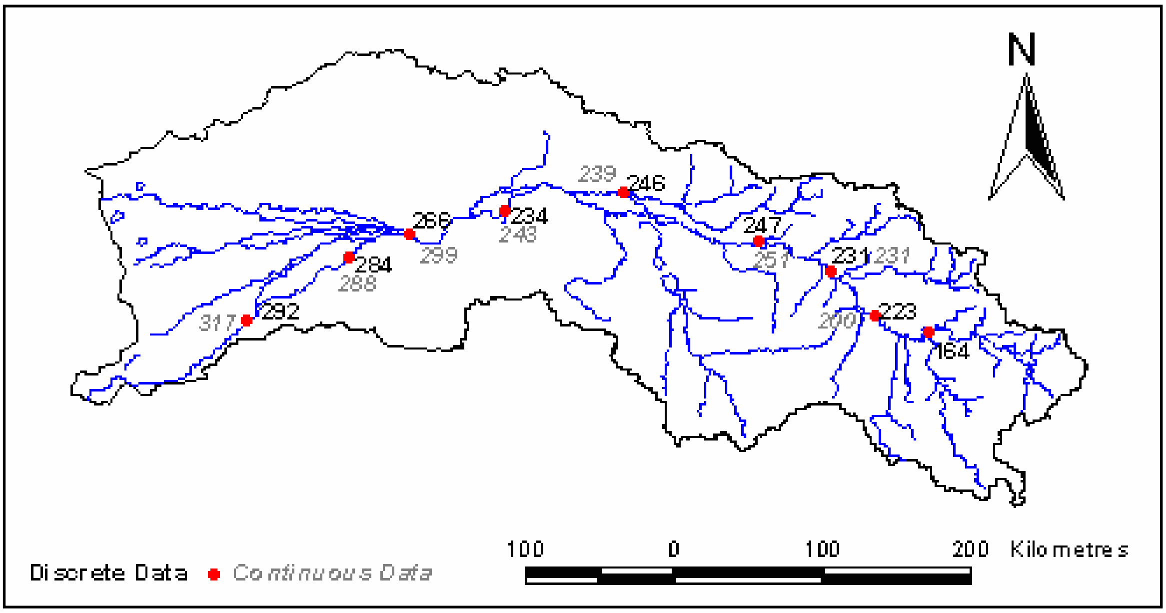


Figure 3.4. Median salinity along main stream

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

Station Number	Station name	Data points removed			Final data days
		<15μS/cm	*zero or missing flow*	*outliers*	
412065	Lachlan R @ Narrawa	0	12	2	151
412028	Abercrombie R @ Abercrombie	0	1	2	107
412083	Tuena Ck @ Tuena	0	29	1	57
412050	Crookwell R @ Narrawa N	0	1	1	91
412029	Boorowa R @ Prossers Crossing	0	77	0	206
412072	Back Ck @ Koorawatha	0	18	3	56
412055	Belubula R @ Bangaroo Bridge	0	21	1	82
412030	Mandagery Ck u/s Eugowra	0	1	0	52
412043	Goobang Ck @ Darby's Dam	0	9	0	47

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

Station Number	Station name	Data points removed			Final data days
		<15μS/cm	*zero or missing flow*	*outliers*	
412067	Lachlan R @ Wyangala	3	11	1	229
412002	Lachlan R @ Cowra	1	21	3	258
412057	Lachlan R @ Nanami	0	6	2	170
412004	Lachlan R @ Forbes	0	9	1	280
412006	Lachlan R @ Condobolin	0	80	2	204
412011	Lachlan R @ Lake Cargelligo	0	103	0	171
412038	Lachlan R @ Willandra Weir	0	51	0	126
412039	Lachlan R @ Hillston Weir	0	8	3	251
412005	Lachlan R @ Booligal Weir	0	12	16	229
412045	Lachlan R @ Corrong	0	21	3	198

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

Station number	Station name	Data use	Data days		Final data days
			Missing flow	*Data errors*	
412065	Lachlan R @ Narrawa	Inflow	67	0	717
412028	Abercrombie R @ Abercrombie	Inflow	0	0	756
412050	Crookwell R @ Narrawa N	Inflow	0	0	585
412029	Boorowa R @ Prossers Crossing	Inflow	15	0	555
412002	Lachlan R @ Cowra	Evaluation	15	0	963
412033	Belubula R @ Helensholme	Inflow	7	0	693
412057	Lachlan R @ Nanami	Evaluation	0	0	712
412004	Lachlan R @ Forbes	Evaluation	6	0	943
412006	Lachlan R @ Condobolin	Evaluation	0	0	865
412011	Lachlan R @ Lake Cargelligo	Evaluation	7	0	749
412038	Lachlan R @ Willandra Weir	Evaluation	0	0	783
412039	Lachlan R @ Hillston Weir	Evaluation	7	0	873
412005	Lachlan R @ Booligal Weir	Evaluation	0	0	797
412045	Lachlan R @ Corrong	Evaluation	9	0	791

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
412065	Lachlan R @ Narrawa	Discrete	inflow	630	542	447	95
412065	Lachlan R @ Narrawa	Continuous	inflow	616	567	500	95
412028	Abercrombie R @ Abercrombie	Discrete	Inflow	210	165	117	185
412028	Abercrombie R @ Abercrombie	Continuous	inflow	214	168	138	185
412083	Tuena Ck @ Tuena	Discrete	Inflow	372	306	216	12
412050	Crookwell R @ Narrawa N	Discrete	inflow	318	264	210	51
412050	Crookwell R @ Narrawa N	Continuous	inflow	263	232	202	51
412067	Lachlan R @ Wyangala	Discrete	Evaluation	187	164	150	N/A
412029	Boorowa R @ Prossers X	Discrete	inflow	726	537	426	36
412029	Boorowa R @ Prossers X	Continuous	inflow	654	524	426	36
412002	Lachlan R @ Cowra	Discrete	Evaluation	303	223	182	N/A
412002	Lachlan R @ Cowra	Continuous	Evaluation	299	200	174	N/A
412072	Back Ck @ Koorawatha	Discrete	inflow	972	750	531	1
412055	Belubula R @ Bangaroo Bridge	Discrete	inflow	447	386	274	94
412033	Belubula R @ Helensholme	Continuous	inflow	477	417	309	94
412057	Lachlan R @ Nanami	Discrete	Evaluation	294	231	184	N/A
412057	Lachlan R @ Nanami	Continuous	Evaluation	307	231	189	N/A
412030	Mandagery Ck u/s Eugowra	Discrete	inflow	765	660	451	35
412004	Lachlan R @ Forbes	Discrete	Evaluation	312	247	204	N/A
412004	Lachlan R @ Forbes	Continuous	Evaluation	328	251	208	N/A
412043	Goobang Ck @ Darby's Dam	Discrete	inflow	274	216	178	4
412006	Lachlan R @ Condobolin	Discrete	Evaluation	303	246	206	N/A
412006	Lachlan R @ Condobolin	Continuous	Evaluation	289	239	206	N/A
412011	Lachlan R @ Lake Cargelligo	Discrete	Evaluation	282	234	201	N/A
412011	Lachlan R @ Lake Cargelligo	Continuous	Evaluation	284	243	214	N/A
412038	Lachlan R @ Willandra Weir	Discrete	Evaluation	312	266	218	N/A
412038	Lachlan R @ Willandra Weir	Continuous	Evaluation	326	299	277	N/A
412039	Lachlan R @ Hillston Weir	Discrete	Evaluation	337	284	234	N/A
412039	Lachlan R @ Hillston Weir	Continuous	Evaluation	320	288	261	N/A
412005	Lachlan R @ Booligal Weir	Discrete	Evaluation	343	292	245	N/A
412005	Lachlan R @ Booligal Weir	Continuous	Evaluation	342	317	285	N/A
412045	Lachlan R @ Corrong	Discrete	Evaluation	365	309	264	N/A
412045	Lachlan R @ Corrong	Continuous	Evaluation	350	312	279	N/A

4. The Lachlan IQQM

4.1. QUANTITY MODEL

The Lachlan IQQM was implemented during the 1990's to assist with water management based on the WARAS model. The model was initially used to investigate the conversion of general security licences to high security licences and adjust the allowances made in resource assessment for storage reserve and transmission and operation losses. Since then, a large number of developments occurred in both water policy and IQQM. The advent of the MDBC Cap and the NSW River Flow Objectives led to a much greater level of model complexity.

The Lachlan IQQM is currently split to two separate models. The first is a simple model of the Lachlan River system upstream of Wyangala Dam. This system comprises five inflows from catchments upstream of Wyangala Dam, as well as one loss/calibration node.

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 Lachlan IQQM is shown at Figure 4.1.

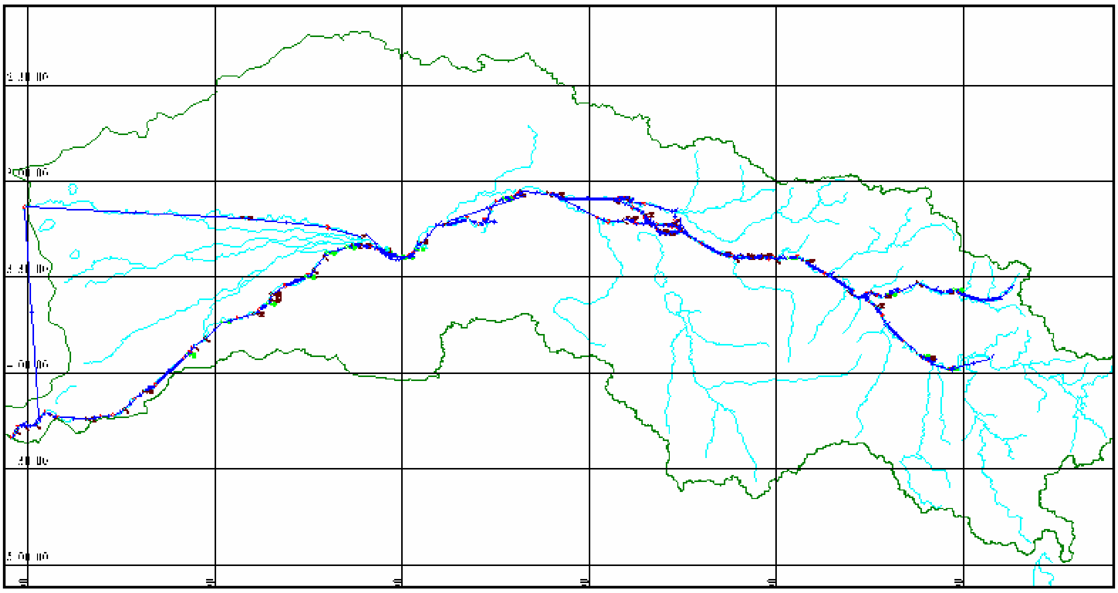


Figure 4.1. Overview of Lachlan IQQM

4.1.1. Wyangala inflows submodel

The Wyangala Inflows submodel has five inflow nodes and one loss/calibration node. There are no diversions in this part of the system. The average annual inflows are reported in Table 4.1. The loss/calibration node removes 84 GL/year on average over the same time period, for a net inflow to Wyangala Dam of 795 GL/year. Although the loss/calibration node removes less than 10% of the flow, it has a significant effect on the distribution of flows entering the storage by removing all of the flow below 150 ML/day, most of the flow up to 260 ML/day, and a significant part of the very high flows.

Table 4.1. Average annual inflows (1/1/1975-30/4/2000) in upstream Wyangala Dam submodel

Inflow location	Average annual inflow (GL/year)
412028: Abercrombie River @ Abercrombie	292
412083: Tuena Creek @ Tuena	36
412065: Lachlan River @ Narrawa	169
412050: Crookwell River @ Narrawa North	90
Residual catchment u/s Wyangala Dam	292
TOTAL	879

Table 4.2. Calibrated relationship for calibration/loss node upstream of Wyangala Dam

Flow in river (ML/day)	Flow removed (ML/day)
0	0
150	150
260	160
1,260	162
4,300	300
7,300	300
15,600	750
50,750	750
120,750	20,000
225,000	20,000
300,000	75,000
10^{37}	10^{36}

4.1.2. Lachlan System model

The Lachlan IQQM consists of 150 nodes with 20 links with hydrologic routing. Detailed outlines of the location and relative magnitude of the specific node groups are:

- inflows and outflow (Figure 4.2 to Figure 4.4);
- storages (Figure 4.5);
- irrigation demands (Figure 4.6 to Figure 4.8);
- instream and environmental demands.

The features of the Lachlan System IQQM are discussed in Sections 4.1.2.1 to 4.1.3.

4.1.2.1. Inflows and calibration

The Lachlan IQQM has fifteen inflow nodes that represent inflow estimates for Wyangala and Carcoar Dams; six gauged tributary locations and seven residual catchments. The model has twenty-six calibration nodes that only required thirteen loss nodes to achieve a satisfactory calibration. The magnitude and distribution of these inflow and effluent nodes is shown in Figure 4.2 to Figure 4.4. These inflow nodes match catchment boundaries as described in Section 4.3. The magnitude of these inflows is also further described there.

The majority of inflows occur upstream of Wyangala Dam (51%), with the significant addition of the Belubula tributary (15%) in conjunction all other tributaries (34%) along the Lachlan. The total losses (200 ML/year) represent 13% of the total inflows into the system.

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 Lachlan Valley Cap calibration report (Hameed et al 2003). For climatic and streamflow variables the following approach was used:

- Rainfall – observed data was gap filled and/or extended by statistical correlation with surrounding long term rainfall sites.

- Evaporation – observed data was gap filled and/or extended by generated data that was derived by statistically relating total evaporation and number of rain days for each month.

- Streamflow – observed data was gap filled and/or extended by generated data from a calibrated Sacramento rainfall runoff model. Ungauged catchment inflows are generally estimated by correlation with surrounding gauging stations and mass balance on the main river.

- Dam inflow – may be either observed data generated by mass balance approach at the dam or upstream flows routed to the dam. As outlined above streamflow data has been gap filled and/or extended by Sacramento rainfall runoff model.

4.1.2.2. Storages

Five storages are modelled in the IQQM as shown with sizes in Figure 4.5. Wyangala Dam operates to meet demands as far as Cargelligo Weir, and Lake Cargelligo and Brewster satisfy requirement from there to the Murrumbidgee junction near Oxley. However, when Lake Brewster is between 30-40% full, Wyangala Dam supplies requirements for the entire Lachlan and maintains 23 GL in Lake Cargelligo. Carcoar Dam is only operated to meet the water supply requirements of users in the Belubula River System. None of the Lachlan storages have specific flood mitigation storage. However, some flood mitigation can be expected when storages have available airspace.

4.1.2.3. Extractive demands

Allocation of water to irrigators in the Lachlan River System occurs under a volumetric allocation system. The total active licence entitlement in this river system is 667 GL, of which about 4% (24GL) are for high security users, including town water supplies and permanent crop types. The majority of the licences are for irrigating crops, with the dominant crop types lucerne, winter and summer pastures and grains, wheat and cotton.

The irrigation licences are represented by twenty-four general and seven high security irrigators based on river reaches. The distribution of water usage for irrigation is shown in Figure 4.6 to Figure 4.8 and shows that the water usage occurs along most of the Lachlan River. However, the major extraction for both high and general security irrigators occurs downstream of Lake Brewster.

4.1.2.4. Surplus water usage

Off allocation periods may be announced in the Lachlan River Valley downstream of Wyangala Dam when flows are more than demands (surplus flows). Surplus flows may comprise operational excess flows, tributary inflows and flood releases from Wyangala Dam. Surplus flows can be extracted for irrigation as off-allocation supply and diverted into various effluent creeks to satisfy domestic requirements and mitigate downstream flooding. Off-allocation diversions cannot exceed 30,000 ML in a water year

4.1.2.5. Other

Town water supplies (TWS) are high security entitlements and are represented as a fixed annual demand with a monthly pattern of use. The towns of Cowra, Forbes, Condobolin, Willandra, Hillston and Booligal were modelled as six separate nodes, with a combined entitlement of 10 GL per year.

Separate stock and domestic licences were modelled, with six nodes as high security users, with a demand of 10 GL/year. High security industrial and mining licences were not modelled in the Lachlan IQQM. These licences only represent 2.3 GL per year.

4.1.3. In-stream demands

In-stream demands are simulated at thirteen locations in the Lachlan System IQQM using Type 9.0, and Type 10.x nodes. The purpose of these nodes is described in Table 4.3.

4.1.4. Peer Review

There have been 2 peer reviews of the quantity component of Lachlan Rivers IQQM, one undertaken by University of Melbourne and the second by Bewsher Consulting for model accreditation under Schedule F of the MDB Agreement. Findings from this review accredited the model. Consultation with Lachlan 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.

Table 4.3. Instream Demands

Instream Ordering Name	Purpose
Downstream of Wyangala Dam	Orders water from Wyangala Dam to maintain a minimum 70ML/day at location for operational purposes.
Belubula @ Bangaroo Bridge	Orders water from Carcoar Dam to maintain a minimum 10 ML/day at location for operational purposes.
Booberoi Weir	Orders water from Wyangala Dam to maintain a minimum 50 ML/day at location for stock and domestic supply down Booberoi Ck effluent.
Lake Cargelligo	Order water from Wyangala Dam to maintain a minimum 15 ML/day at location for operational purposes
Lake Brewster	Order water from Wyangala Dam to maintain a minimum 20 ML/day at location for operational purposes
Corrong Gauge (412045)	Orders water from Wyangala Dam to maintain a minimum 200 ML/day between October and March, and 400 ML/day during April, at location, for stock and domestic supply and ecological needs of Cumbung Swamp.
Booligal	Orders water from Wyangala Dam to maintain a minimum 100ML/day at location for operational purposes.
Willandra Creek	Orders water from Wyangala Dam to maintain a minimum 150ML/day for February to March at location to ensure sufficient time for bird breeding.
Merrowie Creek	Orders water from Wyangala Dam to maintain a minimum 150ML/day for May to June at location to ensure sufficient time for breeding.
Merrimijeel Creek	Orders water from Wyangala Dam to maintain a minimum 150ML/day for 15 March to 15 May to ensure sufficient time for bird breeding.
Lake Brewster translucent flows	This is an environmental requirement for flushing river and wetlands. Targets a flow between June and October at site of a minimum 3,500 ML/d, and a maximum based on how much water is stored in Wyangala Dam. If Wyangala Dam is: (i) empty, the maximum is 4,000 ML/d (ii) eighty percent full, the maximum is 6,000 ML/d (iii) full, the maximum is 8,000 ML/d This maximum flow target is linearly interpolated if the water stored in Wyangala Dam is between these values. This target flow window is passed up to Wyangala Dam, and adjusted on the way to allow for losses and tributary inflows. Releases more than other requirements are made from Wyangala Dam based on the size of the inflow compared with the target window. If inflows to Wyangala Dam 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. The maximum flow that will be released from Wyangala in any water year is 350 GL.
Downstream of Wyangala Dam ECA	A 20 GL environmental contingency allowance (ECA) is made in Wyangala Dam to manage critical environmental events (algal blooms, salinity, bird and fish breeding). This allowance is removed when allocations are below 50% and not reinstated until 75% allocations have been reached.
Wyangala Dam ECA	A 5 GL ECA
Lake Brewster ECA	A 5 GL ECA

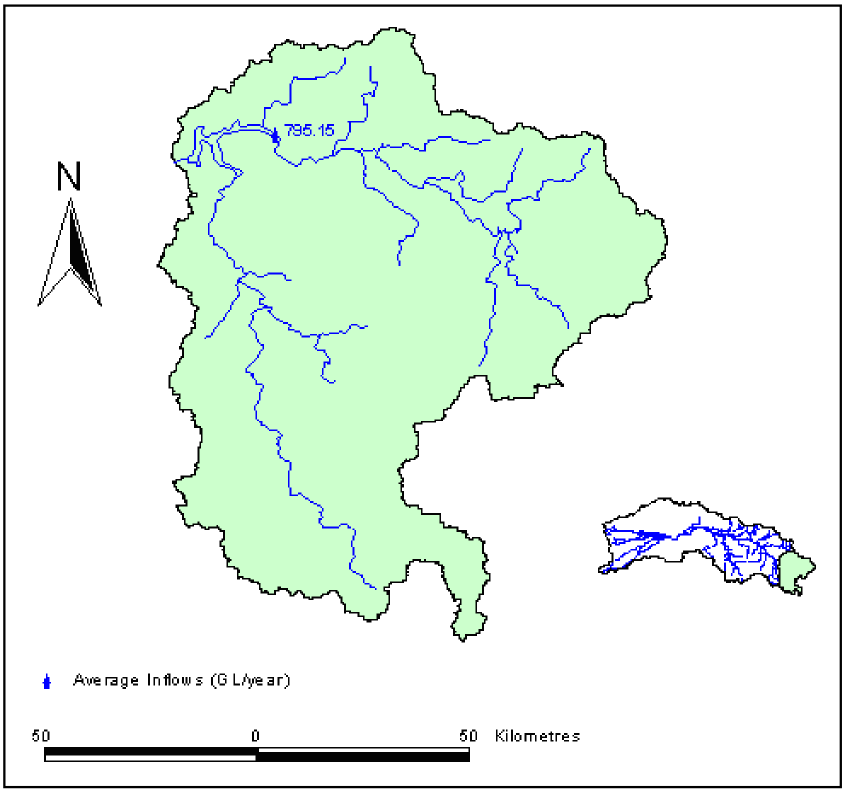


Figure 4.2. Distribution of modelled annual average (1975-2000) inflows and losses in upstream Wyangala region of Lachlan Valley

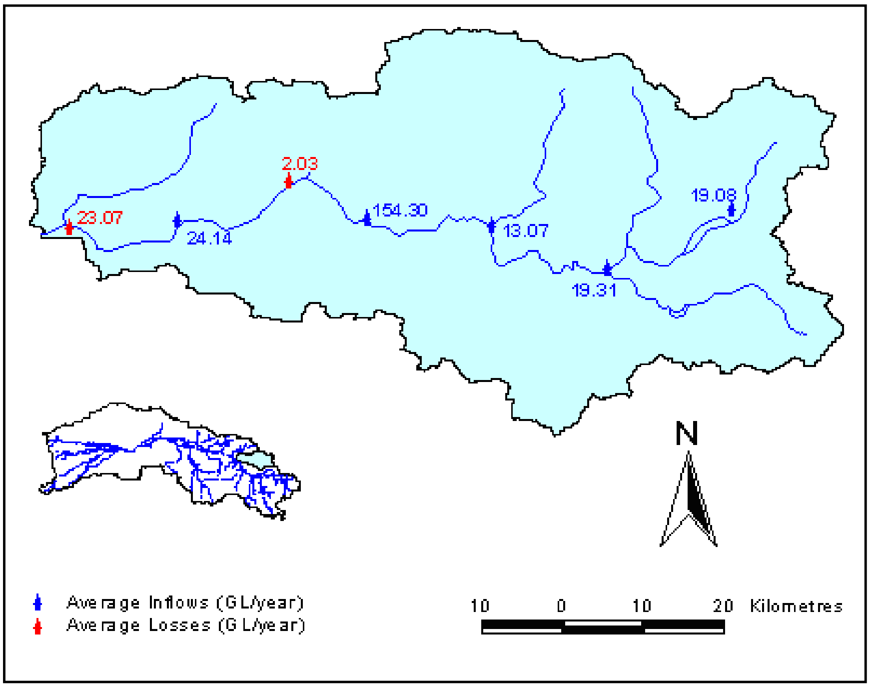


Figure 4.3. Distribution of modelled annual average (1975-2000) inflows and losses in Belabula region of Lachlan Valley

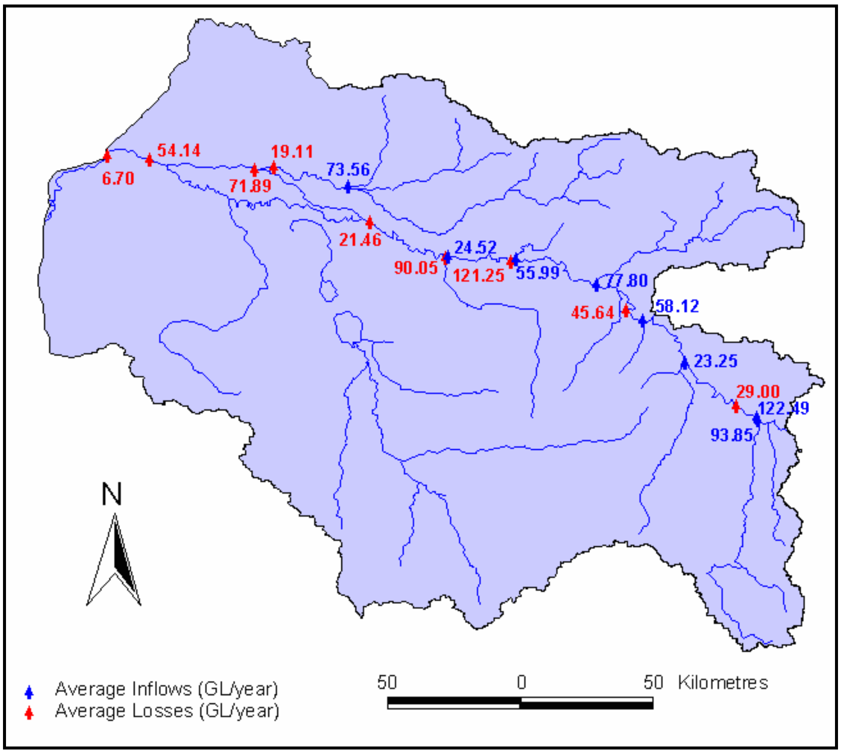


Figure 4.4. Distribution of modelled average annual (1975-2000) inflows and losses in Lake Cargelligo region of Lachlan Valley

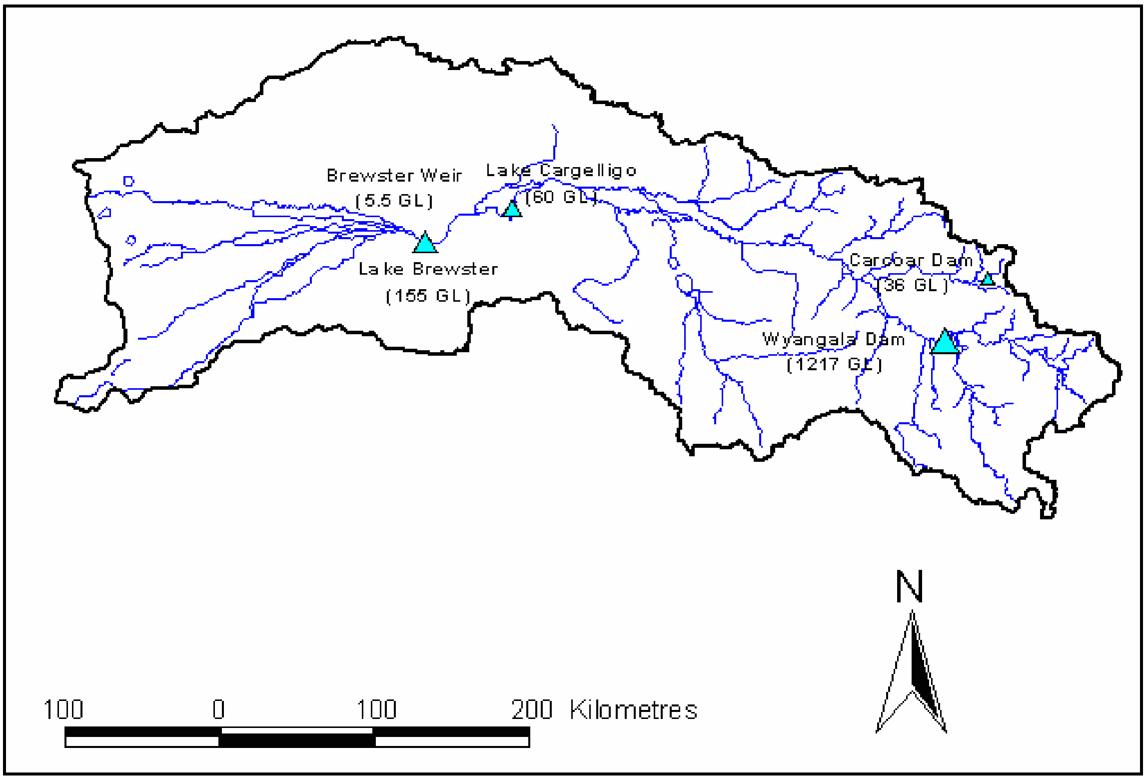


Figure 4.5. Modelled storages in Lachlan System IQQM

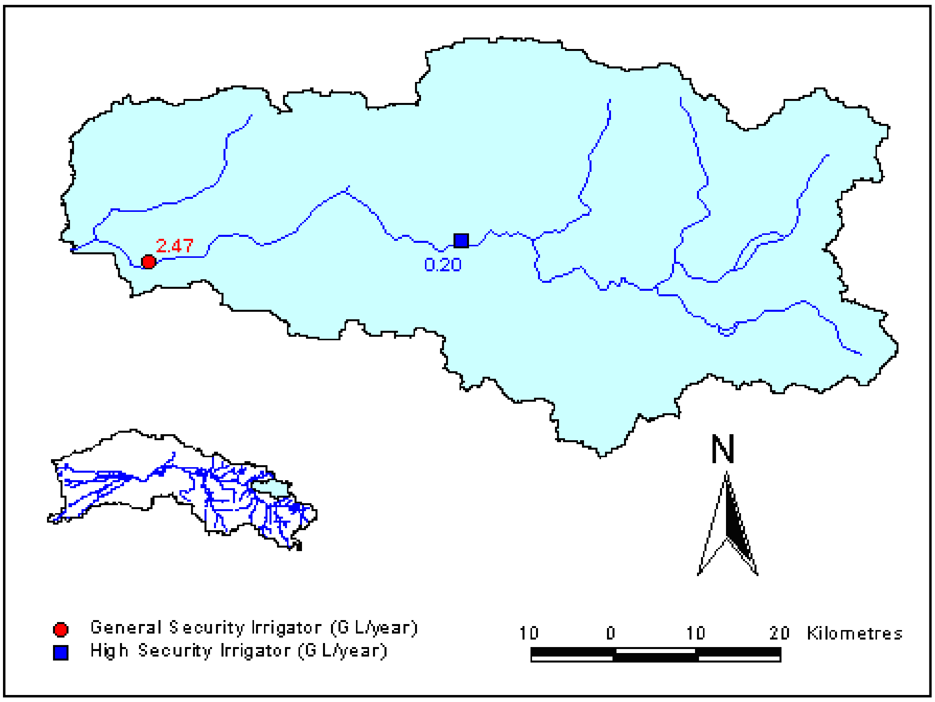


Figure 4.6. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Belabula region

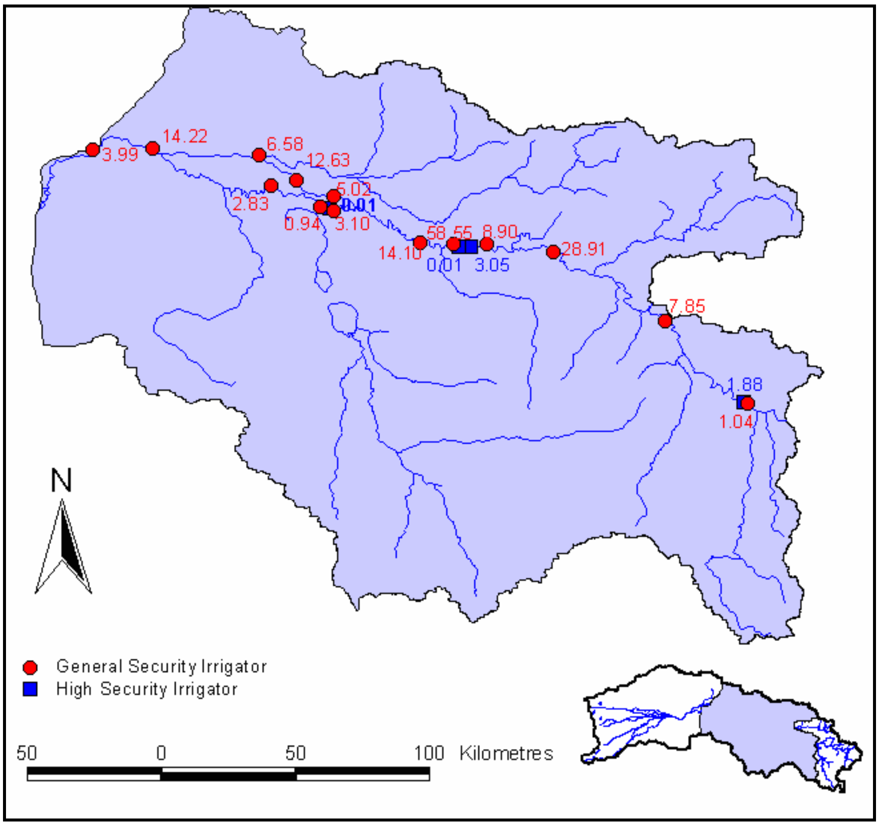


Figure 4.7. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Lake Cargelligo region

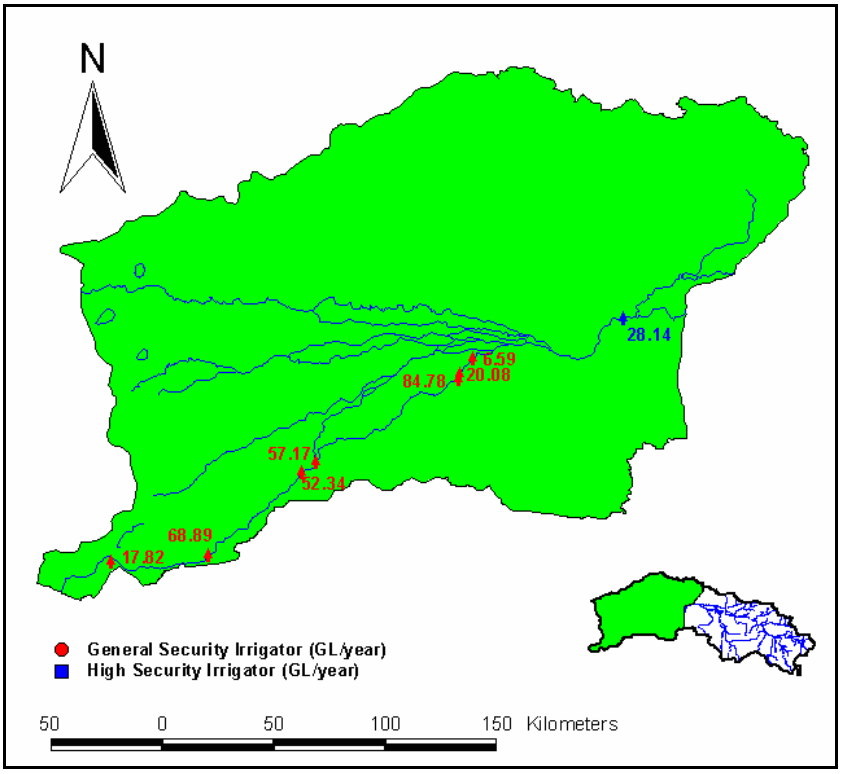


Figure 4.8. Modelled average annual irrigation diversions (GL/year, 1975-2000) for Lower Lachlan Region

4.2. QUALITY ASSURANCE OF QUALITY MODEL

4.2.1. Quality Assurance (QA) Test 1: Update base quantity model

The results of the mass balance check for of all the major water balance components of the base quantity model over the simulation period 1975-2000, are shown at Table 4.4. The total difference over the period of simulation is 14 ML, out of a total inflow of $81*10^6$ ML, or 0.000017 %. This is expected from rounding errors in the calculations. Therefore, we can conclude that there are effectively no mass balance errors in the IQQM software applying on Lachlan Valley.

Table 4.4. Flow mass balance report

Water balance component	Sum over simulation period (ML)
Inflows	81,526,614
Losses	57,713,388
Extractions	23,626,526
Storage change	-186,686
Error	14

4.2.2. QA Test 2: Initiate salinity module with zero input

The purpose of this test was to ensure that initiating salt model would not introduce any sources or sinks of salt and /or water by software bugs.

The results for the quantity mass balance comparison reported in Table 4.5 show no changes for the water balance components and result of QA test 1 is still valid. The salt mass balance report is shown at Table 4.6, demonstrating that no sources or sinks of salt are present 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.

Table 4.5. Flow mass balance comparison report with salt inflows

Water balance component	QA Test 1 Sum over simulation period (ML)	QA Test 2 Sum over simulation period (ML)
Inflows	81,526,614	81,526,614
Losses	57,713,388	57,713,388
Extractions	23,626,526	23,626,526
Storage change	-186,686	-186,686
Error	14	14

Table 4.6. Salt mass balance report for zero 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 of sinks in the model. This was done by setting the flow and concentrations to constant values 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 ± 0.03 mg/l, indicating there were still some minor instabilities that need addressing in the IQQM software.

4.2.4. QA Test 4: Variable flow and constant concentration

The purpose of QA Test 4 was to test (i) the stability of the model under variable flow conditions, and (ii) 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 concentration of 100 mg/l at all inflow nodes, and rainfall and evaporation set to zero.

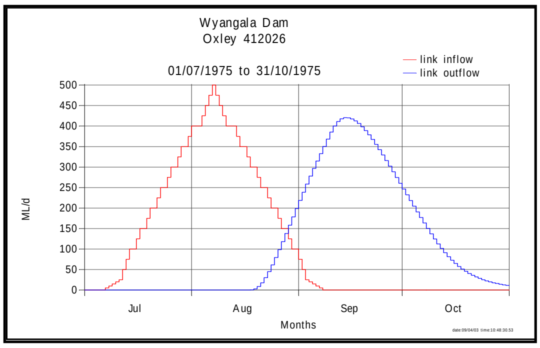
The result aimed for at the end of system was ($\mu \pm \sigma$) 100.0 ± 0.0 mg/l. The actual result was 100.0 ± 0.03 mg/l, indicating there were still some minor instabilities that need addressing in the IQQM software.

4.2.5. QA Test 5: Flow pulse with constant concentration

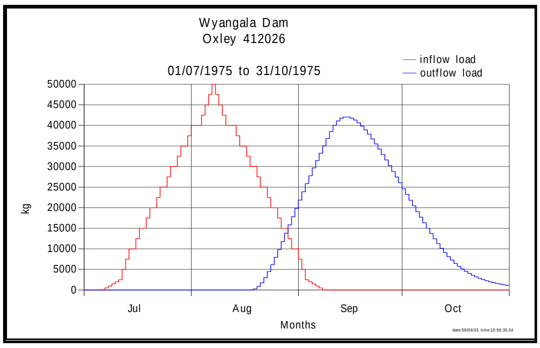
The purpose of QA Test 5 was to verify that salt load was routed through the system consistently with flow. This was done by having a synthetic flow hydrograph at the top of the system with constant concentration of 100 mg/l. All other inflow nodes had zero flow and concentration, and all diversions and effluents removed.

The results are shown at Figure 4.9. 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. The actual result was 100.0 ± 0.07 mg/l, indicating there

(a)



(b)



were still some minor instabilities that need addressing in the IQQM software.

Figure 4.9. (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 load 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 removed from the system.

The results are shown at Figure 4.10. 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.

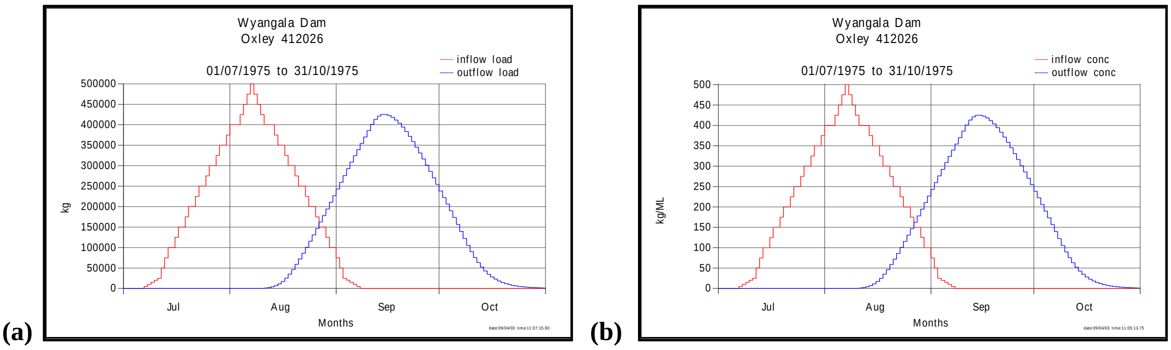


Figure 4.10. (a) Salt load inflows and EOS salt loads; (b) Concentration inflows and EOS concentration

4.3. QUALITY MODEL DEVELOPMENT

The IQQM model passed the QA tests sufficiently well to further develop the quality model for salt transport under BSMS baseline conditions. The initial stage in this development is to compare the Salinity Audit against a 'first cut' IQQM model by using the Salinity Audit salt inflows. In later stages of development the quality model is evaluated against in-stream concentration data and, if required, the salt inflow estimates are then adjusted to improve the match with the concentration data.

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 is firstly tested for consistency with the Salinity Audit results. 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) Capped concentration to highest observed.

(v) Accounting for different benchmark climatic condition Audit compared with BSMS.

The relationship between 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 catchments, the parameters of the salt load relationships from the Audit are directly transferable such as catchments 421035, and 421101. While, for others the parameters had to be modified and more than one IQQM inflow node (e.g., 421079 with two nodes, or R4 with fourteen nodes) was used to model flow from that catchment. The concentration cap adopted for point (iv) above is also shown in Table 5.1 and Table 5.2.

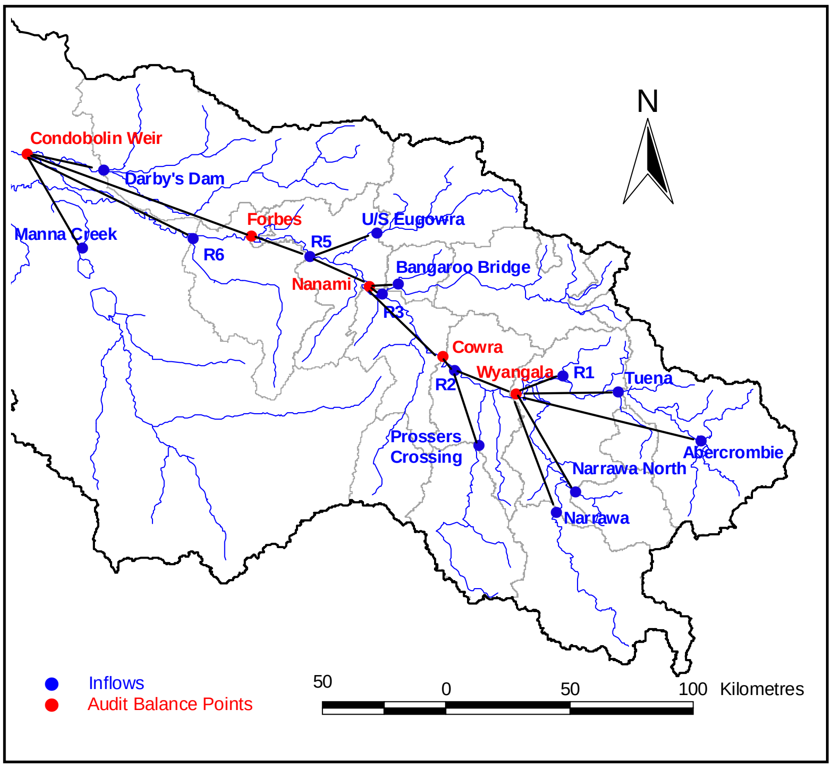


Figure 5.1. Geographic representation of 1999 Salinity Audit schematic of inflows and balance points

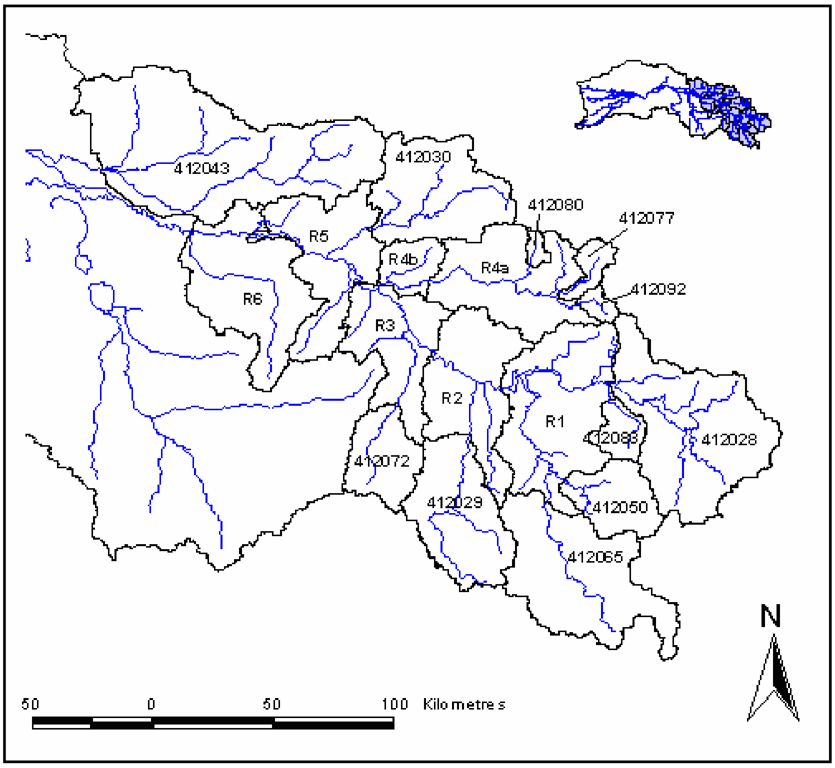


Figure 5.2. Inflow catchments used for 1999 Salinity Audit

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)
	Upstream Wyangala Dam					
412065	Lachlan R @ Narrawa	001	IIC	54.10	13.0	769
412050	Crookwell R @ Narrawa North	002	IIC	10.10	11.4	623
412083	Tuena Ck @ Tuena	015	IIC	6.85	10.5	480
412028	Abercrombie R @ Abercrombie	011	IIC	25.00	6.9	316
	Belubula system					
412077	Belubula R at Carcoar	350	IIC	4.87	14.0	450
412092	Coombing Ck near Neville	352	IIC	4.756	14.0	450
412080	Flyers Ck @ Beneree	353	IIC	3.15	14.0	450
	Downstream ***Wyangala Dam***					
412029	Boorowa R @ Prossers Crossing	004	IIC	26.40	11.7	1050
412072	Back Ck @ Koorawatha	012	IID	3.86	0.8	1224
412030	Mandagery Ck @ U/S Eugowra	034	IIC	16.30	26.6	1170
412043	Goobang Ck @ Darby's Dam	127	IIC	57.30	14.0	423

Table 5.2. Salt inflow model parameters for residual catchments

Number	Subcatchment Description	IQQM inflow node number	Audit load flow model Type	η	λ	C_{max} (mg/L)
R1	Ungauged Lachlan River u/s Wyangala Dam	004	IIC	24.00	11.0	623
R2	Ungauged Lachlan River between Wyangala Dam and Cowra	005	IIC	26.10	13.0	623
R3	Ungauged Lachlan River between Cowra and Nanami	031	IIC	20.00	9.0	623
R4a	Ungauged Belubula River between Carcoar Dam and Canowindra	358	IIC	38.62	14.0	630
R4b	Ungauged Belubula River between Canowindra and Bangaroo Bridge	361	IIC	5.90	14.0	600
R5	Ungauged Lachlan River between Nanami and Forbes	039	IIC	20.00	13.0	1170
R6	Ungauged Lachlan River between Forbes and Condobolin	042	IIC	21.60	18.1	1170

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 is in error, then that will incorrectly estimate simulated concentration at the gauge locations (C_{obs}).

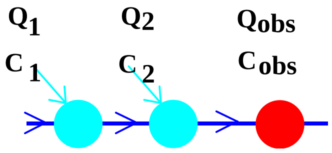


Figure 5.3. Calculating resultant concentration from two tributaries

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

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 Lachlan System IQQM provides good estimates of flow upstream of storages. However, downstream of storages, observed flows extremely depend a lot on management rules, and consequently, releases from the storages. 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 Lachlan 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 entered the Lachlan River upstream (Figure 4.2 to Figure 4.4) of most of the diversions (Figure 4.6 to Figure 4.8).

5.2.2. Selection of evaluation sites

A total of twenty-four locations have data that could be used for model evaluation (Table 3.2 and Table 3.3), and fourteen 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 412004: Lachlan River @ Forbes.

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

(ii) Station 412067: Lachlan River @ Wyangala;

(iii) Station 412002: Lachlan River @ Corowa;

(iv) Station 412009: Belubula River @ Canowindra;

(v) Station 412057: Lachlan River @ Nanami; and

(vi) Station 412006: Lachlan River @ Condobolin; and

(vii) Station 412005: Lachlan River @ Booligal Weir

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

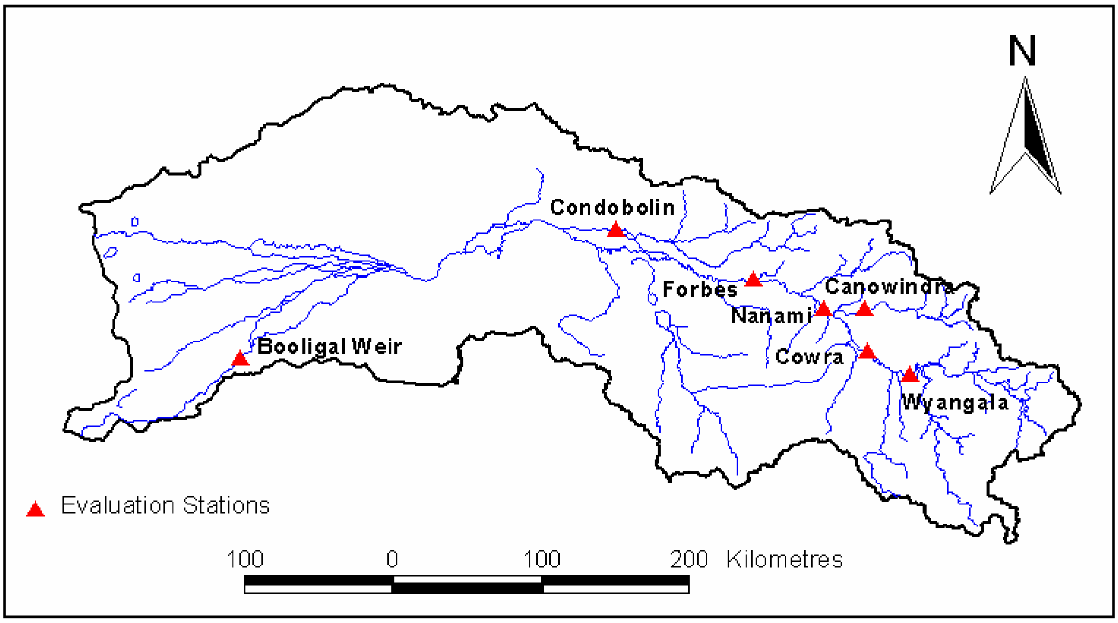


Figure 5.4. Location of evaluation sites

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. These factors include: total flow; proportion of base flow compared with surface flow; where in catchment flow originated; stream-aquifer interactions; degree of regulation; antecedent conditions; season variability; and underlying trend, if any.

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

(i) number of data points and their frequency;

(ii) period of the data collection;

(iii) seasonal distribution of the data; and

(iv) data distribution within the flow ranges.

Graphs of the full set of screened salinity data and observed flow at evaluation locations are shown in (Figure 5.20 to Figure 5.27). Performance measures (i), (ii), and (iii) from above are 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 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 5.2). Except for times of very high inflows, the daily variation in salinity is very low.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5.2.4.2. In-stream

Performance measures for comparing simulated versus 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:

(i) mean

(ii) standard deviation

(iii) maximum; and

(iv) minimum

For the observed and simulated data. 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 of the Table with these results is shown in Table 5.6.

5.3. EVALUATION OF INITIAL SALINITY AUDIT ESTIMATES

The model was evaluated at seven sites along the main streams of the Lachlan River Valley. The basis for selecting these sites is discussed in Section 5.2.2. Time series plots of observed versus simulated salinity are located at the end of this chapter, and discussion of these results with performance measures are presented in Sections 5.3.7 to 5.3.8.

5.3.1. Wyangala Dam

The discrete data is represented by station 412067: Lachlan River d/s Wyangala Dam (see Figure 5.20 and Figure 5.21). The salinity during this period ranges from just over 320 mg/L, when storage is almost empty, to about 87 mg/L when storage is full and spilling. Storage has a median salinity of 164 mg/L for the period of record

The simulation using Salinity Audit relationships significantly underestimates salinities in the storage (Figure 5.28) when storage has high salinity, 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 decreases after storage is filling up. 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 Wyangala Dam using Salinity Audit relationships

Performance measure	Result
Pattern match	0.34
Mean match	0.16
Average error	0.17
Range match	0.66
R^2	0.74

5.3.2. Station 412067 Lachlan River @ Wyangala

The station along Lachlan River @ Wyangala has had data collected consistently every 1-2 months over the evaluation period, with the exception of a large gap of 12 years (early 1987 to late 1998). The salinity ranges from about 87-320 mg/L, with a median salinity of 164 mg/L; similar to the median salinity of water released from Wyangala Dam. The data is well represented through all the flow ranges and months (Table 5.4). Salinity data has similar statistical characteristics to the whole flow record for all flow ranges (Table 5.5).

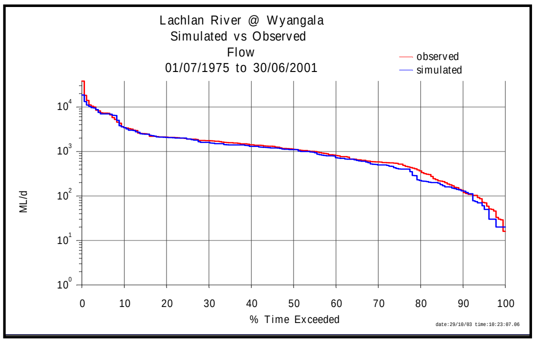
The results for the simulation using the Salinity Audit relationships show that the observed flow distribution is being maintained (Figure 5.5) as would be expected with forced releases from Wyangala Dam, but that observed salinity data is consistently underestimated (Figure 5.28), except for lower salinity range. The salinity distribution is much flatter and does not capture the rises for the non-exceedance probability of 10% and less or 80% and higher.

Table 5.4. Distribution of flow with discrete EC across flow ranges and months for Station 412067: Lachlan River @ Wyangala

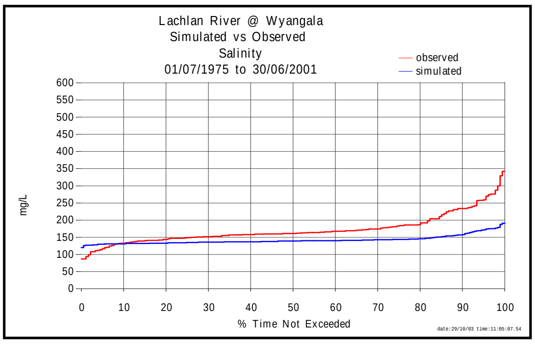
Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2001	31	0	1	0	0	4	6	5	5	3	0	1	0
Medium		125	9	9	12	10	9	3	5	3	6	7	9	9
High		26	2	0	1	1	2	0	3	2	5	3	3	0
All		182	9	10	13	11	13	8	11	9	12	9	12	9

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 412067: Lachlan River @ Wyangala

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	125	66	8	257
	With EC obs	120	67	16	244
Medium	*All*	1244	611	258	2536
	With EC obs	1211	596	274	2531
High	*All*	6947	8403	2537	149510
	With EC obs	7766	7255	2545	37979
ALL	*All*	2160	4499	8	149510
	With EC obs	1962	3650	16	37979



(a)



(b)

Figure 5.5. Station 412067: Lachlan River @ Wyangala; (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 412067: Lachlan River @ Wyangala

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	120	67	16	244	193	60	126	342			21
	Simulated	112	72	20	287	146	16	131	191	47	0.77	16
Medium	Observed	1211	596	274	2531	169	38	87	276			205
	Simulated	1135	610	137	2497	141	12	120	179	33	0.60	161
High	Observed	7766	7255	2545	37979	154	21	112	186			1160
	Simulated	6616	3849	2467	18524	138	7	127	154	23	0.11	904
All	Observed	1962	3650	16	37979	171	42	87	342			310
	Simulated	1743	2535	20	18524	142	12	120	191	34	0.63	242

5.3.3. Station 412002: Lachlan River @ Cowra

The station along Lachlan River @ Cowra has had data collected consistently every 1-2 months over the evaluation period. The data is uniformly distributed across the flow ranges, as well as throughout the year (Figure 5.22). 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 223 mg/L (Table 3.4), significantly higher than that for the Wyangala Dam.

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 be generally at the scale plotted (Figure 5.29). However, in the first year of simulation the salinity is underestimated. This is due to warming up period of IQQM. 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 412002: Lachlan River @ Cowra

Flow range	Period	Number Points	Number of months with data											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Low	1975-2001	50	0	2	1	4	5	6	8	4	1	1	4	1
Medium		126	12	12	13	9	12	6	6	5	10	5	10	11
High		35	3	1	3	2	1	0	3	2	5	6	4	0
All		211	14	14	19	13	19	12	17	10	15	13	18	12

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 412002: Lachlan River @ Cowra

Flow range	Data set	Flow (ML/d)			
		Mean	SD	Min	Max

Low	*All*	343	135	37	572
	With EC obs	341	139	120	572
Medium	*All*	1419	564	574	2806
	With EC obs	1432	625	577	2791
High	*All*	8520	9608	2809	107455
	With EC obs	7541	8367	2873	47528
ALL	*All*	2622	5243	37	107455
	With EC obs	2187	4184	120	47528

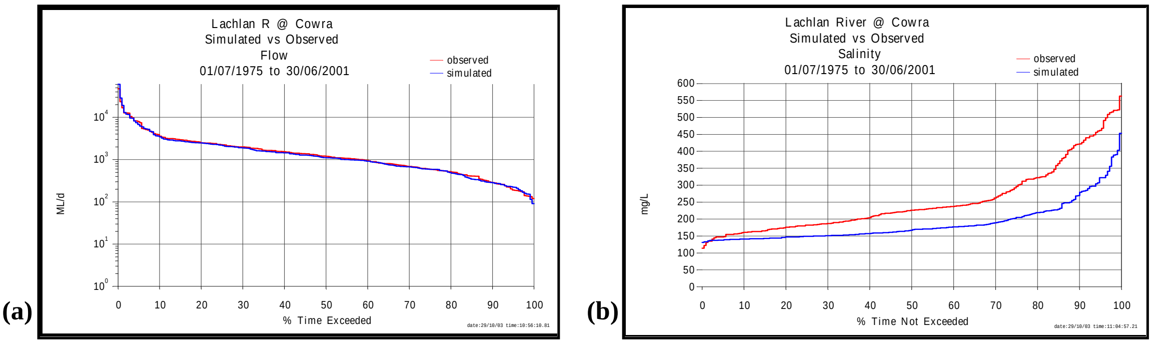


Figure 5.6. Station 421002: Lachlan River @ Cowra; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

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 412002: Lachlan River @ Cowra

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*	341	139	120	572	360	108	171	563			117
	Simulated	343	154	91	720	264	70	149	453	108	0.29	85
Medium	*Observed*	1432	625	577	2791	222	67	114	499			300
	Simulated	1364	617	473	2908	168	23	131	248	57	0.46	219
High	*Observed*	7541	8367	2873	47528	205	64	122	516			1416
	Simulated	7872	10694	2447	60911	145	7	133	164	62	0.00	1107
All	*Observed*	2187	4184	120	47528	252	99	114	563			442
	Simulated	2201	5035	91	60911	187	58	131	453	70	0.54	335

5.3.4. Station 412057: Lachlan River @ Nanami

The station along Lachlan River @ Nanami has had data collected consistently every 1-2 months over the evaluation period, with the exception of a large gap of 12 years from early 1987 to late 1998. The data is uniformly distributed across the flow ranges, as well as throughout the year (Table 5.10), 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 231 mg/L (Table 3.4), similar to Lachlan River at Cowra.

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 under-estimates the observed salinity data at the scale plotted (Figure 5.24). This characteristic is also apparent in the simulated non-exceedance curve compared with the observed (Figure 5.7).

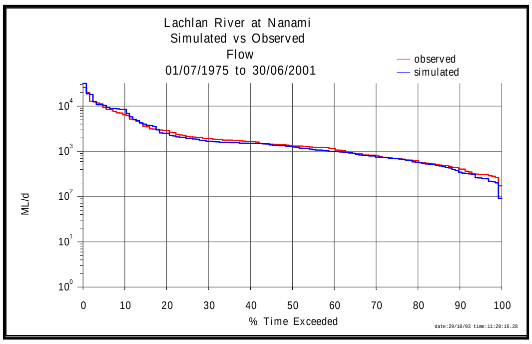
Table 5.10. Distribution of flow with discrete EC across flow ranges and months for Station 412057: Lachlan River @ Nanami

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2001	36	0	3	1	2	3	6	5	3	1	1	0	3
Medium		68	3	8	5	7	6	1	2	3	4	7	3	9
High		23	2	0	1	0	0	1	2	3	4	4	2	1
All		127	4	10	7	9	9	9	8	8	8	10	4	13

Table 5.11. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 412057: Lachlan River @ Nanami

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	501	170	129	788
	With EC obs	495	165	177	760
Medium	*All*	1732	617	789	3218
	With EC obs	1617	570	789	2985
High	*All*	10438	11171	3220	129233
	With EC obs	8411	5513	3248	25865
ALL	*All*	3226	6196	129	129233
	With EC obs	2529	3665	177	25865

(a)



(b)

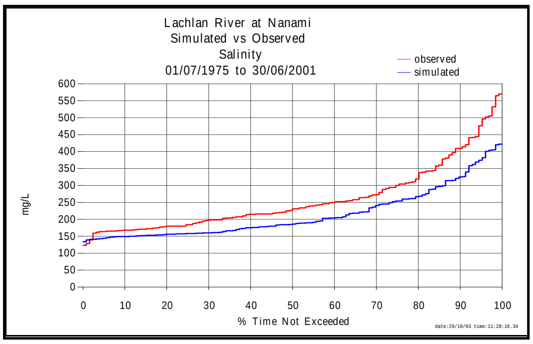


Figure 5.7. Station 412057: Lachlan River @ Nanami; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.12. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for 412057: Lachlan River @ Nanami

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*	495	165	177	760	356	97	207	570	81	0.33	172
	Simulated	472	206	92	964	296	75	149	422			133
Medium	*Observed*	1617	570	789	2985	225	69	159	565	47	0.30	351
	Simulated	1566	1213	677	10427	187	40	134	325			286
High	*Observed*	8411	5513	3248	25865	206	60	123	390	51	0.14	1591
	Simulated	8959	6592	1679	31745	163	22	139	245			1389
All	*Observed*	2529	3665	177	25865	259	98	123	570	57	0.56	525
	Simulated	2595	4199	92	31745	214	72	134	422			442

5.3.5. Station 412004: Lachlan River @ Forbes

The station along Lachlan River @ Forbes has had data collected consistently every 1-2 months over the evaluation period. The data is uniformly distributed across the flow ranges, as well as throughout the year (Table 5.11), 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 247 mg/L (Table 3.4), a little higher than that for the Lachlan River @ Nanami.

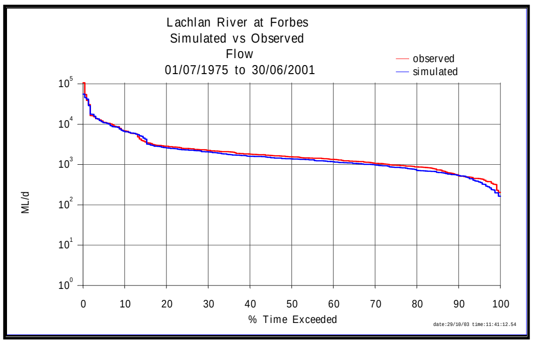
The simulated salinity appears to be underestimated for the evaluation period. This is apparent in Figure 5.8, the simulated non-exceedance curve compared with the observed and Table 5.15.

Table 5.13. Distribution of flow with discrete EC across flow ranges and months for Station 412004: Lachlan River @ Forbes

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2001	43	1	1	3	4	6	9	6	2	1	0	1	1
Medium		148	11	15	14	13	9	8	8	6	10	10	10	17
High		38	2	0	3	0	0	1	4	6	6	7	3	0
All		229	13	16	19	15	15	18	17	14	16	16	13	18

Table 5.14. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 412004: Lachlan River @ Forbes

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	569	177	185	859
	With EC obs	557	178	204	855
Medium	*All*	1718	603	860	3303
	With EC obs	1697	602	862	3145
High	*All*	11079	12822	3304	141823
	With EC obs	13568	18486	3332	106340
ALL	*All*	3359	6941	185	141823
	With EC obs	3453	8737	204	106340

(a)


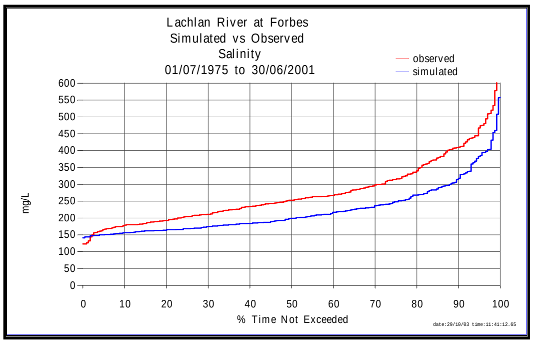
(b)


Figure 5.8. Station 412004: Lachlan River @ Forbes; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.15. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for 412004: Lachlan River @ Forbes

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*	557	178	204	855	373	113	196	662			203
	Simulated	585	393	163	2703	324	85	165	557	91	0.16	178
Medium	*Observed*	1697	602	862	3145	259	75	156	534			423
	Simulated	1539	746	321	6046	204	43	141	364	60	0.42	301
High	*Observed*	13568	18486	3332	106340	216	60	123	370			2495
	Simulated	11897	11930	2491	55539	168	18	144	220	60	0.23	1923
All	*Observed*	3453	8737	204	106340	273	96	123	662			726
	Simulated	3078	6258	163	55539	220	72	141	557	66	0.47	547

5.3.6. Station 412006: Lachlan River @ Condobolin

The station along Lachlan River @ Condobolin has had data collected consistently every 1-2 months over the evaluation period, with a few exceptions. The data is uniformly distributed across the flow ranges, as well as throughout the year (Table 5.16), 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 246 mg/L (Table 3.4), similar to that for the Lachlan River @ Forbes.

The simulated flows and salinity are both lower than the observed data over the evaluation period. In particular, in high flow range the difference is very significant. It does not even capture about 6% of the flow This characteristic is apparent in the steeply rising part of the simulated non-exceedance curve compared with the observed (Figure 5.9).

Table 5.16. Distribution of flow with discrete EC across flow ranges and months for Station 412006: Lachlan River @ Condobolin

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2001	40	7	3	2	4	4	5	4	4	0	1	1	5
Medium		115	9	15	15	8	13	7	7	6	6	7	10	9
High		33	1	1	0	0	0	0	2	6	8	5	7	0
All		188	16	18	17	12	17	12	14	15	14	13	18	14

Table 5.17. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 412006: Lachlan River @ Condobolin

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	326	90	0	456
	With EC obs	339	91	144	454

Medium	*All*	1058	550	457	2962
	With EC obs	1162	623	462	2895
High	*All*	8454	4563	2963	34138
	With EC obs	8726	5803	3104	34050
ALL	*All*	2389	3689	0	34138
	With EC obs	2315	3861	144	34050

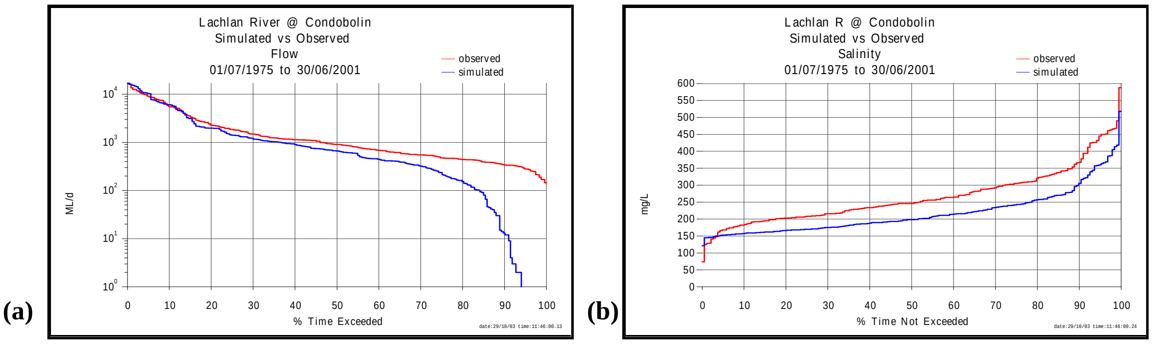


Figure 5.9. Station 412006: Lachlan River @ Condobolin; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.18. 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 412006: Lachlan River @ Condobolin

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*	339	91	144	454	307	79	184	463			102
	Simulated	287	450	0	2428	273	97	145	518	78	0.26	90
Medium	*Observed*	1162	623	462	2895	270	82	125	588			314
	Simulated	850	959	0	6063	213	52	146	387	73	0.26	183
High	*Observed*	8725	5803	3104	34050	211	59	74	338			1703
	Simulated	8921	8310	1957	47681	177	22	145	227	51	0.12	1510
All	*Observed*	2315	3861	144	34050	265	83	74	588			541
	Simulated	2147	4721	0	47681	217	66	145	518	70	0.30	420

5.3.7. Station 412005: Lachlan River @ Booligal

The station along Lachlan River @ Booligal has had data collected consistently every 1-2 months over the evaluation period, with the exception of a gap in 1991. The data is uniformly distributed across the flow ranges, as well as throughout the year (Figure 5.27), 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 292 mg/L (Table 3.4), significantly higher than that for the Lachlan River @ Condobolin.

The simulated flows and salinity are generally lower than the observed data over the evaluation period. In particular, in high flow range the difference is very significant. It does not even capture about 9% of the flow at the high end. This characteristic is apparent in the steeply rising part of the simulated non-exceedance curve compared with the observed (Figure 5.10).

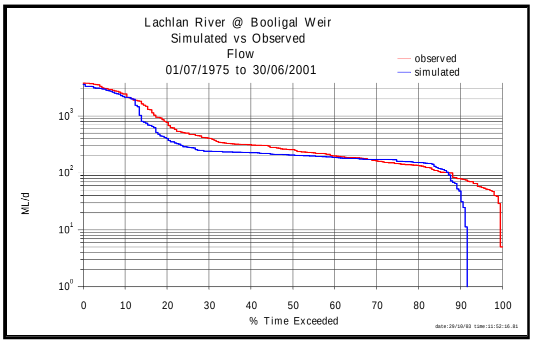
Table 5.19. Distribution of flow with discrete EC across flow ranges and months for Station 412005: Lachlan River @ Booligal

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2001	44	2	0	2	7	5	7	4	3	3	1	2	1
Medium		110	14	8	15	6	11	9	8	6	6	7	10	3
High		32	1	1	1	1	0	0	2	4	4	5	5	5
All		186	17	9	18	14	15	15	13	14	12	12	17	9

Table 5.20. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 412005: Lachlan River @ Booligal

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	92	32	2	139
	With EC obs	87	34	6	138
Medium	*All*	287	134	140	823
	With EC obs	293	141	140	806
High	*All*	2551	1037	832	5001
	With EC obs	2143	840	860	3650
ALL	*All*	700	1043	2	5001
	With EC obs	562	812	6	3650

(a)



(b)

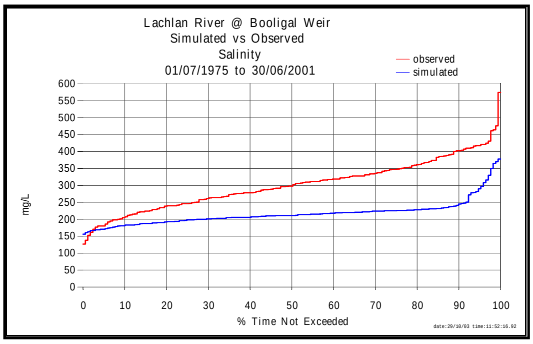


Figure 5.10. Station 412005: Lachlan River @ Booligal; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.21. 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 412005: Lachlan River @ Booligal

Flow range	Data set	Distributions								C_o versus C_s		Mean load (t/d)
		Flow (ML/d)				Salinity (mg/L)						
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*	*Mean error (mg/L)*	R^2	
Low	*Observed*	90	33	29	138	314	64	222	574			28
	Simulated	217	301	23	2001	236	49	169	378	96	0.03	50
Medium	*Observed*	304	143	140	806	316	71	171	476			97
	Simulated	247	191	13	1541	217	29	156	365	106	0.00	52
High	*Observed*	2143	840	860	3650	239	64	127	417			485
	Simulated	1708	1194	183	3587	191	19	161	228	60	0.27	314
All	*Observed*	604	840	29	3650	301	74	127	574			155
	Simulated	517	799	13	3587	216	36	156	378	95	0.02	101

5.3.8. 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 storages, also at the lower end of the Lachlan River. The observed and simulated results shows that salinity increases along the river and by the time reaches to the end of the system become double the salinity released from Wyangala Dam. In the absence of specific criteria for model acceptability, the results at Wyangala 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 Lachlan enters Wyangala Dam. Undoubtedly, the underestimates into Wyangala Dam translate to the underestimate at end of the system.

Overall, the 'first cut' results are such that the model is not currently fit for estimating a baseline for the BSMS. 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 yet, as it would require recalibrating the quantity model, which would take some time.

5.4. SALINITY MODEL CALIBRATION

5.4.1. Methods (General)

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

5.4.1.1. Headwater catchments

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

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

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

$$SL = e^{\eta} Q^{\lambda} \tag{5.1}$$

The flow versus concentration LUT is based on the assumption that flow is inversely related to concentration (Equation 5.2). 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.

$$C \propto \frac{1}{Q} \tag{5.2}$$

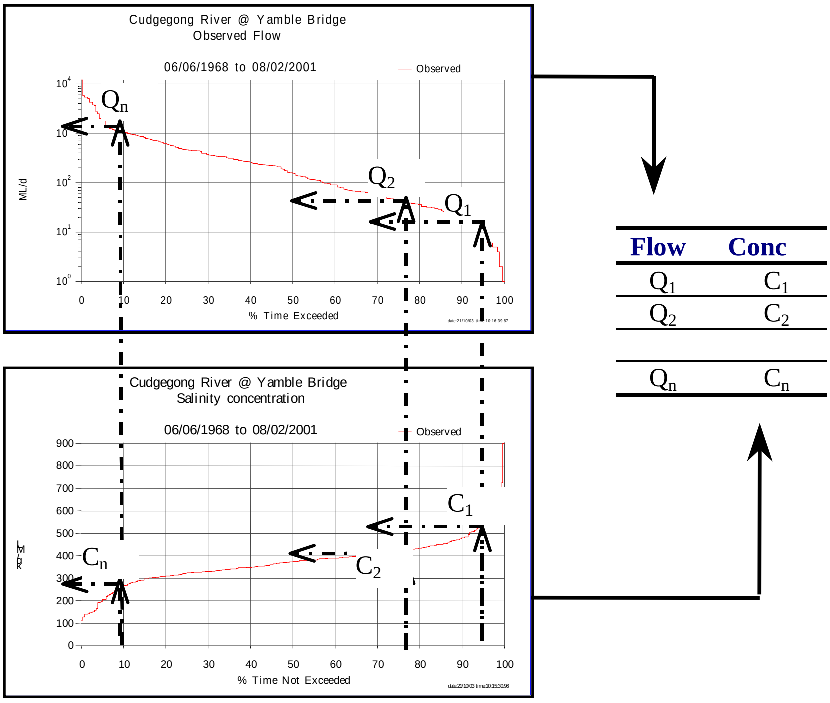


Figure 5.11. Derivation of flow versus concentration LUT from exceedance curves

5.4.1.2. Residual catchments

The 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 5.1). 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.

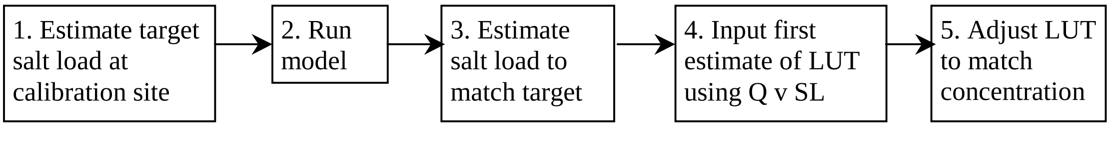


Figure 5.12. Procedure to calibrate salt inflows from residual catchments

5.4.2. Wyangala Dam

The first cut inflow to Wyangala dam was derived using IIC relationships. These produced simulated salinity at Wyangala lower than observed. Improving the salinity inflows at catchments and residuals upstream Wyangala dam improved the match between the simulated and observed salinity at Wyangala. The flow-concentration LUT was derived using the method from Section 5.4.1.2, and the final calibrated relationship shown in Table 5.22 to Table 5.26.

Table 5.22. Calibrated flow versus salinity relationship used for inflows in 412065

Flow (ML/d)	Concentration (mg/L)
0	769
2	769
7	678
18	660
28	649
35	636
50	615
72	594
88	543
123	504
164	458
268	413
393	336
651	294
1052	259
7787	120
1e37	120

Table 5.23. Calibrated flow versus salinity relationship used for inflows in 412050

Flow (ML/d)	Concentration (mg/L)
0	414
2	414
6	366
13	348
16	330
20	324
21	312
28	300
39	282

Flow (ML/d)	Concentration (mg/L)
50	257
69	246
100	219
145	210
176	189
236	162
607	122
3654	66
1e37	66

Table 5.24. Calibrated flow versus salinity relationship used for inflows in 412083

Flow (ML/d)	Concentration (mg/L)
0	563
1	563
2	408
5	397
6	375
7	369
10	337
16	306
36	281
52	255
65	222
74	210
187	180
276	141
732	117
2670	69
1e37	69

Table 5.25. Calibrated flow versus salinity relationship used for inflows in 412028

Flow (ML/d)	Concentration (mg/L)
0	316
7	316

Flow (ML/d)	Concentration (mg/L)
13	270
40	240
71	225
125	198
176	180
228	162
350	145
509	127
968	108
1,898	87
3,548	72
16,304	68
$1*10^{37}$	68

Table 5.26. Calibrated flow versus salinity relationship used for residual inflow R1

Flow (ML/d)	Concentration (mg/L)
0	2,000
92	2,000
126	1500
179	800
277	300
439	202
560	183
740	164
1,028	150
1,567	150
$1*10^{37}$	150

The simulated salinity upstream of Wyangala dam from the calibrated inflow salinity using flow salinity table was used as salinity inflow. The input daily inflows at Wyangala used in quantity model were backcalc inflows, which matches the simulated inflow. There are dry periods when the simulated inflow is less than the backcalc inflow. This is due to the loss node upstream of Wyangala dam, which removes water below 150 ML/d. For this reason; high salinity at low flows can not get into the storage. The results of this simulation can be seen shown in Figure 5.35. 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 overestimated during this period. The performance measures improved, with the mean match, average error and range all improving. The distribution of salinities also compares quite well with observed (Figure 5.11).

Table 5.27. Results of performance measures for simulated versus observed salinities in Wyangala Dam using calibrated relationship

Performance measure	Result
Pattern match	0.35
Mean match	0.01
Average error	0.09
Range match	0. 35
R^2	0.80

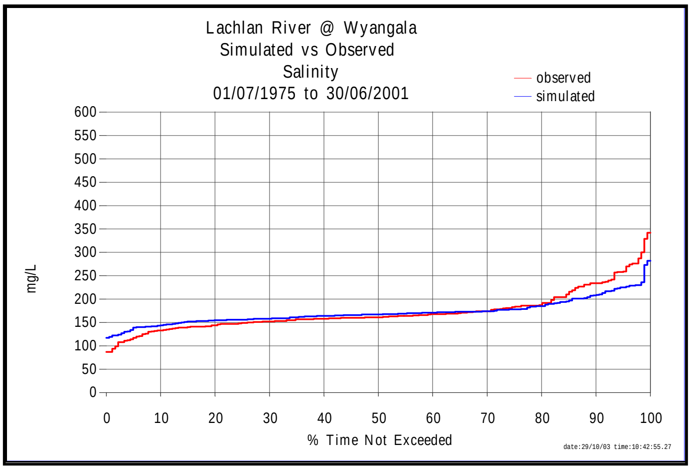


Figure 5.13. Non-exceedance curve for observed versus simulated salinity for calibrated model at Wyangala Dam

5.4.3. Station 412002: Lachlan River @ Cowra

Improving the results of the salinity simulation in Wyangala Dam improved the results at this station. Further improvements were made by rederiving the flow versus load relationship for the catchment Station 412029: Boorowa River @ Prossers Crossing. The flow-concentration LUT was derived using the method from Section 5.4.1.2, and the final calibrated relationship for 412029 is shown in Table 5.28. The flow-concentration LUT for the residual between Wyangala and Cowra is shown in Table 5.29.

Table 5.28. Calibrated flow versus salinity relationship used for inflows in 412029

Flow (ML/d)	Concentration (mg/L)
0	1,038
1	1,038
3	870
17	672
43	537

Flow (ML/d)	Concentration (mg/L)
77	462
370	337
2011	186
1e37	186

Table 5.29. Calibrated flow versus salinity relationship used for inflows for R2

Flow (ML/d)	Concentration (mg/L)
0	1,000
7	1,000
10	900
57	800
123	750
214	600
400	380
519	350
800	320
1300	300
4000	200
50000	130
1e37	130

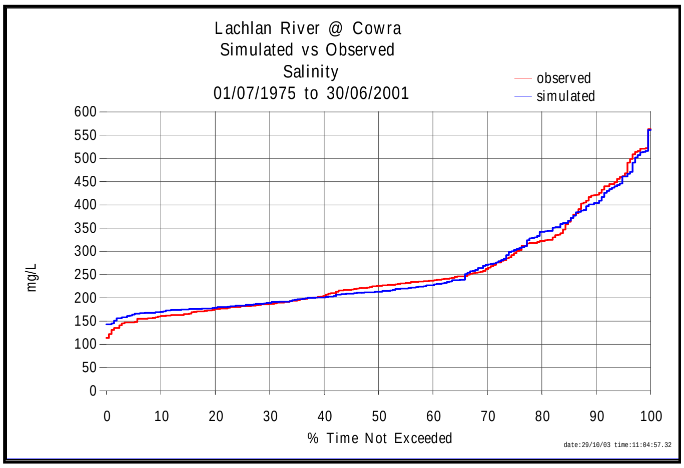


Figure 5.14. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 412002: Lachlan River @ Cowra

Table 5.30. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 412002: Lachlan River @ Cowra

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	360	108	171	563	60	0.52	117
	Simulated	367	101	187	561			124
Medium	*Observed*	222	67	114	499	26	0.68	300
	Simulated	224	62	143	440			286
High	*Observed*	205	64	122	516	26	0.07	1416
	Simulated	189	20	143	222			1398
All	*Observed*	252	99	114	563	34	0.71	442
	Simulated	252	95	143	561			432

5.4.4. Station 412009: Belubula River @ Canowindra

Belubula River starts at Carcoar Dam. Tributary inflows upstream Canowindra include Coombing Ck (412092), Flyers Creek (412080), and residual inflow from Carcoar to Canowindra. The IIC relationship was used at the gauged inflows. However, at the residual, which has the highest inflow, a LUT was derived to match the observed salinity at Canowindra. The flow-concentration LUT for the residual between Carcoar and Canowindra is shown in Table 5.31

Table 5.31. Calibrated flow versus salinity relationship used for residual inflows R4a

Flow (ML/d)	Concentration (mg/L)
0	800
25	800
36	650
70	630
113	550
196	500
263	450
362	400
876	250
1713	200
6371	180
1.00E+37	180

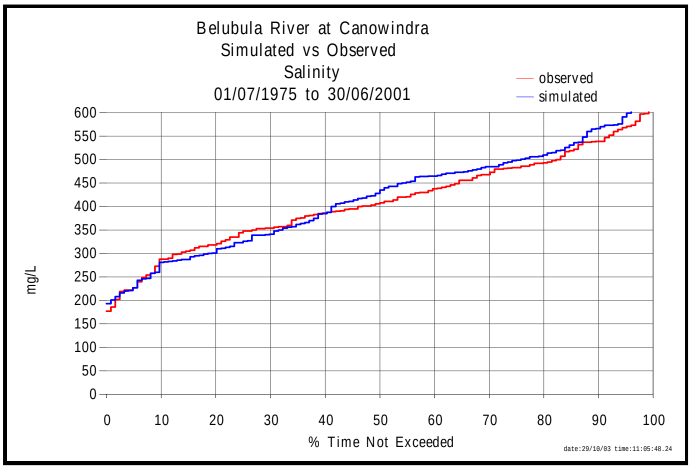


Figure 5.15. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 412009: Belubula River @ Canowindra

Table 5.32. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 412009: Belubula River @ Canowindra

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	450	55	360	560	105	0.08	20
	Simulated	508	125	300	700			32
Medium	*Observed*	426	88	186	598	67	0.27	70
	Simulated	432	86	243	574			67
High	*Observed*	294	107	172	630	84	0.00	369
	Simulated	277	64	175	428			296
All	*Observed*	404	103	172	630	77	0.32	120
	Simulated	415	117	175	700			106

5.4.5. Station 412057: Lachlan River @ Nanami

Back Creek is a small catchment with zero inflow about 50% of the time. The IID relationship was not revised. For the Belubula catchment, the IIC relationships at residual R4b between Canowindra and Bangaroo Bridge was maintained. The residual salinity inflow from Cowra to Nanami (R3) was changed to flow salinity table to improve the salinity at Nanami. The flow-concentration LUT for the residual R3 is shown in Table 5.33.

Table 5.33. Calibrated flow versus salinity relationship used for residual inflows R3

Flow (ML/d)	Concentration (mg/L)
0	1,000
3	1,000
12	600
32	500
87	400
285	300
738	200
$1*10^{37}$	200

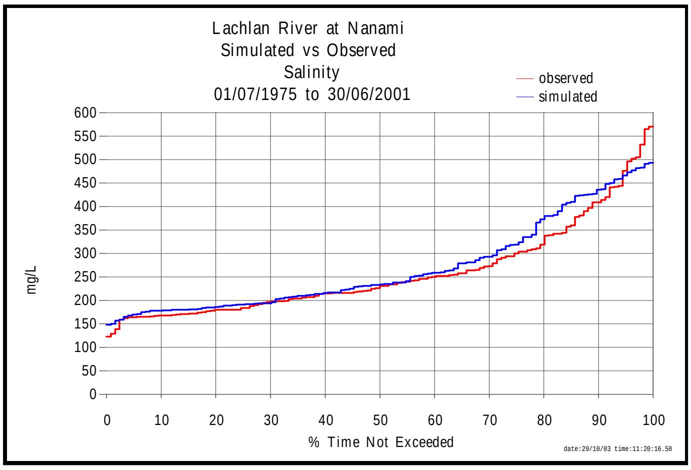


Figure 5.16. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 412057: Lachlan River @ Nanami

Table 5.34. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 412057: Lachlan River @ Nanami

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	356	97	207	570	54	0.57	172
	Simulated	367	95	181	493			172
Medium	*Observed*	225	69	159	565	35	0.40	351
	Simulated	237	70	157	466			360
High	*Observed*	198	45	123	309	25	0.49	1553
	Simulated	207	42	148	335			1687
All	*Observed*	258	98	123	570	39	0.68	510
	Simulated	269	97	148	493			538

5.4.6. Station 412004: Lachlan River @ Forbes

The adopted flow-concentration LUTs for the inflows between Nanami and Forbes are shown in Table 5.35 and Table 5.36 for Mandagery Ck inflow and residual inflow, R5 respectively.

Table 5.35. Calculated flow versus salinity relationship for salt inflows from catchment Station 412030: Mandagery Creek @ U/S Eugowra

Flow (ML/d)	Concentration (mg/L)
0	1,170
2	1,170
6	816
17	750
29	720
36	660

Flow (ML/d)	Concentration (mg/L)
51	600
67	507
132	432
389	324
661	200
1e37	200

Table 5.36. Calibrated flow versus salinity relationship for inflows in R5

Flow (ML/d)	Concentration (mg/L)
0	2000
5	2000
17	1034
24	900
30	800
42	567
60	500
91	336
146	265
184	239
237	218
417	185
594	160
1e37	160

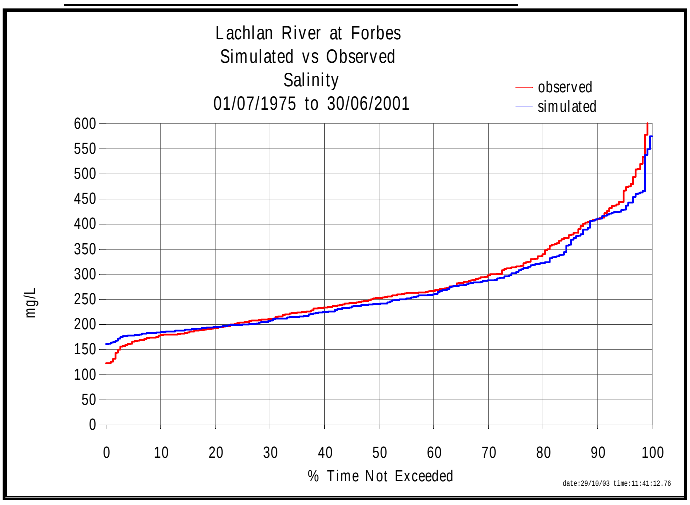


Figure 5.17. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 412004: Lachlan River @ Forbes

Table 5.37. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 412004: Lachlan River @ Forbes

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	373	113	196	662	69	0.31	203
	Simulated	373	90	205	575			210
Medium	*Observed*	259	75	156	534	36	0.51	423
	Simulated	251	61	165	454			375
High	*Observed*	216	60	123	370	31	0.76	2495
	Simulated	203	29	161	284			2245
All	*Observed*	273	96	123	662	41	0.59	726
	Simulated	266	84	161	575			655

5.4.7. Station 412006: Lachlan River @ Condobolin

From Forbes to Condobolin, inflows are R6 and Goobang Ck inflow (412043), and effluents. Residual inflow IIC relationship maintained at R6 which has small inflow.

Table 5.38. Calculated flow versus salinity relationship for salt inflows from catchment Station 412043: Goobang Creek @ Darbys Dam

Flow (ML/d)	Concentration (mg/L)
0	423
2	423
4	300
11	250
20	201
36	180
109	165
266	141
773	125
3000	69
1e37	69

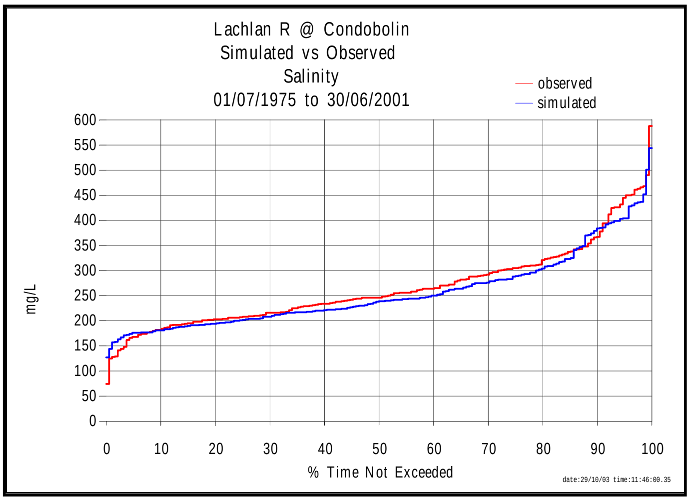


Figure 5.18. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 412006: Lachlan River @ Condobolin

Table 5.39. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 412006: Lachlan River @ Condobolin

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	296	78	168	463			99
	Simulated	298	97	127	544	67	0.32	86
Medium	*Observed*	269	80	125	588			304
	Simulated	256	64	176	452	46	0.39	211
High	*Observed*	211	59	74	338			1703
	Simulated	202	34	144	292	35	0.33	1640
All	*Observed*	265	80	74	588			506
	Simulated	256	74	127	544	48	0.41	435

5.4.8. Station 412005: Lachlan River @ Booligal

From Condobolin to Booligal, the only tributary inflow is the occasional inflow from the northern catchment. There is inflow only about 7 % of the time ranging from 500 to 4650 mg/L. There is no observed EC data, hence a constant salinity of 423 mg/L was assumed. This salinity was based on the observed EC at Goobang Creek .

The simulated salinity at Booligal is less than observed at all flow ranges. This may be due to increase in salinity due to unmodelled inflow and changes in salinity due to the operations of Lake Cargelligo and Lake Brewster. The discrepancy in flow behaviour and magnitudes between the simulated and observed flow makes the salinity calibration at Booligal very difficult.

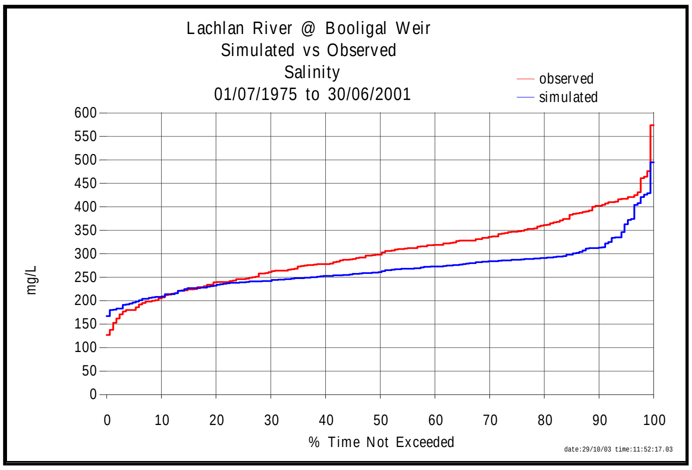


Figure 5.19. Non-exceedance curve for observed versus simulated salinity for calibrated model at Station 412005: Lachlan River @ Booligal

Table 5.40. Comparison of statistics within flow ranges of: (i) observed discrete versus simulated salinity; and (ii) observed versus simulated load for Station 412005: Lachlan River @ Booligal

Flow range	Data set	Distributions				C_o versus C_s		Mean load (t/d)
		Salinity (mg/L)				*Avg. error (mg/L)*	R^2	
		Mean	*S.D*	*Min*	*Max*			
Low	*Observed*	314	64	222	574	72	0.03	28
	Simulated	294	60	214	495			62
Medium	*Observed*	316	71	171	476	75	0.01	97
	Simulated	269	39	192	429			65
High	*Observed*	239	64	127	417	36	0.53	485
	Simulated	226	35	167	292			362
All	*Observed*	301	74	127	574	67	0.06	155
	Simulated	267	49	167	495			120

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 5.42 to Figure 5.46 for the evaluation sites on the Lachlan River at Cowra, Nanami, Forbes and Condobolin, as well as Belabula River @ Helensholme.

The graphs show that the simulated results match the patterns and timing of the two years of observed salinity at Cowra (Figure 5.42) and Nanami (Figure 5.44). In the case of Cowra the model is underestimating the earlier spikes in salinity, but matches the higher salinities closely during the year 2000. The lower salinities are slightly overestimated, and salinities are also slightly overestimated at Nanami during 2000, but match the lower salinities quite well. The results for Belabula River @ Helensholme are not as close, with significant overestimates and differences in patterns compared with observed. The simulated results at Forbes (Figure 5.45) and Condobolin (Figure 5.46) also match the salinity patterns of the observed data, however, the timing of simulated salinity peaks lags observed salinity peaks by one to two weeks. The simulated salinities overestimate the salinities in the latter period at Forbes, but match the magnitudes of observed salinities well at Condobolin.

Overall, with the exception of Belabula River, and timing for the lower reaches of the system, the salinity model appears to be simulating the salinity behaviour of the Lachlan River system quite well,

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 5.41), as well as those used for the initial model evaluation (column 4 in Table B.). 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 412067 Lachlan R at Wyangala. The differences at the balance points ranges from 2.5% compared to the Audit for Station 412004: Lachlan River @ Forbes, the last balance point recorded in the Audit, to 46% at Belubula River @ Bangaroo Bridge. At Tuena Creek @ Tuena, the difference compared with the reported values in the Salinity Audit is the decrease of 17%.

Table 5.41. Comparison of average annual salt loads with Salinity Audit, and Audit as modified

Number	Audit inflow / balance point Name	Mean salt load ('000 t/year) *Audit*	*Audit (modified) (4)*	*Calibrated*
412065	Lachlan R @ Narrawa	*42*	38	41
412050	Crookwell R @ Narrawa North	*15*	14	11
412083	Tuena Ck @ Tuena	*6*	5	5
412028	Abercrombie R @ Abercrombie	*32*	29	28
R1*	Ungauged Lachlan River u/s Wyangala Dam	*35*	23	41
412067	**Lachlan R at Wyangala**	*127*	109	125
412029	Boorowa R @ Prossers Crossing	*32*	18	24
R2*	Ungauged Lachlan River between Wyangala Dam and Cowra	*32*	18	34
412002	**Lachlan River @ Cowra**	*205*	143	181
412072	Back Ck @ Koorawatha	*9*	10	10
412009	**Belubula R @ Canowindra**	*57*	42	50
412055	**Belubula R @ Bangaroo Bridge**	*57*	40	47
R3*	Ungauged Lachlan River between Cowra and Nanami	*13*	2	7
412057	**Lachlan River @ Nanami**	*247*	194	244
412030	Mandagery Ck @ U/S Eugowra	*29*	27	22
R5	Ungauged Lachlan River between Nanami and Forbes	*33*	14	14
412004	**Lachlan River @ Forbes**	*238*	205	244
R6	Ungauged Lachlan River between Forbes and Condobolin	*14*	5	5
412043	Goobang Ck @ Darby's Dam	*26*	15	8
412034/006	**Lachlan River @ Condobolin Bridge**	*171*	143	163

Notes:

Audit. From audit report conversion factor (0.64)
(4). Different comparison period, lower conversion factor(0.6), concentration limit
Calibrated with lower conversion factor(0.6), concentration limit

- *These residuals have losses included in their calculation.*
  R1* = inflow (4) – loss (5) in U/S Wyangala system file
  R2* = inflow (5) – loss (10) in D/S Wyangala system file
  R3* = inflow (31) – loss (32) in D/S Wyangala system file

The Salinity audit did not have a separate loss node at this location. All other residuals had separate loss nodes

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 landuse 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 Lachlan IQQM is a robust and reliable water balance model of the Lachlan 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 Wyangala Dam. These methods developed a model that was fit for the purpose of water sharing, but creates difficulties in calibrating the salt balance. There are also appears to be some issues relating to travel times of flows in the lower reaches.

The result of the comparison for salinity and salt loads from the tables in Section 5.4 are summarised in Table 5.42. 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 was matched within ±10% with only two exceptions. These exceptions are the low flow range at Belabula River @ Canowindra, and the medium flow range for the Lachlan River @ Booligal, which were ±20%. The salt load matches were also within ±10% for Lachlan River at Cowra, Nanami, and Forbes. The results for Belabula River, and for the lower reaches of the Lachlan River are not to the same accuracy. In the case of the lower reaches of the Lachlan River, this is probably because of the mismatch in timing shown by the continuous graphs.

In summary, the model appears to simulate the salinity behaviour in most parts of 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 include Belabula River, and possibly the Lachlan River at Booligal. The model appears to be able to reproduce the overall mean salt loads as well, except for the Belabula River.

Table 5.42. 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%							
412067	Lachlan River @ Wyangala Dam	-	-	-	1	-	-	-	1
412002	Lachlan River @ Cowra	1	1	1	1	1	1	1	1
412009	Belabula River @ Canowindra	2	1	1	1	3	1	2	2
412057	Lachlan River @ Nanami	1	1	1	1	1	1	1	1
412004	Lachlan River @ Forbes	1	1	1	1	1	2	1	1
412006	Lachlan River @ Condobolin	1	1	1	1	2	3	1	2
412005	Lachlan River @ Booligal	1	2	1	2	3	3	3	3

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 Wyangala Dam would remove nearly all the low flow salt load from the upper Lachlan. This would then underestimate the impact of land management of the catchments in the Upstream Wyangala Region.

5.6.3. Water management scenarios

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

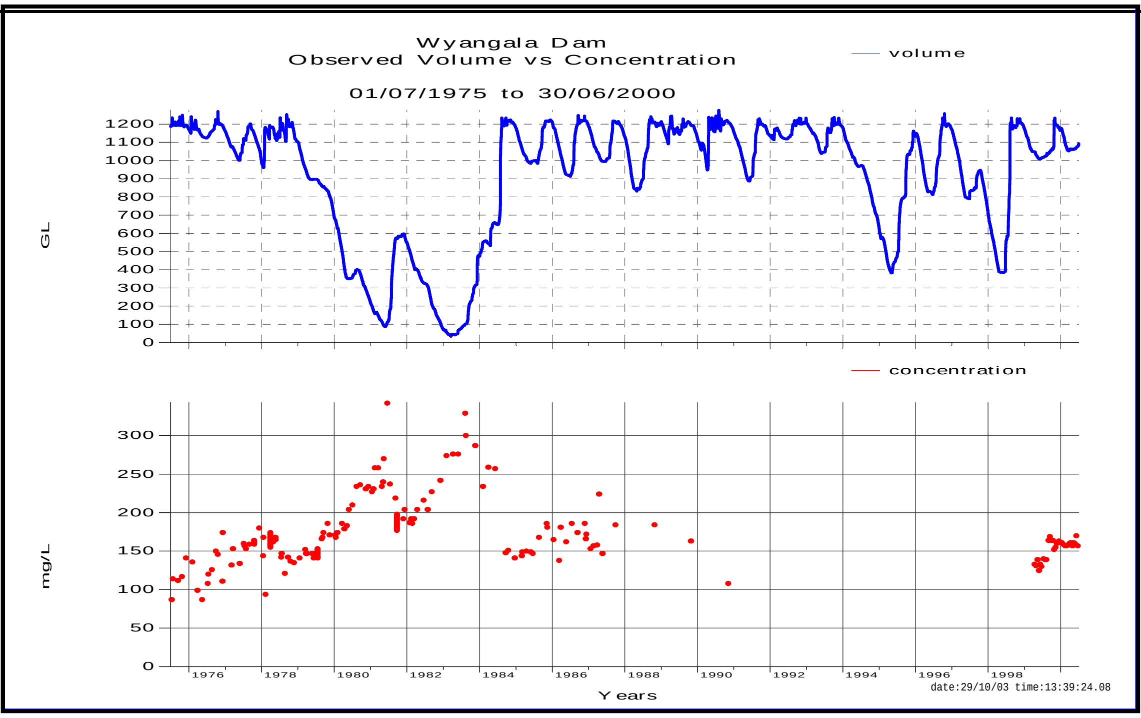


Figure 5.20. Wyangala Dam storage volume and concentration data

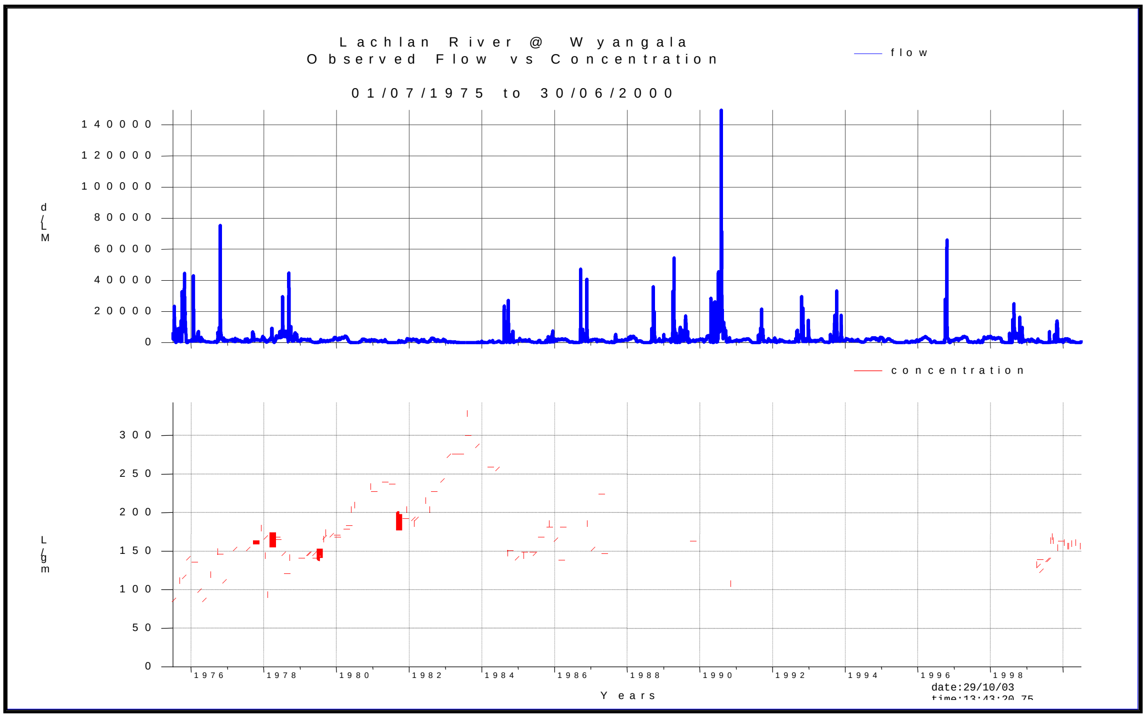


Figure 5.21. Station 412067: Lachlan River d/s Wyangala Dam flow and concentration data

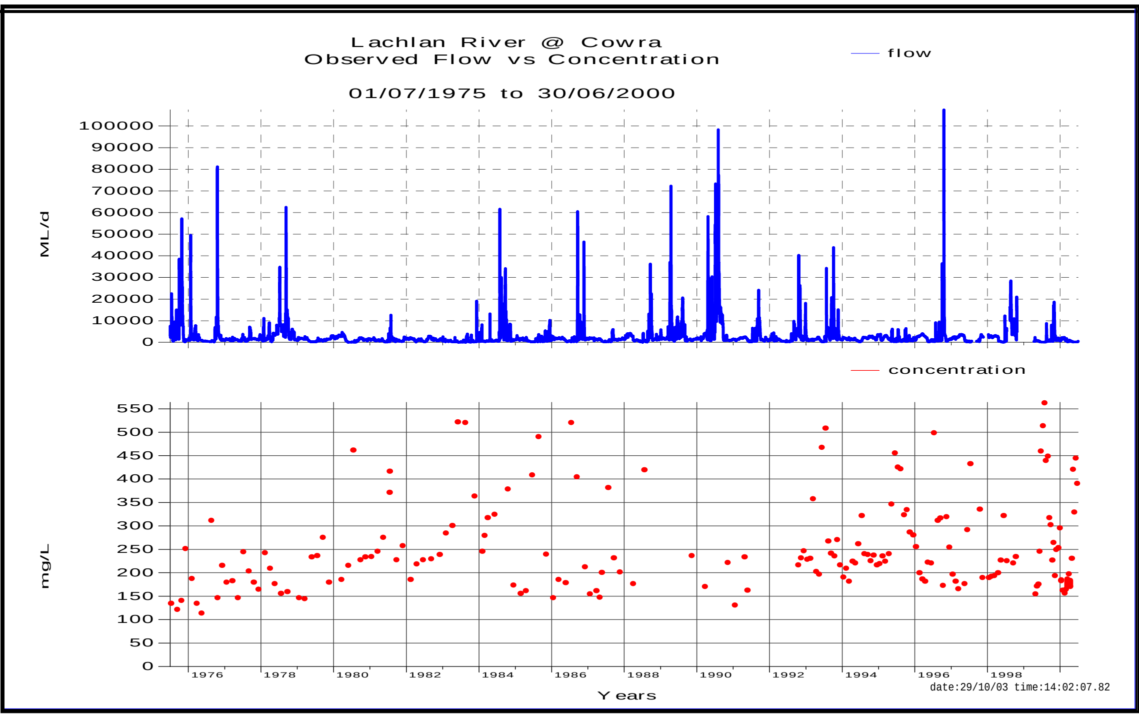


Figure 5.22. Station 412002: Lachlan River @ Cowra observed flow and concentration

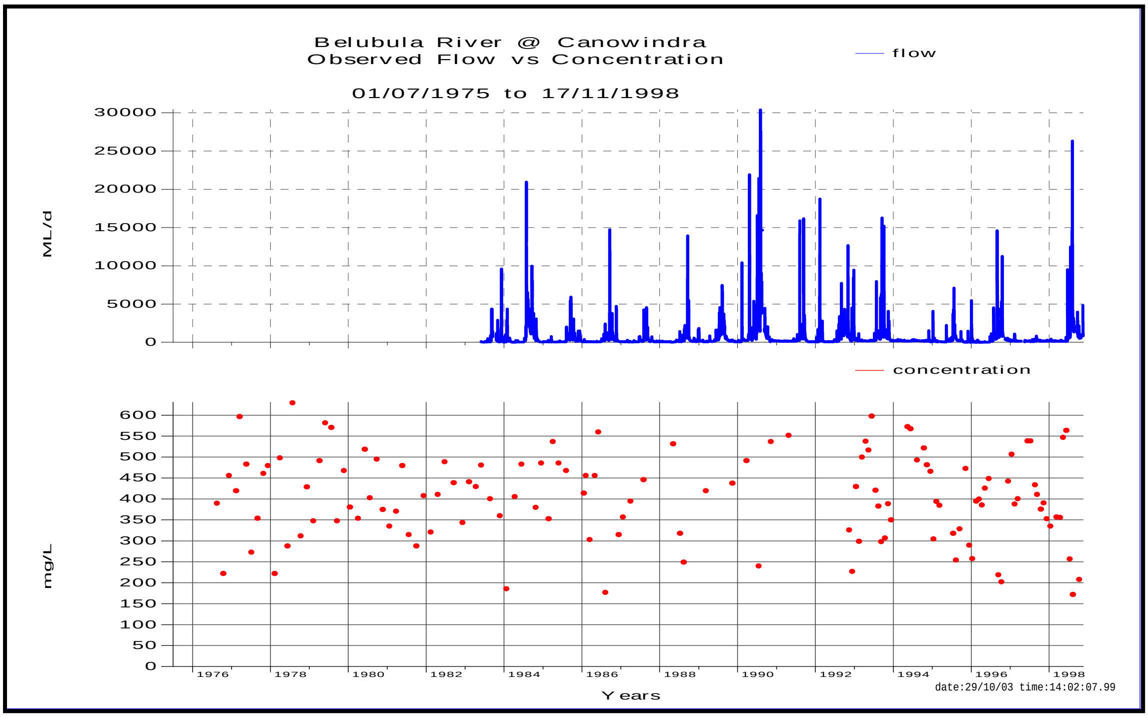


Figure 5.23. Belubula River @ Canowindra observed flow and concentration

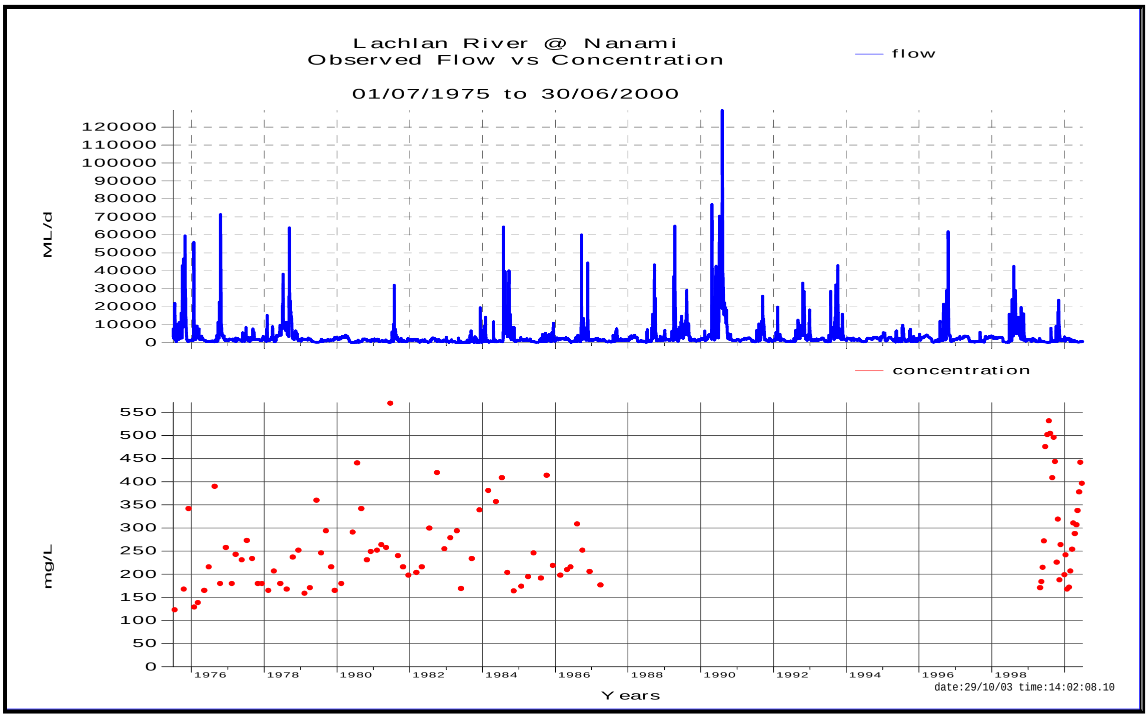


Figure 5.24. Station 412057: Lachlan River @ Nanami, flow and concentration data

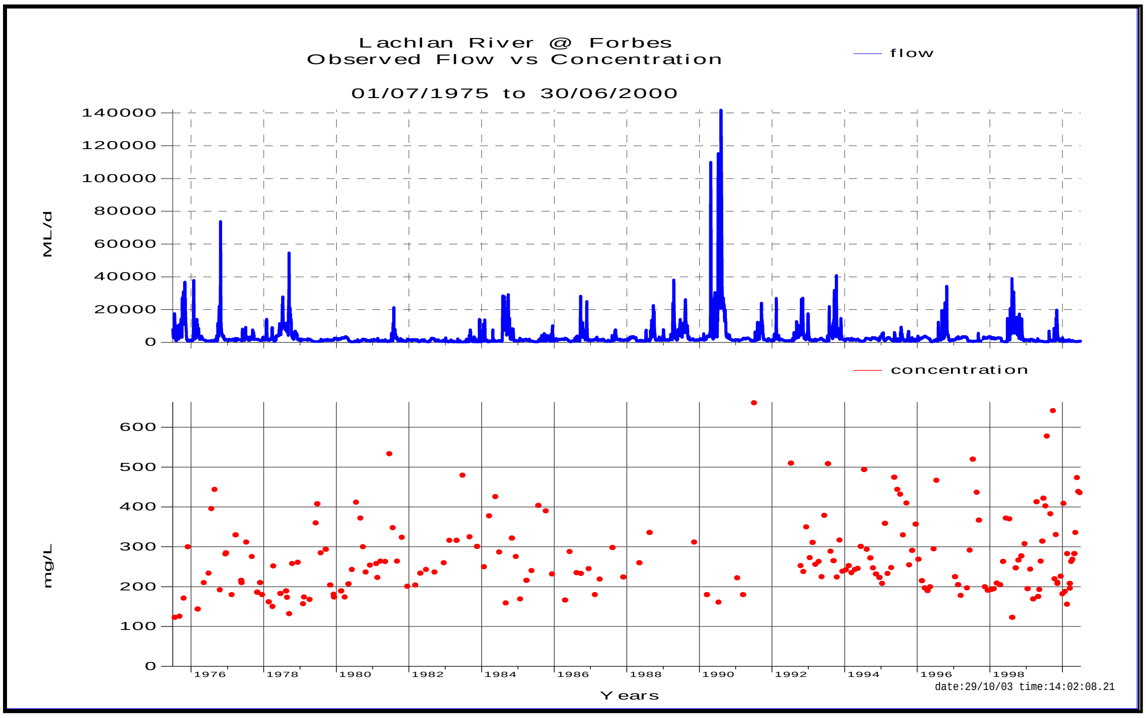


Figure 5.25. Station 412004: Lachlan River @ Forbes, flow and concentration data

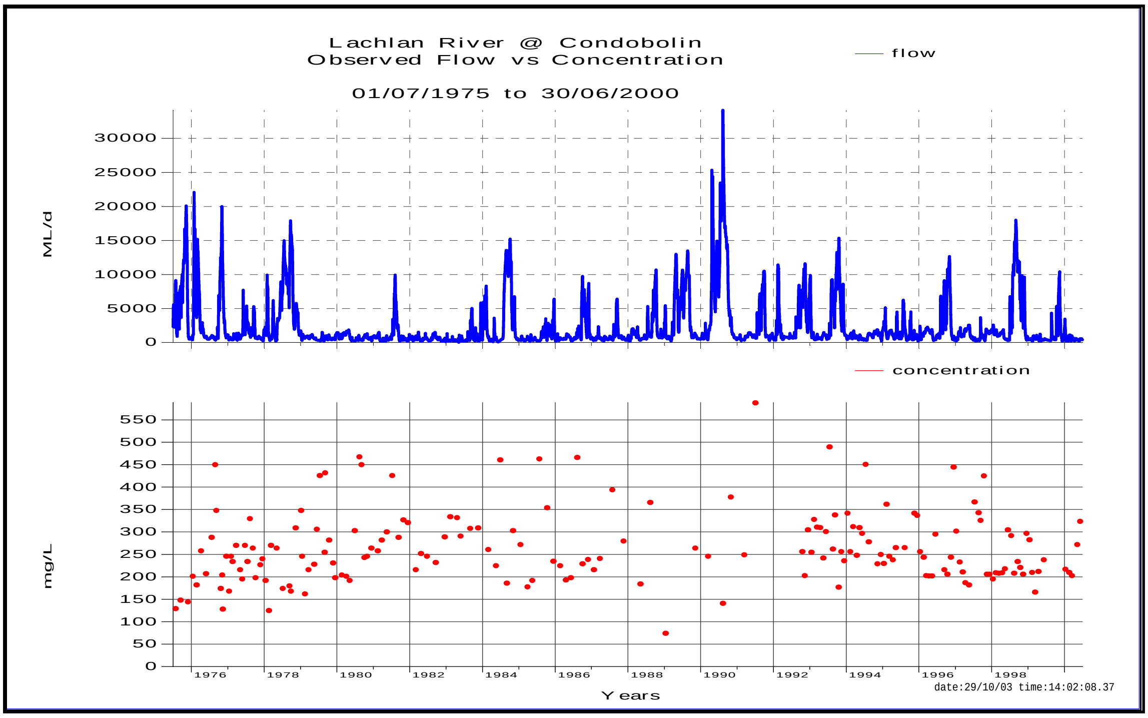


Figure 5.26. Station 412006: Lachlan River @ Condobolin, flow and concentration data

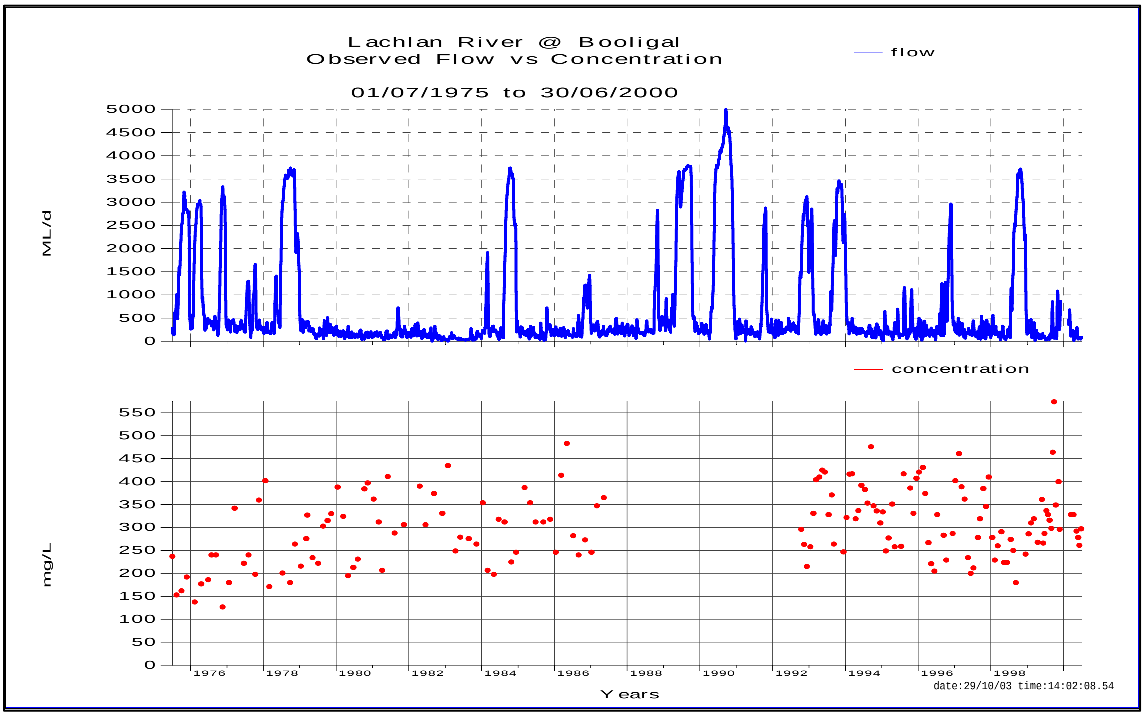


Figure 5.27. Station 412005: Lachlan River @ Booligal, flow and concentration data

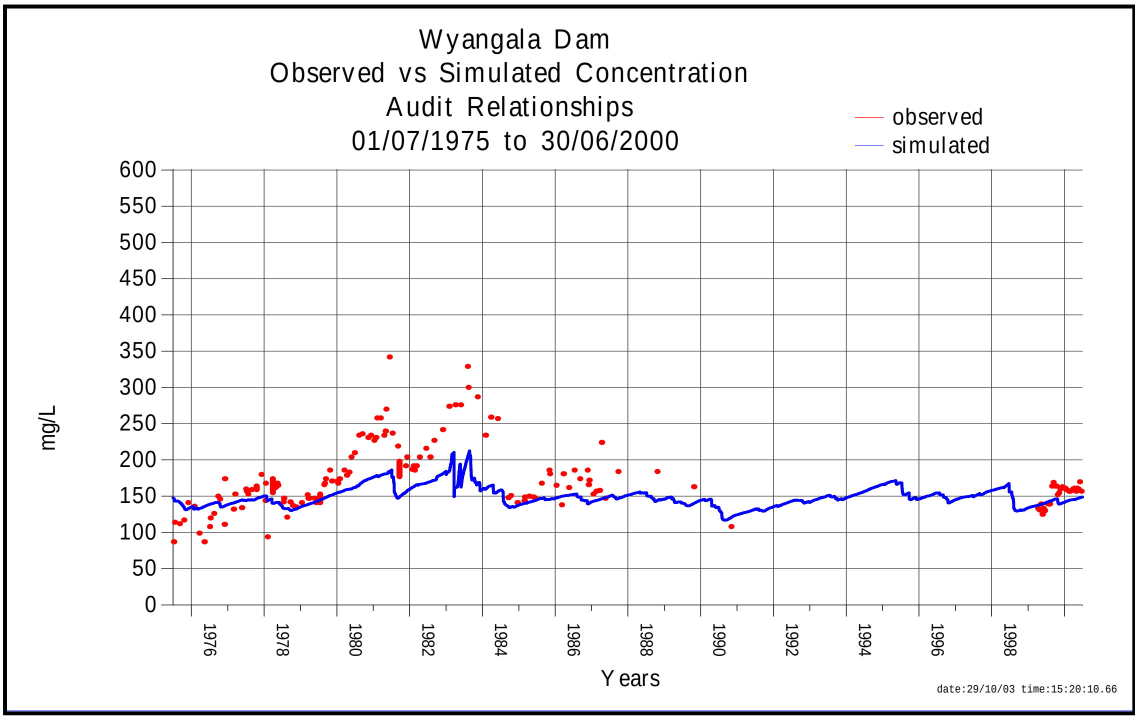


Figure 5.28. Simulated versus observed concentration at Wyangala Dam, using Salinity Audit relationships.

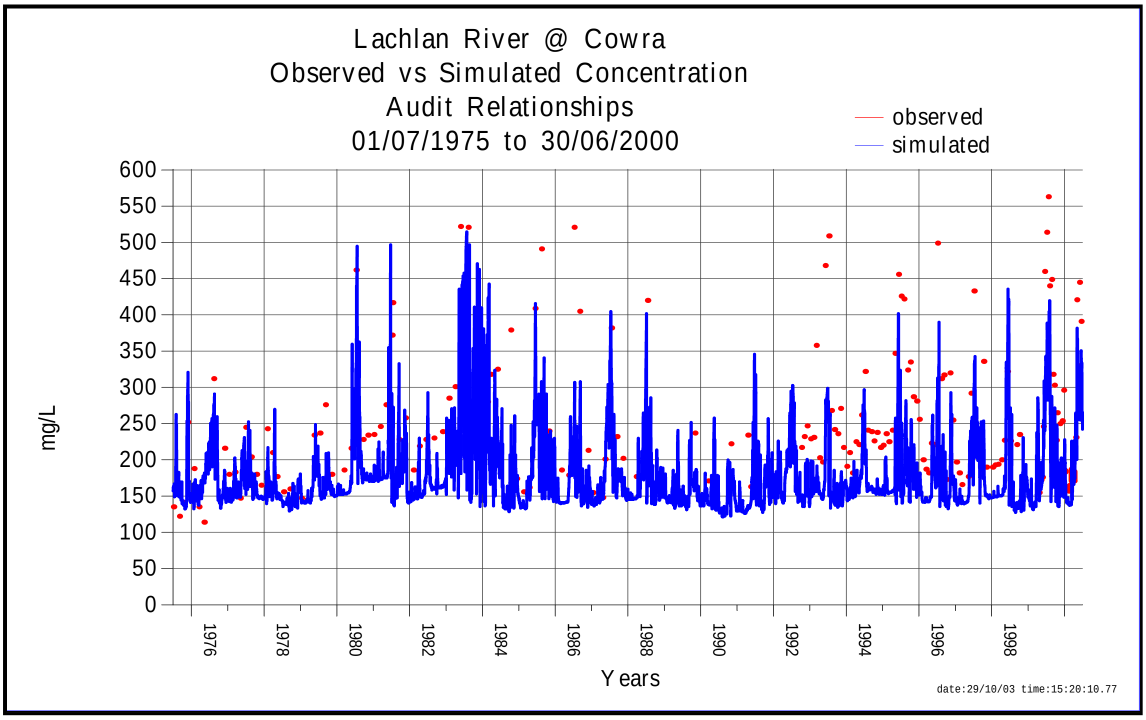


Figure 5.29. Simulated versus observed salinities at Station 412002: Lachlan River @ Cowra, using Salinity Audit relationships.

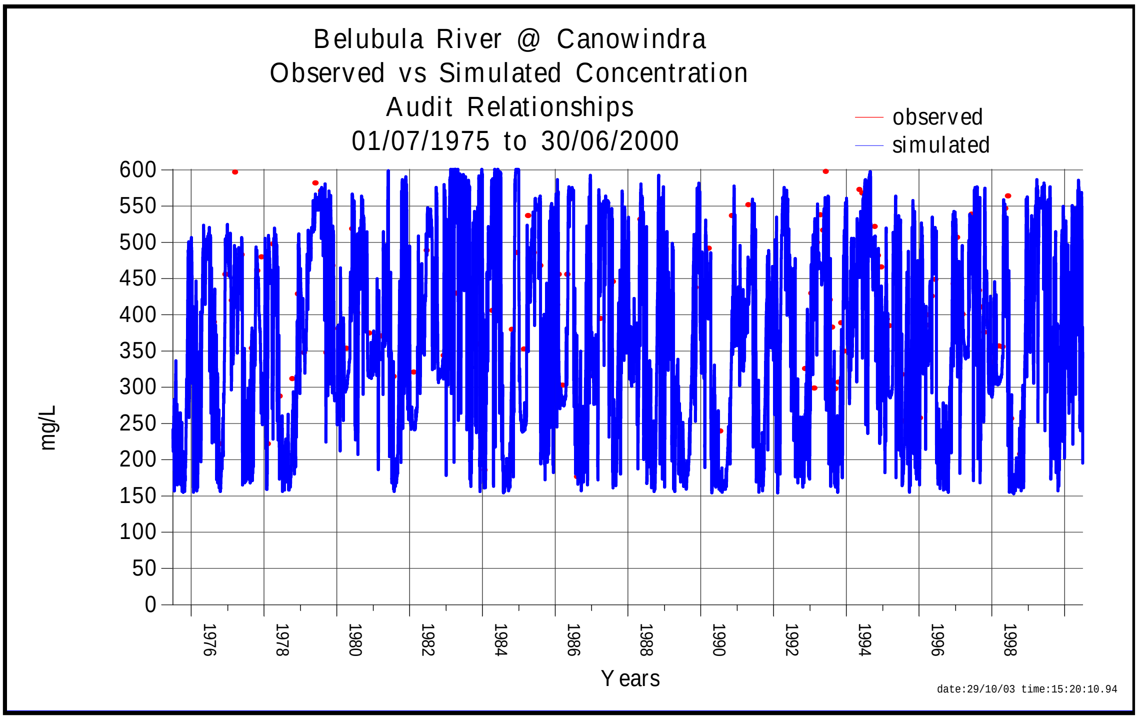


Figure 5.30. Simulated versus observed salinities at Station 412009: Belubula River @ Canowindra, using Salinity Audit relationships.

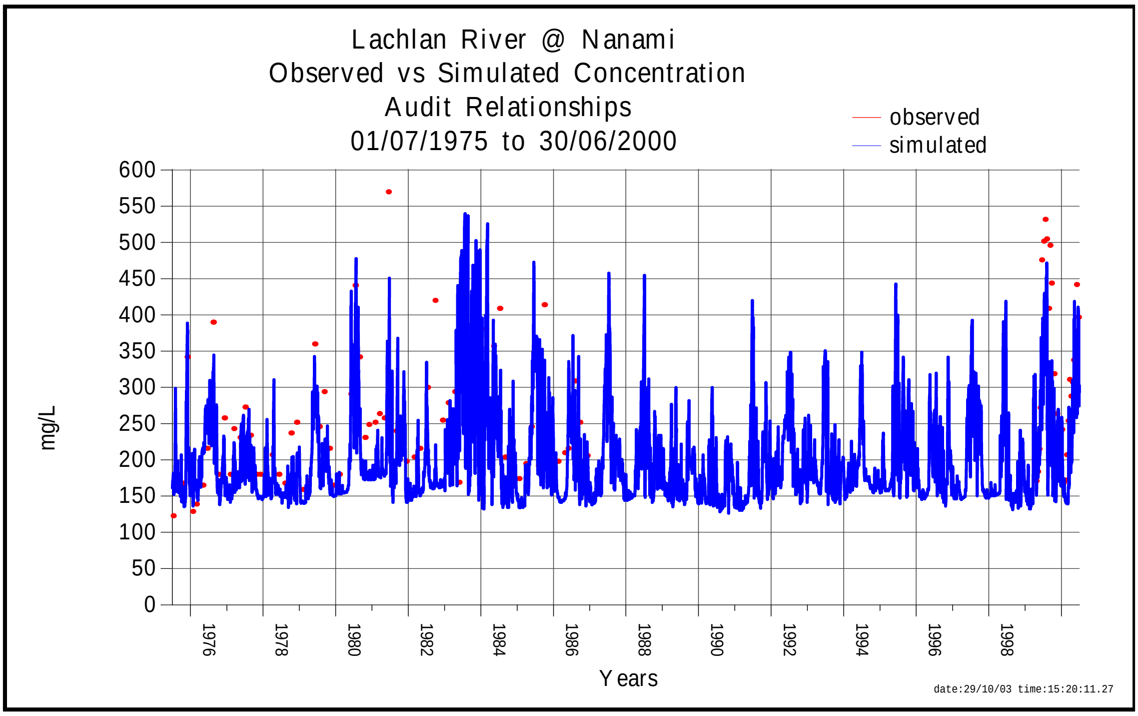


Figure 5.31. Simulated versus observed salinities at Station 412057: Lachlan River @ Nanami, using Salinity Audit relationships.

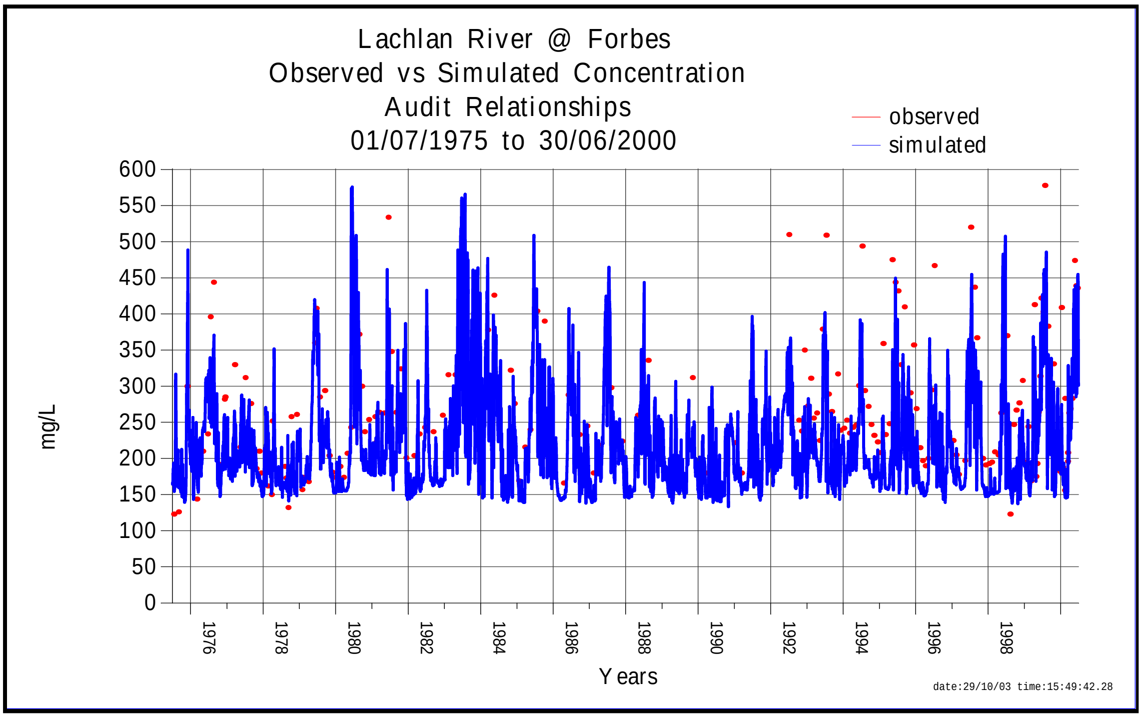


Figure 5.32. Simulated versus observed salinities at Station 412004: Lachlan River @ Forbes, using Salinity Audit relationships.

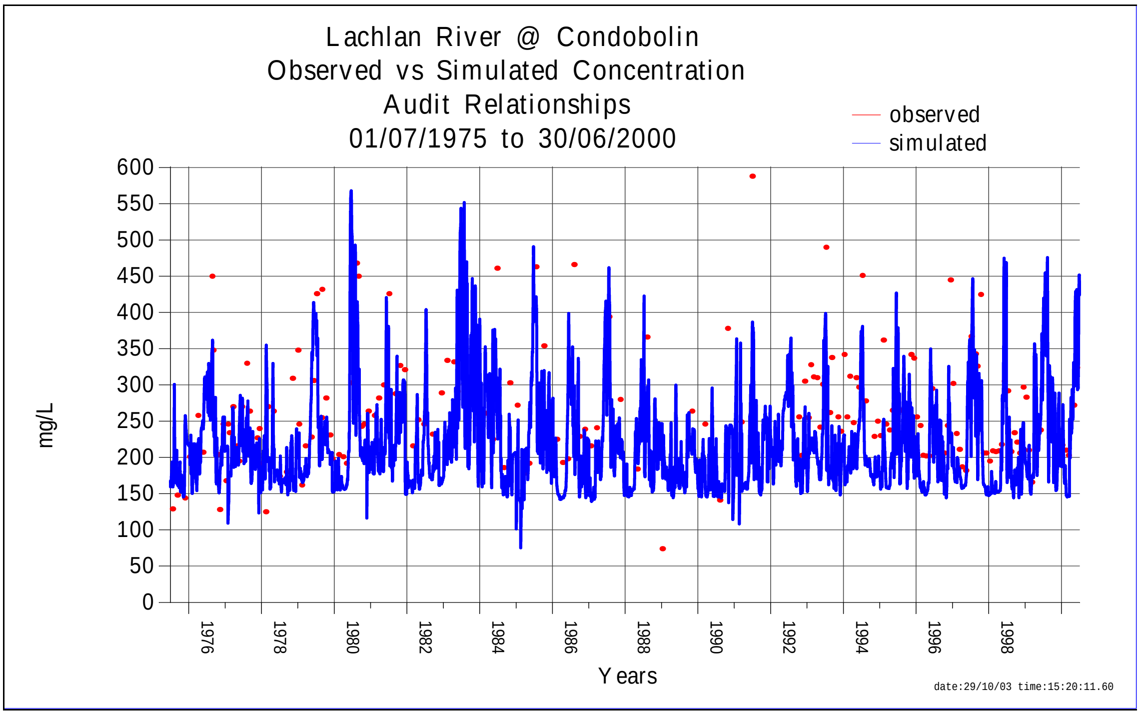


Figure 5.33. Simulated versus observed concentration at Station 412006: Lachlan River @ Condobolin, using Salinity Audit relationships.

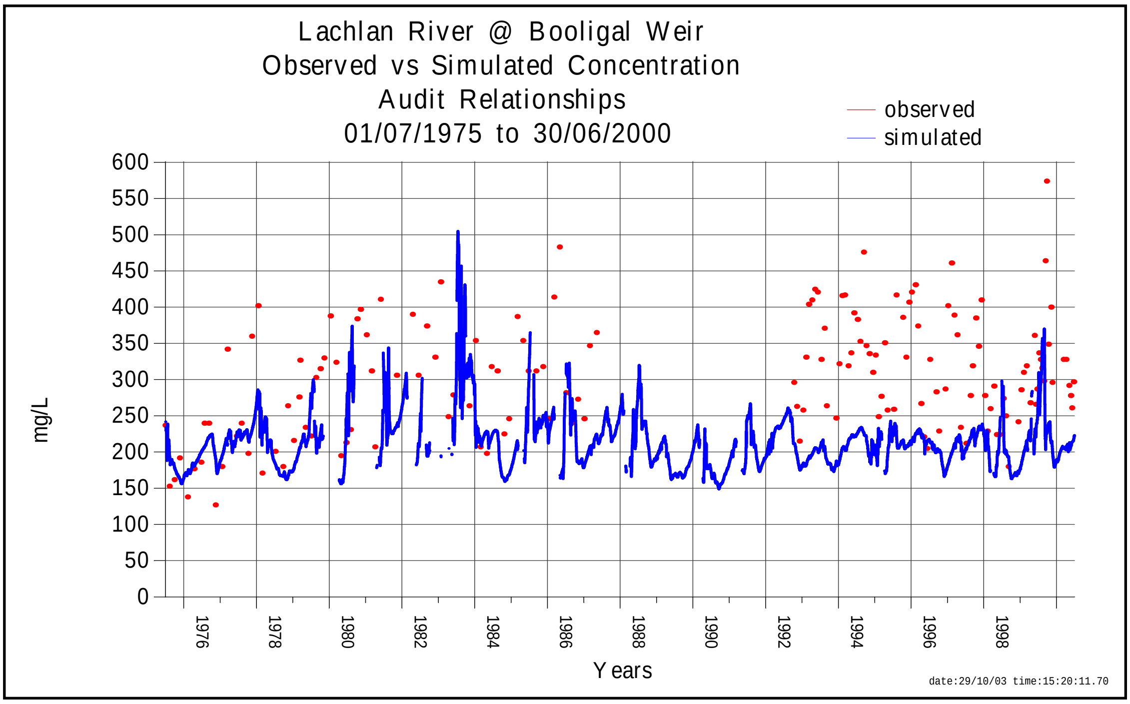


Figure 5.34. Simulated versus observed concentrations at Station 412005: Lachlan River @ Booligal, using Salinity Audit relationships.

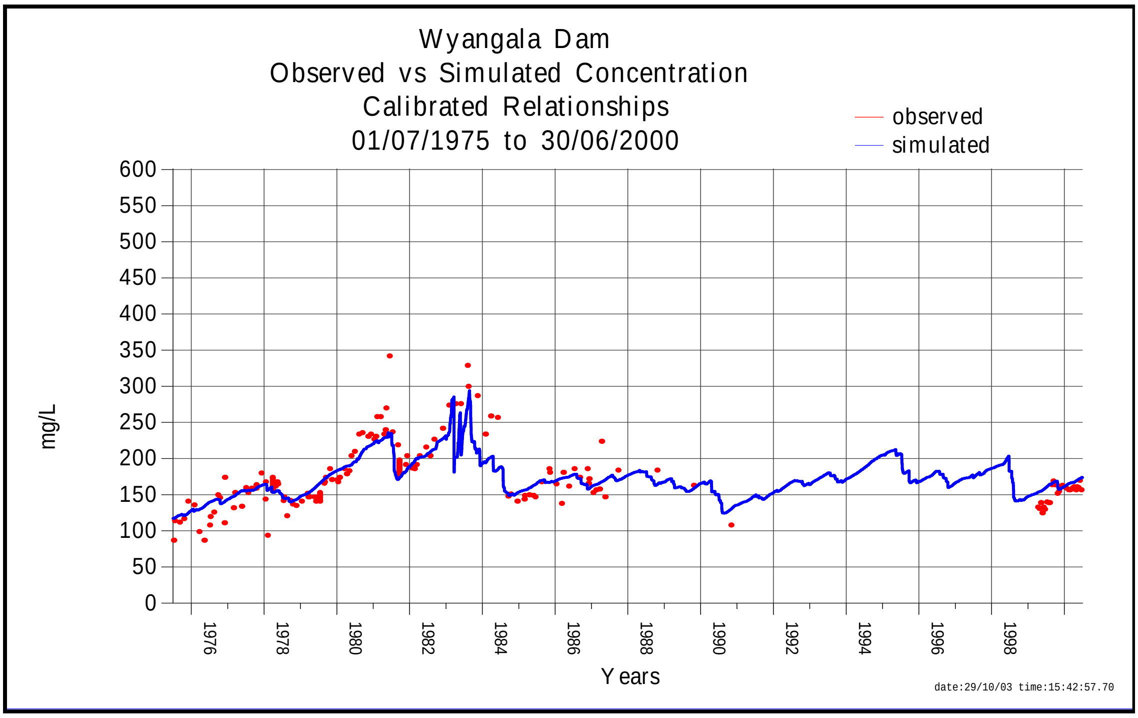


Figure 5.35. Simulated versus observed salinity at Wyangala Dam, using calibrated relationship.

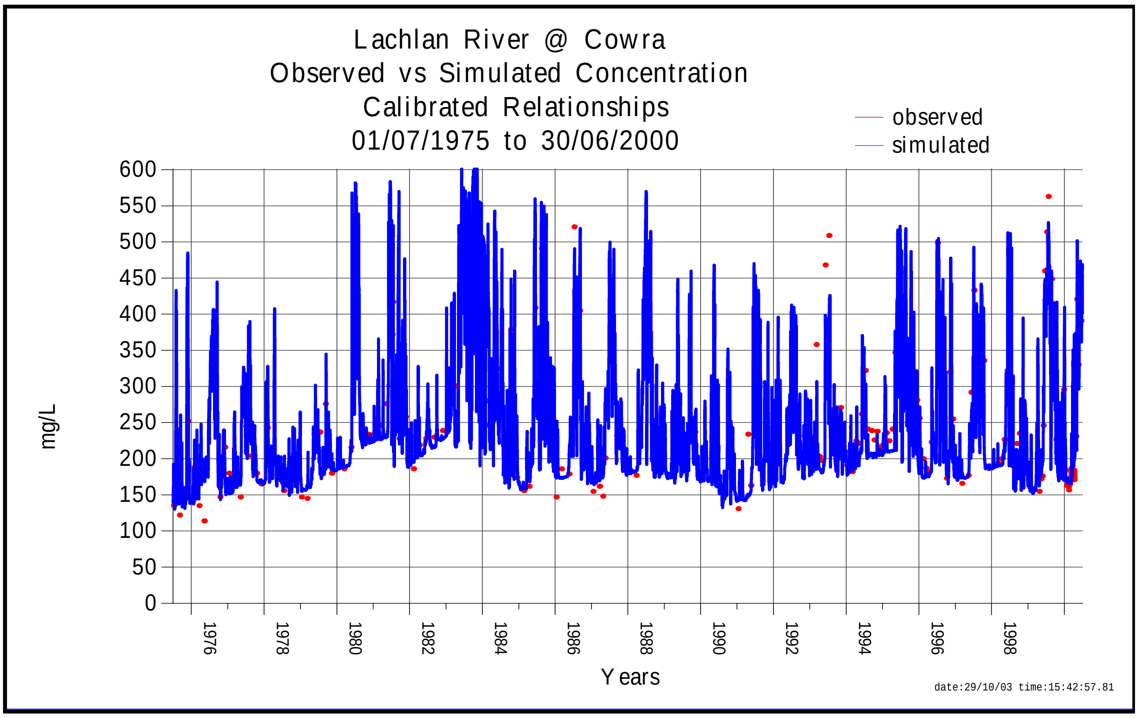


Figure 5.36. Simulated versus observed salinity for Station 412002: Lachlan River @ Cowra, using calibrated relationships.

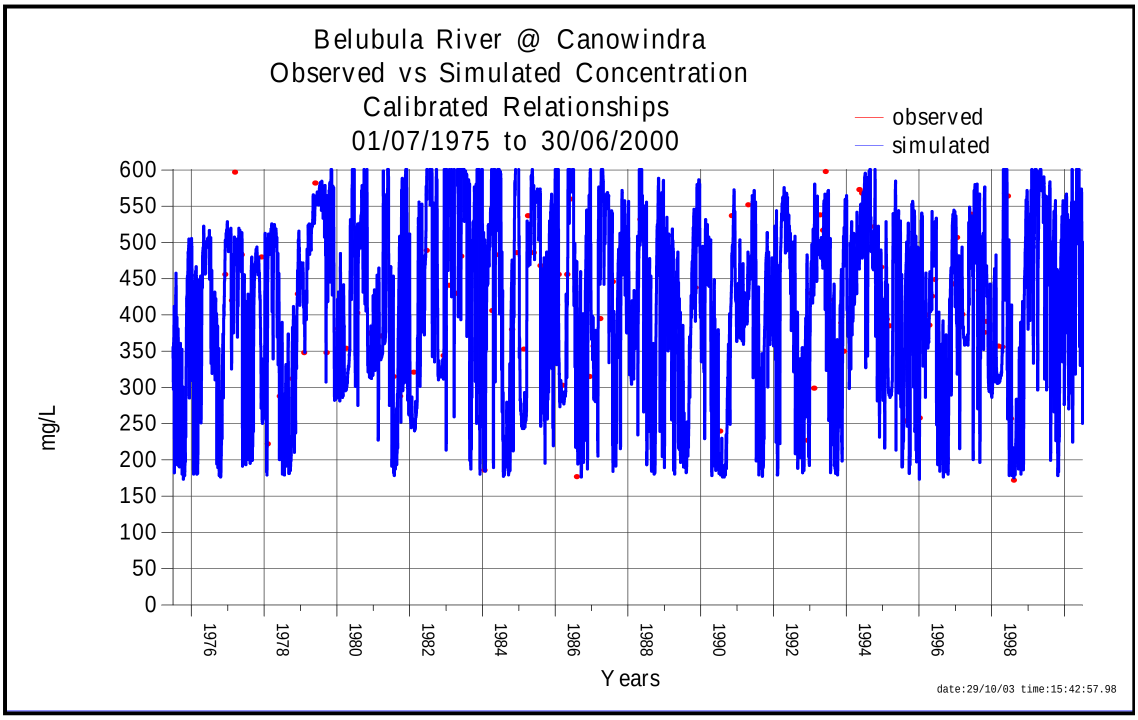


Figure 5.37. Simulated versus observed salinity for Station 412009: Belubula River @ Canowindra, using calibrated relationship.

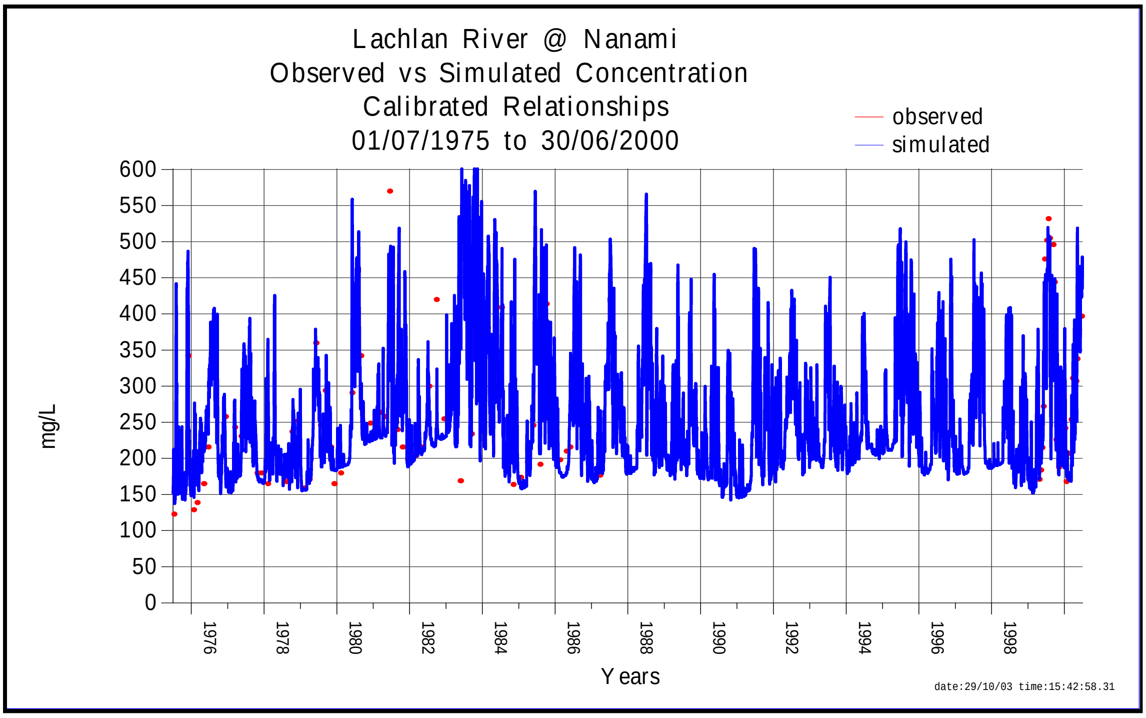


Figure 5.38. Simulated versus observed salinity for Station 412057: Lachlan River @ Nanami, using calibrated relationship.

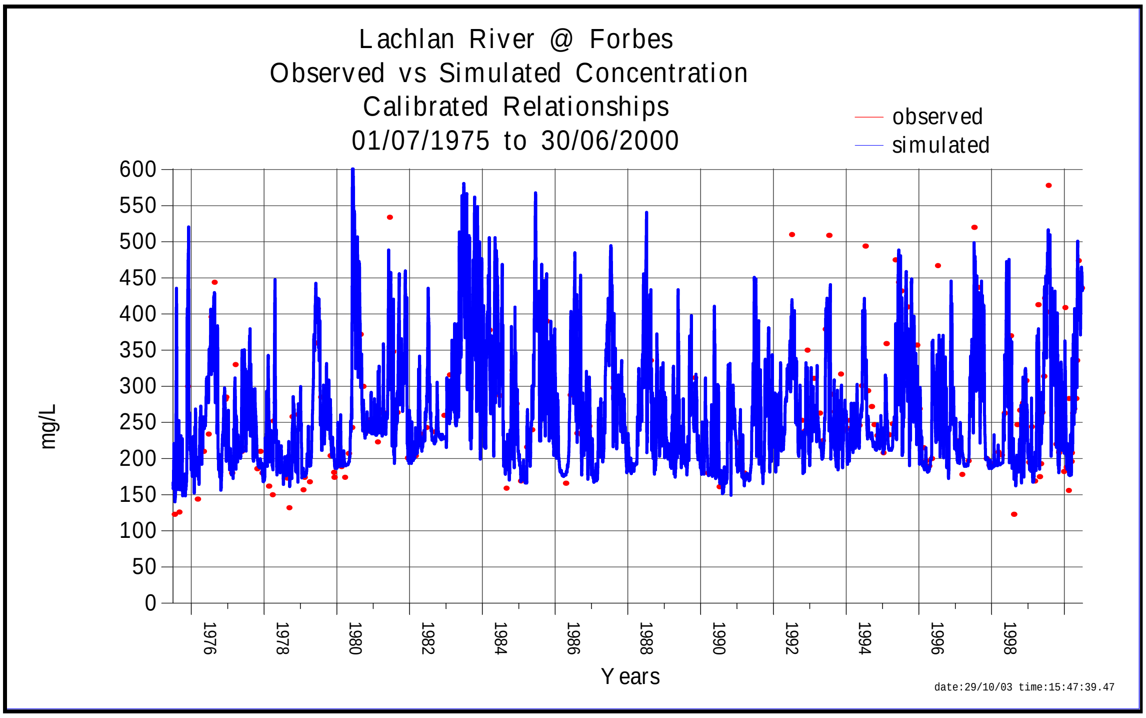


Figure 5.39. Observed versus simulated concentrations for Station 412004: Lachlan River @ Forbes using calibrated relationship.

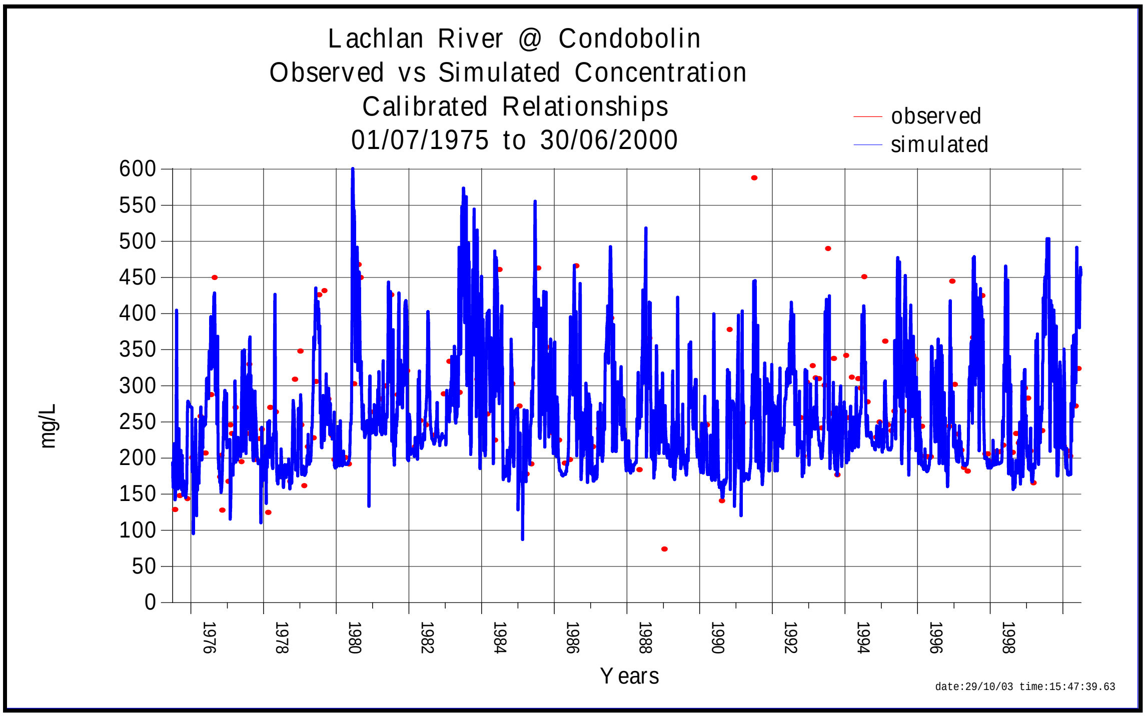


Figure 5.40. Observed versus simulated concentrations for Station 412006: Lachlan River @ Condobolin, using calibrated relationships

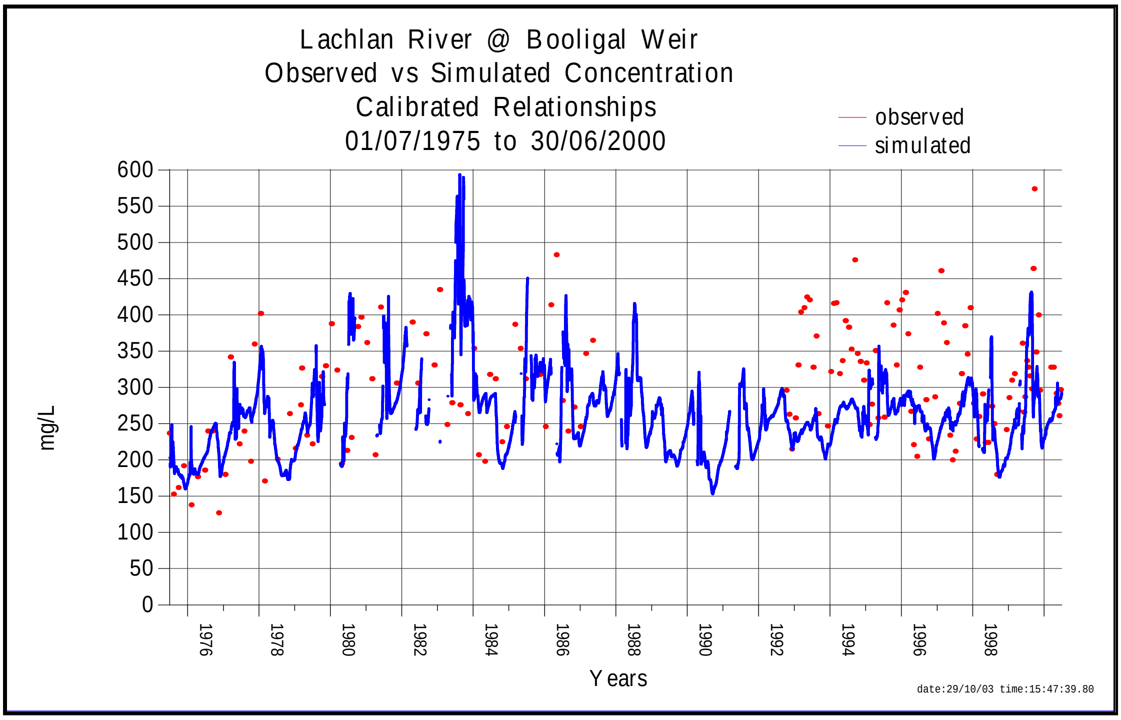


Figure 5.41. Observed versus simulated concentrations for Station 412005: Lachlan River @ Booligal Weir, using calibrated relationships.

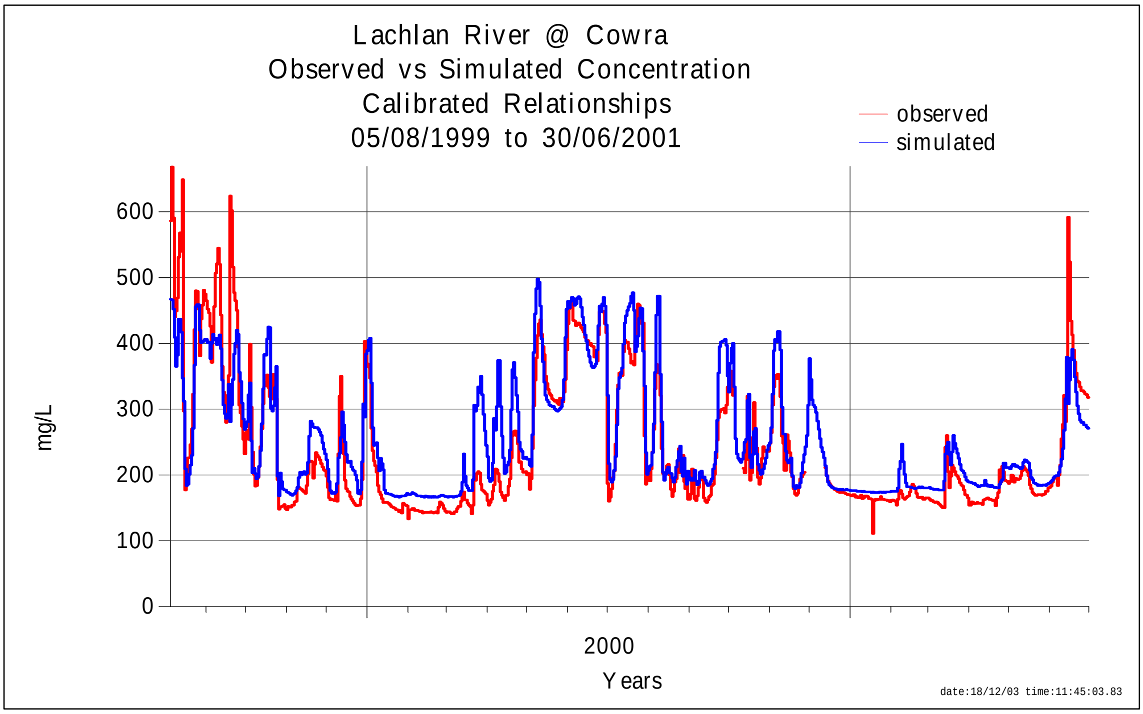


Figure 5.42. Continuous observed versus simulated salinities for Lachlan River @ Cowra using calibrated relationships.

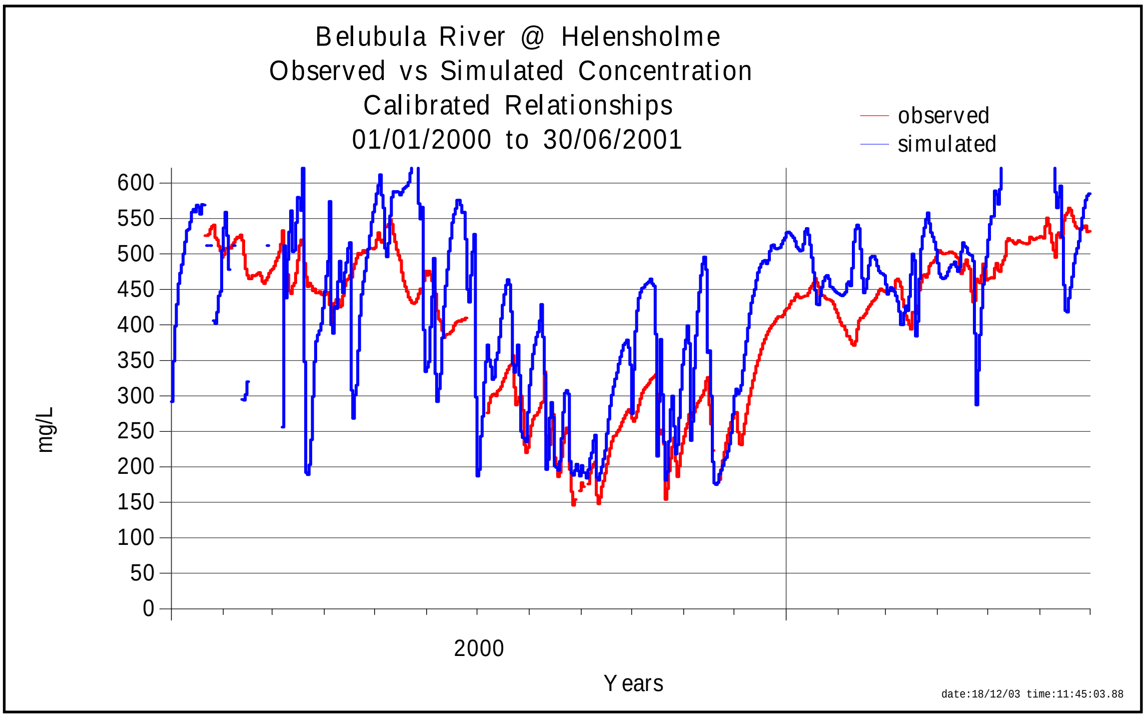


Figure 5.43. Continuous observed versus simulated salinities for Belabula River @ Helensholme using calibrated relationships.

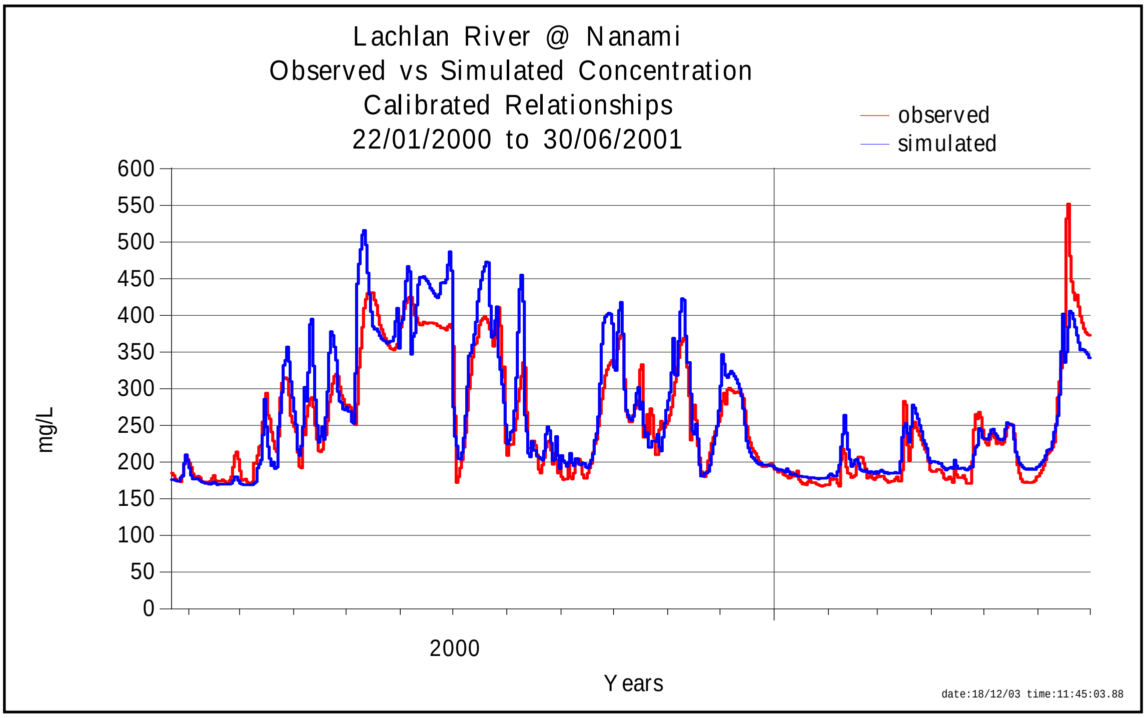


Figure 5.44. Continuous observed versus simulated salinities for Lachlan River @ Nanami using calibrated relationships.

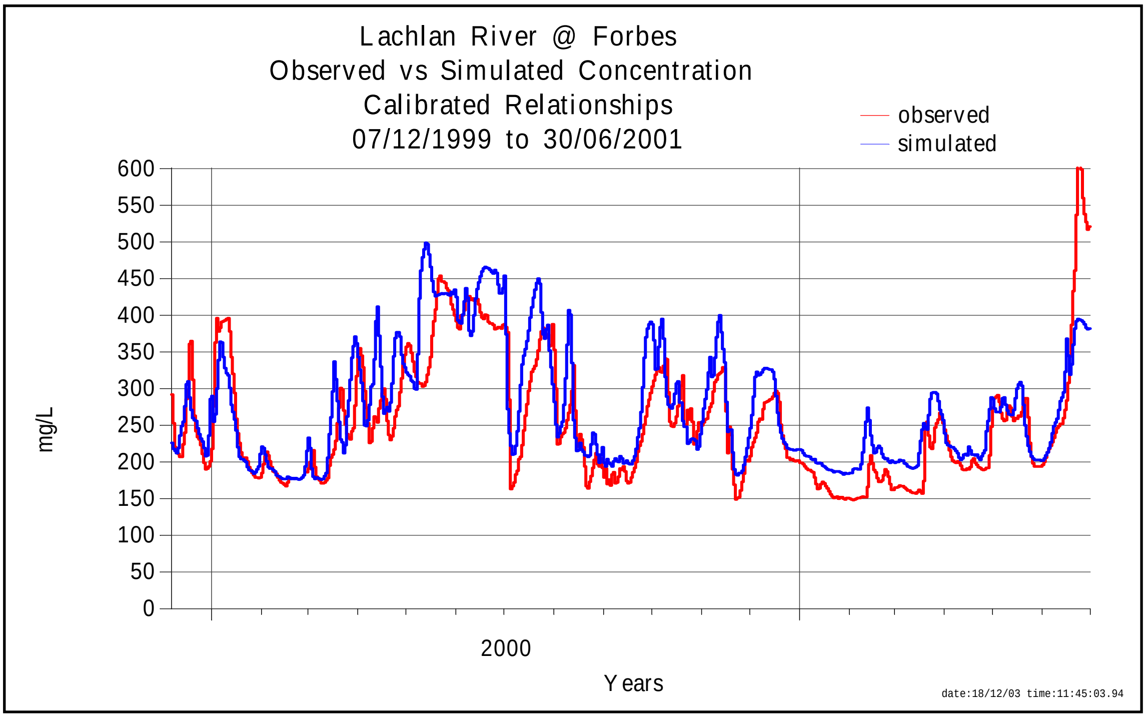


Figure 5.45. Continuous observed versus simulated salinities for Lachlan River @ Forbes using calibrated relationships.

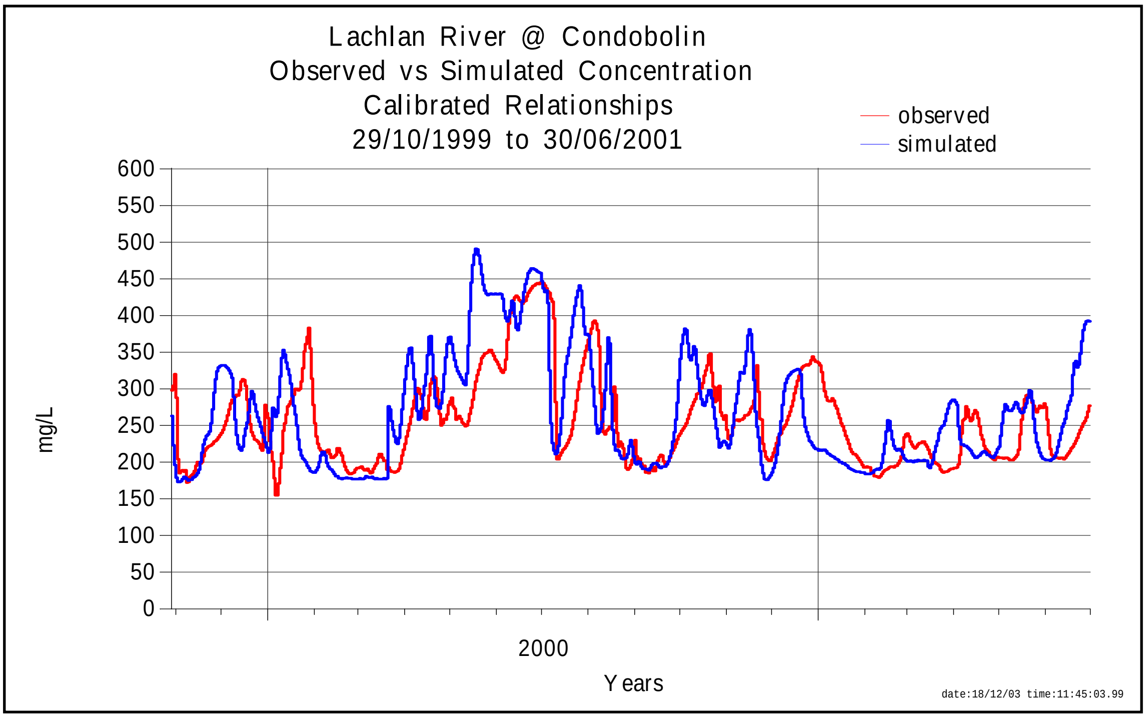


Figure 5.46. Continuous observed versus simulated salinities for Lachlan River @ Condobolin using calibrated relationships.

6. Baseline Conditions Model Results

6.1. BASELINE CONDITIONS

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

(i) land use;

(ii) water use;

(iii) land and water management policies and practices;

(iv) river operating regimes;

(v) salt interception schemes;

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

(vii) groundwater status and condition.

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

Defining the points affecting inputs to the flows and salt inputs to the IQQM is problematic, with difficulties arising from sparse data to describe the important biophysical characteristics, as well as how to reliably estimate the quantitative response of 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, e.g.; 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 Lachlan 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)*		
Upstream Wyangala Dam	795	GL/year
Belabula River	230	GL/year
Wyangala to Condobolin	530	GL/year
Downstream of Condobolin	28	GL/year
Storages		
Carcoar		
Active storage	36	GL
Storage reserve	0	GL
Transmission and operation losses	0	GL
Wyangala		
Active storage	1217	GL
Storage reserve	0	GL
Transmission and operation losses	0	GL
Lake Cargelligo		
Active storage	23	GL
Lake Brewster		
Active storage	133	GL
Irrigation		
General security licences	640	GL/year
High security licences	24	GL/year
Maximum allocation	100	%
Maximum irrigable area	80,782	Ha
Pump capacity	19	GL/day
Crop types (See Table)		-
Surplus flow entitlement	N/A	GL/year
Town water supply		
Cowra	4.2	GL/year
Forbes	4.1	GL/year
Condobolin	1.2	GL/year
Willandra + Hillston + Booligal	0.5	GL/year
Other high security users	10.0	GL/year
In-stream water supply *(refer* Table 4.3 *for details)*		
Downstream Wyangala Dam	25.6	GL/year
Belabula @ Bangaroo Bridge	3.6	GL/year
Booberoi Weir	18.3	GL/year
Lake Cargelligo	5.5	GL/year
Lake Brewster	7.3	GL/year
Corrong Gauge	48.4	GL/year
Booligal	36.5	GL/year
Willandra Creek	9.0	GL/year
Merrowie Creek	9.0	GL/year
Merrimijeel Creek	9.0	GL/year
Downstream Wyangala Dam ECA	20.0	GL/year
Wyangala Dam ECA	5.0	GL/year
Lake Brewster ECA	5.0	GL/year

Table 6.2. Croptypes, 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
Lucerne	19	0.85	0.85	0.80	0.70	0.60	0.50	0.45	0.50	0.50	0.70	0.80	0.80	0.90
Winter pasture	16	0.85	0.00	0.00	0.00	0.50	0.60	0.70	0.80	0.85	0.85	0.90	0.70	0.00
Wheat	19	0.75	0.00	0.00	0.00	0.00	0.30	0.50	0.80	1.00	0.80	0.40	0.10	0.00
Cotton	16	0.73	0.75	0.95	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.50
Summer cereal	11	0.85	0.80	1.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.60
Sum. pasture	4	0.85	0.60	0.80	0.60	0.50	0.00	0.00	0.00	0.00	0.00	0.30	0.40	0.50
Winter cereal	5	0.75	0.00	0.00	0.00	0.40	0.50	0.80	1.00	1.00	0.80	0.50	0.00	0.00
Oil seed	6	0.85	0.60	0.60	1.10	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.40
Vegetables	2	0.85	0.90	0.90	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.80	0.80
Forage	1	0.85	1.00	0.90	0.80	0.80	0.60	0.50	0.00	0.00	0.00	0.40	0.50	1.00
Other crops	1	0.85	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70	0.80	0.80	0.80

6.2. RESULTS

The model was run for the Benchmark Climate period with the calibrated salinity inflows, and the water usage and policies that existed as at 1 January 2000. The results for the mean, and percentile non-exceedances for daily concentration and daily salt load at 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 concentrations increasing steadily along the Lachlan River. Salt loads also increase along the Lachlan River until Forbes, after which it decreases downstream to Booligal as water and salt is removed from the river system by irrigation diversions (Figure 4.8).

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 (kg/ML)				Salt Load (T/day)				No Flow Days
Number	Name	*Mean*	*Percentile non exceedance*			*Mean*	*Percentile non exceedance*			*(%)*
			20	*50*	*80*		*20*	*50*	*80*	
412067	Lachlan River @ Wyangala	170	150	170	190	340	14	140	560	0
412002	Lachlan River @ Cowra	270	180	220	370	490	100	250	760	0
412009	Belubula River @ Canowindra	420	320	440	530	140	29	55	170	0
412057	Lachlan River @ Nanami	280	190	240	380	660	150	340	870	0
412004	Lachlan River @ Forbes	290	200	260	400	670	180	370	860	0
412006	Lachlan River @ Condobolin	280	190	250	370	460	53	200	660	0
412005	Lachlan River @ Booligal	270	210	260	310	130	25	43	180	7

- In Bewsher (2004) it has been recommended that the Lachlan 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 (x 1000 T/year)			
Number	Name	*Mean*	*Percentile non exceedance*		
			20	*50*	*80*
412067	Lachlan River @ Wyangala	123	57	124	173
412002	Lachlan River @ Cowra	178	120	170	234
412009	Belubula River @ Canowindra	51	22	47	71
412057	Lachlan River @ Nanami	240	167	203	322
412004	Lachlan River @ Forbes	245	170	218	340
412006	Lachlan River @ Condobolin	170	107	152	251
412005	Lachlan River @ Booligal	46	19	45	79

- In Bewsher (2004) it has been recommended that the Lachlan 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 Lachlan River @ Forbes

Parameter	Units	Mean	Percent non-exceedance		
			20	50	80
Flow	(ML/d)	3378	3307	1573	866
Salinity	(mg/L)	271	190	250	340
Salt load	(Tonnes/d)	714	244	385	670

Figure 6.1 to Figure 6.10 compare the baseline conditions with observed data for Lachlan River at Forbes.

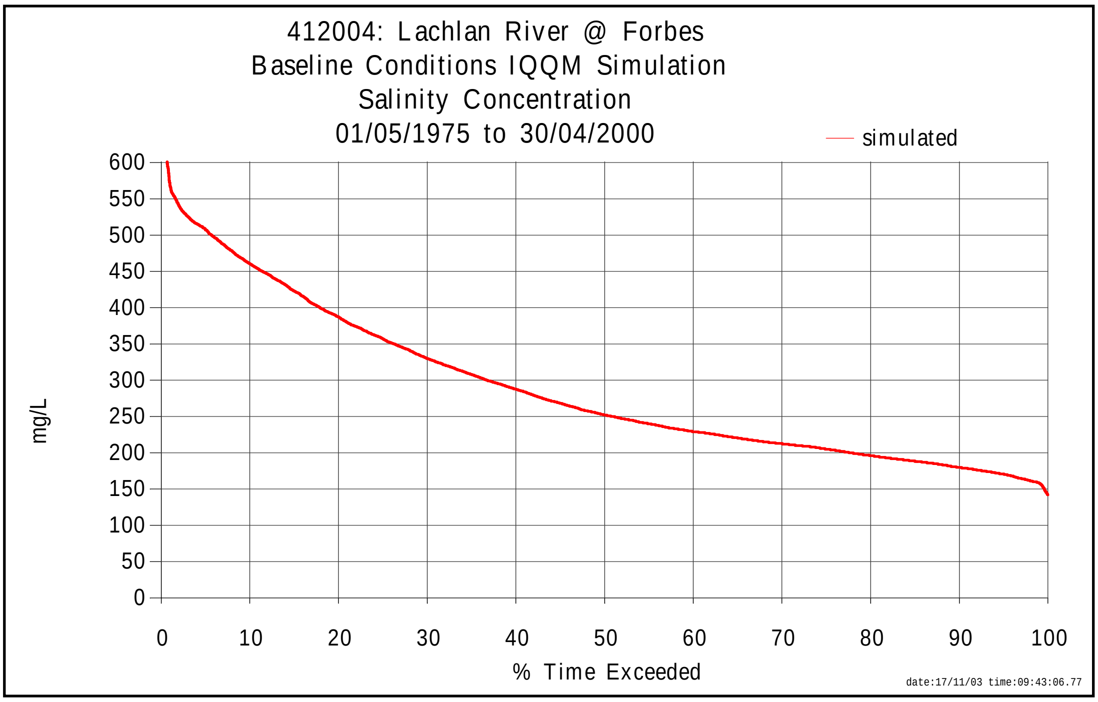


Figure 6.1. Frequency of exceedance of simulated salinity for Baseline Conditions scenario (1/5/1975-30/4/2000) for Lachlan River @ Forbes.

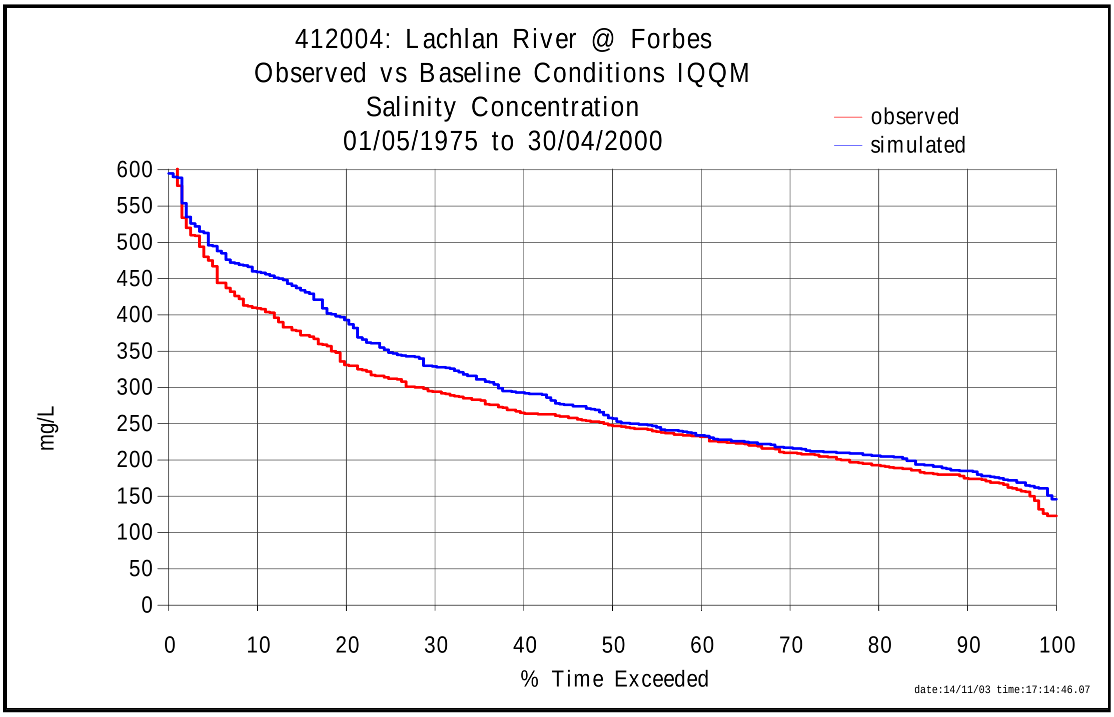


Figure 6.2. Frequency of exceedance of simulated salinity for Baseline Conditions scenario on days with salinity observations (1/5/1975-30/4/2000), compared with salinity observations for Lachlan River @ Forbes.

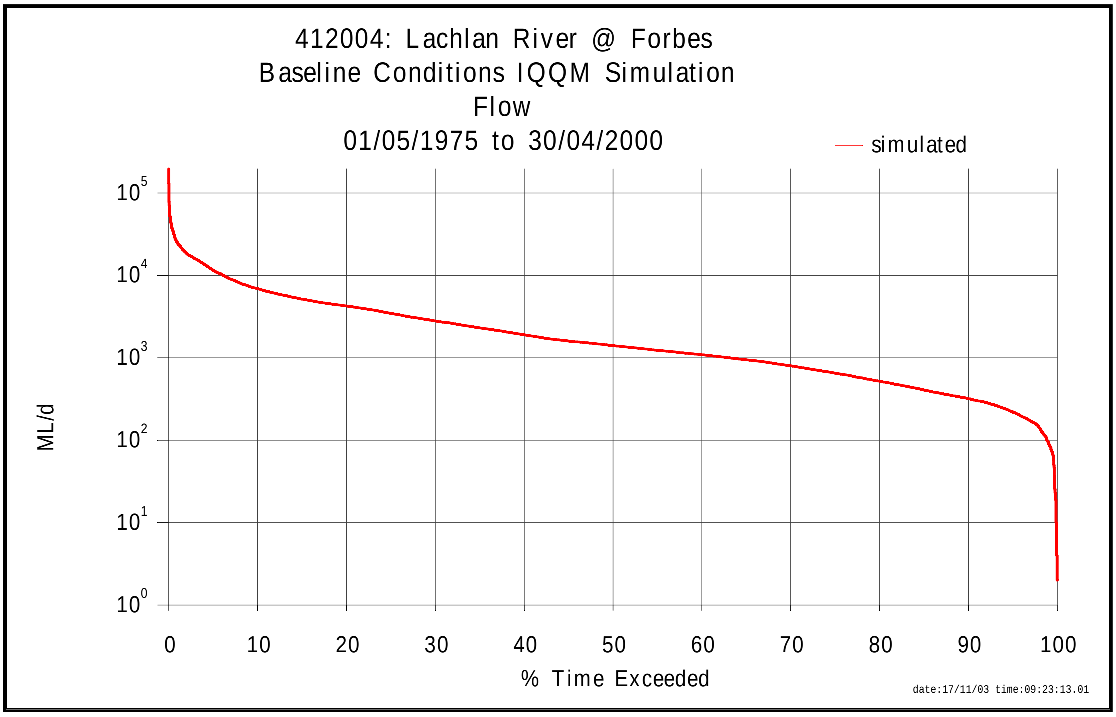


Figure 6.3. Frequency of exceedance of simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Lachlan River @ Forbes

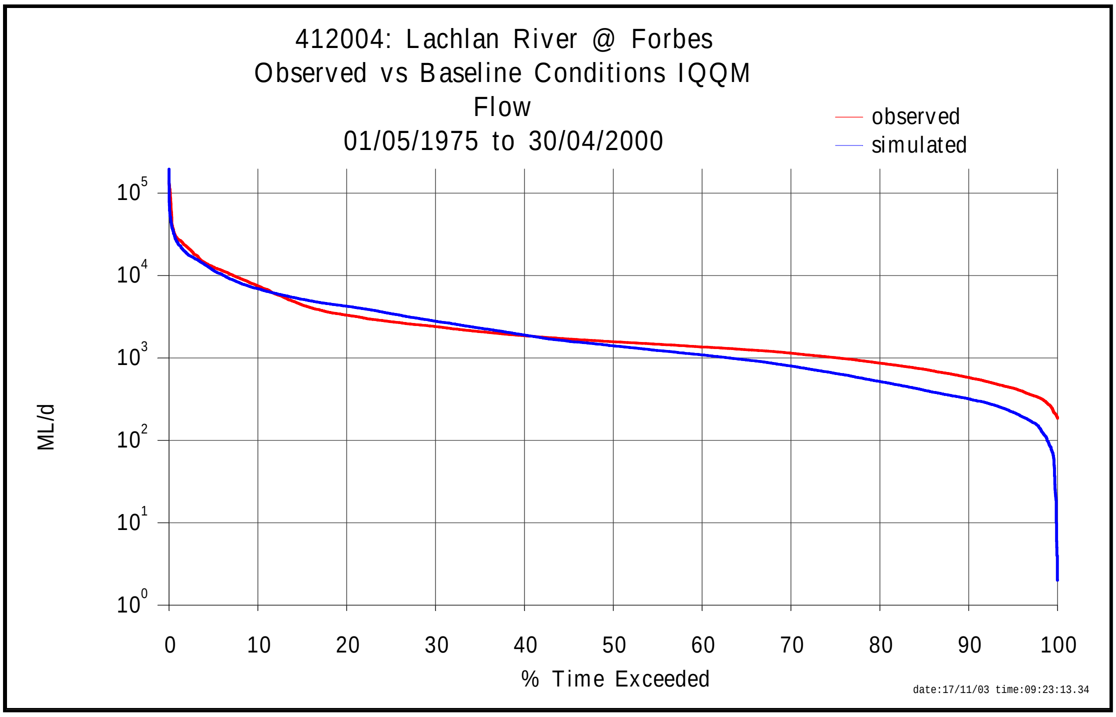


Figure 6.4. Frequency of exceedance of simulated flow for Baseline Conditions scenario on days with flow observations (1/5/1975-30/4/2000), compared with observed flow for Lachlan River @ Forbes.

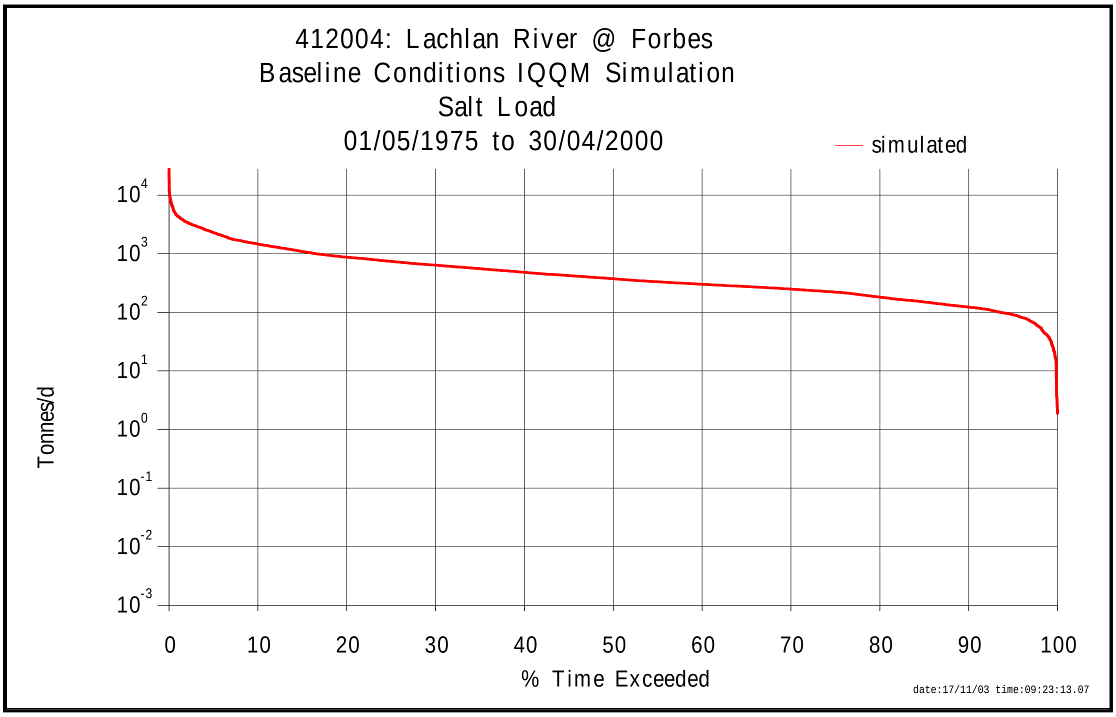


Figure 6.5. Frequency of exceedance of simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Lachlan River @ Forbes.

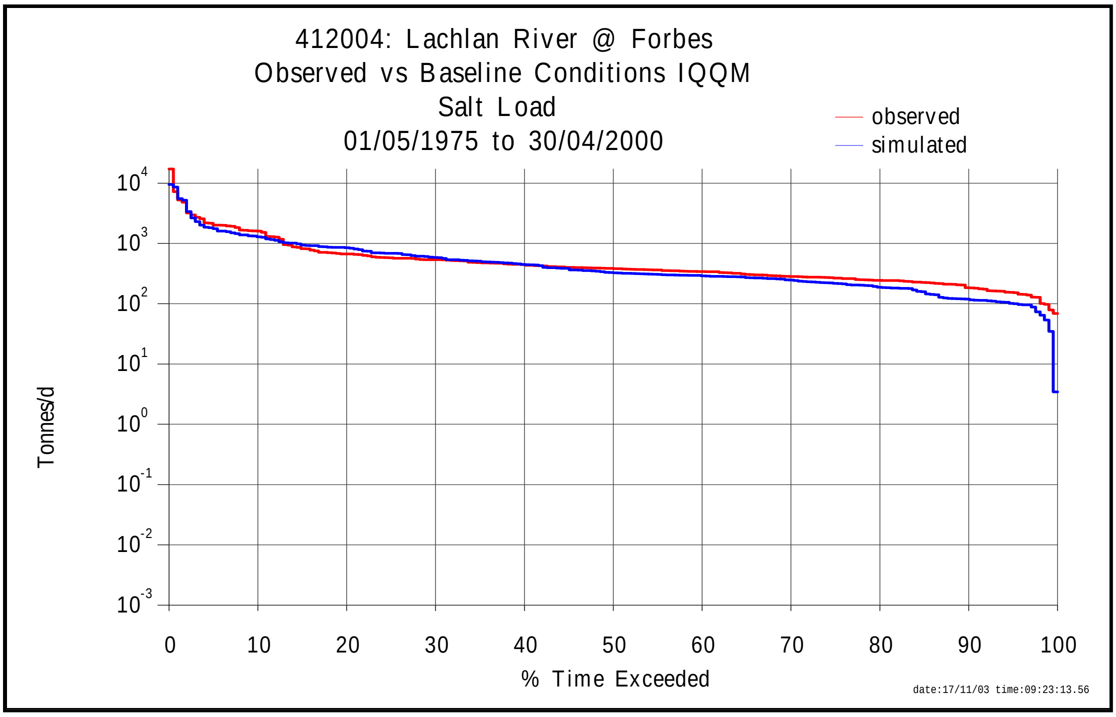


Figure 6.6. Frequency of exceedance of simulated salt load for Baseline Conditions scenario on days with salinity and flow observations (1/5/1975-30/4/2000), compared with salinity observations for Lachlan River @ Forbes.

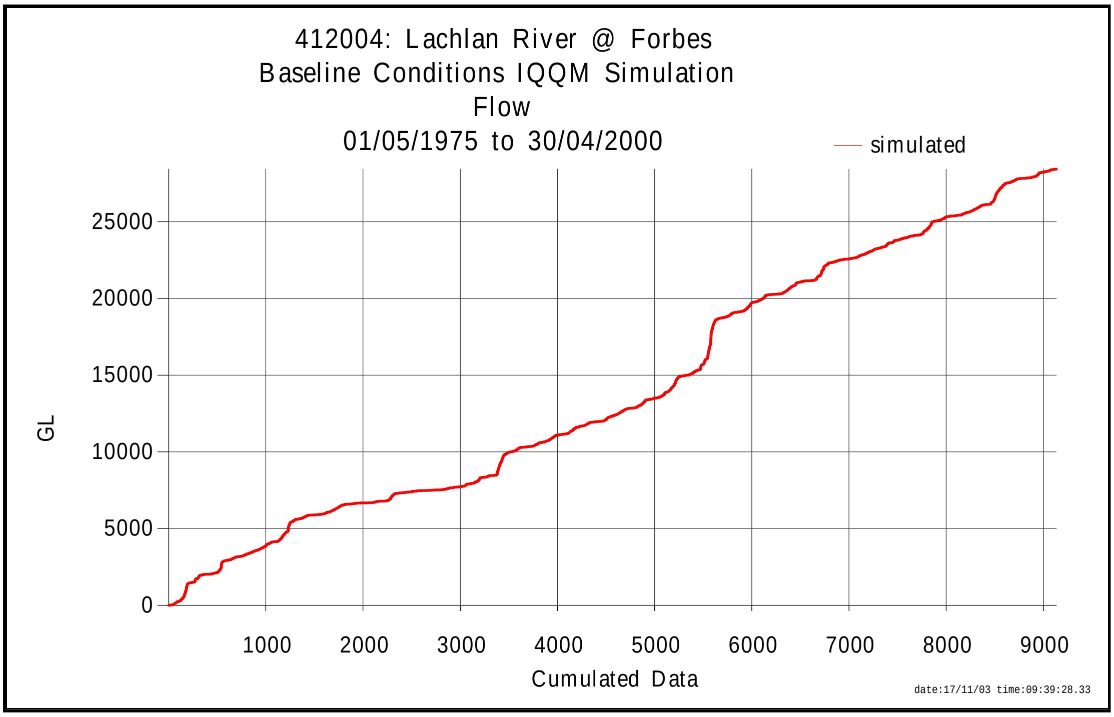


Figure 6.7. Cumulative simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Lachlan River @ Forbes.

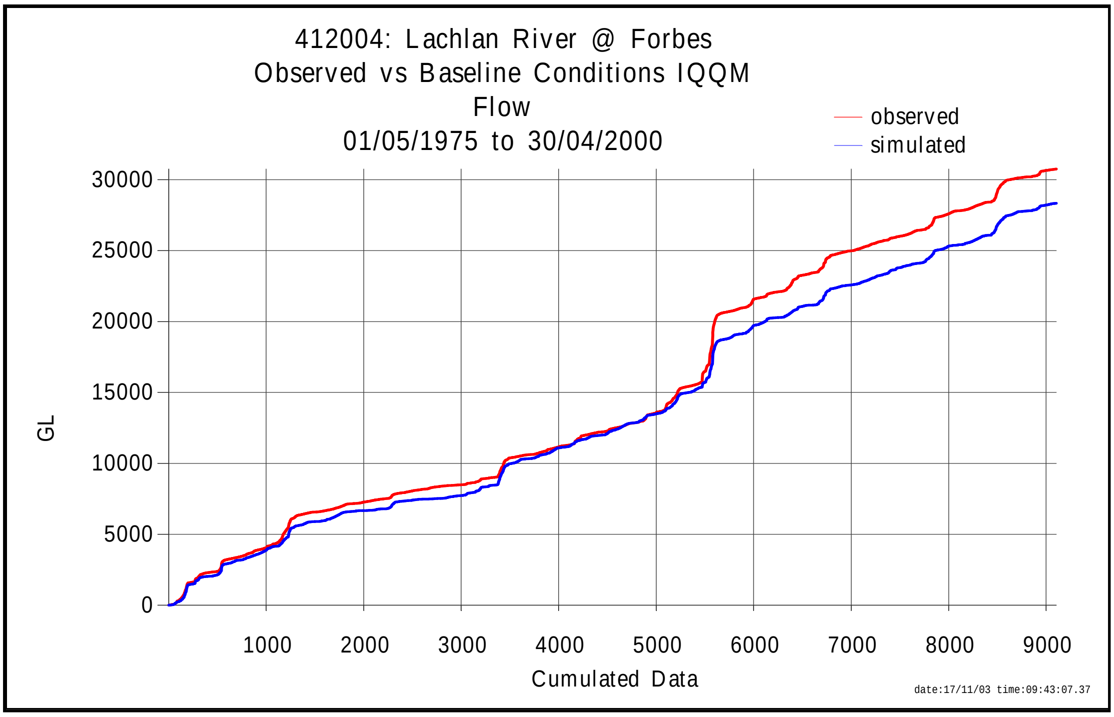


Figure 6.8. Cumulative simulated flow for Baseline Conditions scenario for days with observed flow, and observed flow (1/5/1975-30/4/2000) for Lachlan River @ Forbes.

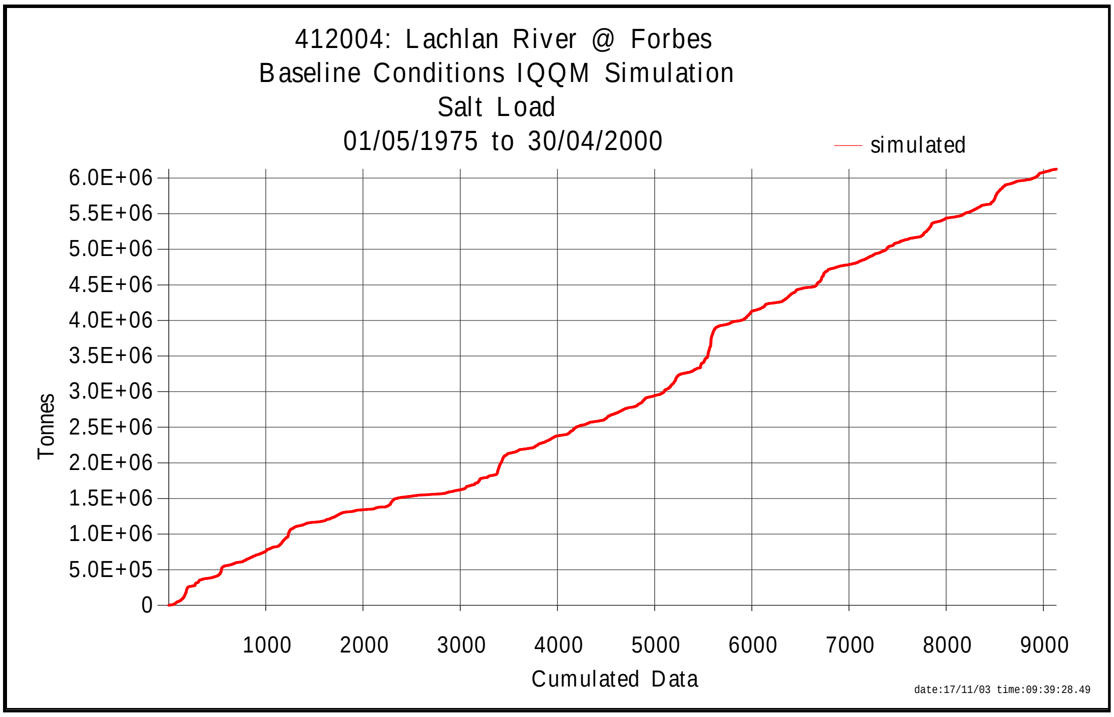


Figure 6.9. Cumulative simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Lachlan River @ Forbes.

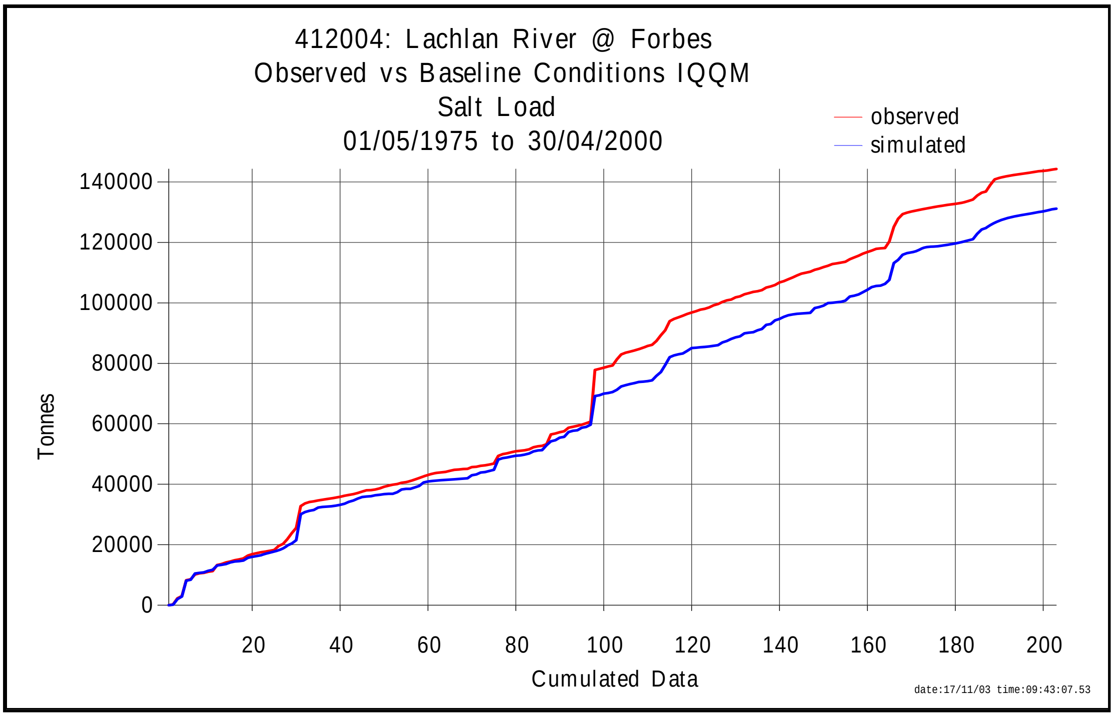


Figure 6.10. Cumulative simulated salt load for Baseline Conditions scenario for days with observed salt load, and observed salt load (1/5/1975-30/4/2000) for Lachlan River @ Forbes.

7. Recommendations

7.1. CONCLUSION

The Lachlan 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 Nanami and Forbes signify that these Baseline Conditions results are quite reliable. The uncertainty in model results starts to increase at Condobolin and Booligal, largely because of timing issues.

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

The Lachlan 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 flows versus concentration relationships do not reproduce the variability in the salt load generation. Catchment process based modelling with continuous data would improve salt export relationships..

- The methods to achieve water balance of inflows to Wyangala Dam must be reviewed to better estimate the frequency of low flows. This will enable the model to better estimate the effects of land use change in the Upstream Wyangala Region.

7.3. RECOMMENDED FUTURE DATA COLLECTION

Catchment process based modelling like CATSALT has the capability to predict the effect of antecedent soil moisture conditions, rise in groundwater level and the impacts of land use changes on salt exports from the tributary catchments in the Lachlan River. However, for salt inflows from ungauged catchments and from groundwater interaction within the river, more data will be required to identify the source of salt and to understand the processes affecting salinity in the main streams of the catchment. The following reccomdation are made for future data collection.

- Sufficient continuous EC data at all gauging stations will improve estimate of salt balance in river reaches at all flow regimes, wet and dry periods, and summer and winter seasons. This will identify specific areas where there is a huge inflow of salt loads. Continuous EC data at Wyangala Dam (412067) will improve the salt inflow estimate from residual catchment and groundwater contribution from Wyangala Dam to Cowra. Continuous EC data at Belubula River at Carcoar Dam (412077) and at Canowindra (412009) will improve the salt inflow estimate from the Belubula River.

- Loss functions in IQQM must be revised to improve flow calibration at low flow events when high salinity is significant. These can be achieved by modeling the river-aquifer interaction to estimate the amount of water getting into/out of the river. To model this process, river cross-sections, surface water level, groundwater level near the river, aquifer storage and riverbed leakage properties must be available. Reaches ranked with high vulnerability in groundwater resources are listed in Section 2.3.

- Evaporation loss at the river may be significant during summer season. This may increase the salinity in areas with large flood plain areas. In this case, a table of flow and flood plain areas can be modelled in IQQM. Abrupt changes in the reach storage volume may result to a sudden increase in simulated salinity.

- Observed daily water diversions are necessary to calibrate low flows in the river. This is necessary to separate the transmission loss and irrigation diversion components when analysing water balance between gauging stations.

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

- Knowledge of the distribution of water in effluents and EC readings for each effluent will identify possible sources of salinity in the next downstream gauge. Continuous EC readings at Goobang Ck (412014), Island Ck(412023), Wallamundry Ck(412016) will assist in predicting the impacts of effluent regulation on the salinity at the Lachlan River at Condobolin (412006).

- Continuous EC data at storage inflow and at outflows will assist in modelling salinity behaviour in storages. For long storages like Brewster Lake, flow and salinity routing within the storage may be necessary. In this case, reach lengths and widths are necessay to model salt movements.

- Weirs are used to regulate the flow of water. Effects of regulation on salinity can be understood if continuous EC data are available with flows and storage properties (area submerged and depth of water). The increase in median salinity from Condobolin to Booligal Weir in Table 3.4 may be due to regulation of weirs and storages.

- Measurements of soil salinity and groundwater salinity near the river will assist in identifying possible sources of salinity, from floodplain or directly from groundwater.

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. Availability of salinity data

Table A.1.Salinity data available in Lachlan Valley

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
412002	Lachlan R @ Cowra	33.8347	148.6833	Discrete	1970-2002	283
412002	Lachlan R @ Cowra	33.8347	148.6833	continuous	1999-2002	978
412004	Lachlan R @ Forbes	33.4042	147.9903	Discrete	1970-2002	290
412004	Lachlan R @ Forbes	33.4042	147.9903	continuous	1999-2002	949
412005	Lachlan R @ Booligal Weir	33.8706	144.8800	Discrete	1970-2002	257
412005	Lachlan R @ Booligal Weir	33.8706	144.8800	continuous	1999-2002	797
412006	Lachlan R @ Condobolin	33.0917	147.1472	Discrete	1970-2002	286
412006	Lachlan R @ Condobolin	33.0917	147.1472	continuous	1999-2002	865
412007	Lachlan R @ Willanthry	33.3444	145.8339	Discrete	1990-1990	1
412008	Lake Creek @ Lake Cargelligo Outlet	33.2447	146.4042	Discrete	1970-2002	170
412009	Belubula R @ Canowindra	33.5722	148.6639	Discrete	1969-1998	140
412010	Lachlan R @ Wyangala dam	33.9700	148.9500	Discrete	1976-1989	9
412011	Lachlan R @ Lake Cargelligo Weir	33.2072	146.4514	Discrete	1969-2002	274
412011	Lachlan R @ Lake Cargelligo Weir	33.2072	146.4514	continuous	2000-2002	756
412012	Willandra Creek @Road Bridge	33.3467	145.8792	Discrete	1972-1987	87
412014	Goobang Ck @Condobolin	33.0847	147.1611	Discrete	1970-1987	98
412016	Wallamundry Ck @ Offtake Island	33.2292	147.3236	Discrete	1970-1987	91
412017	Bumbuggan Ck @ Offtake	33.2278	147.4583	Discrete	1968-1987	86
412020	Willandra Ck @Tocabil	33.3222	145.8181	Discrete	1970-1976	16
412021	Lachlan R @Booberoi Weir	33.0383	146.6433	Discrete	1970-1987	89
412022	Booberoi Ck @Offtake	33.0383	146.6411	Discrete	1968-1984	49
412023	Island Ck @ Fairholme	33.2792	147.3806	Discrete	1971-1987	90
412026	Lachlan R @ Oxley	34.2161	144.1028	Discrete	1969-1982	71
412028	Abercrombie R @ Abercrombie	33.9569	149.3236	Discrete	1967-1993	110
412028	Abercrombie R @ Abercrombie	33.9569	149.3236	continuous	1999-2002	756
412029	Boorowa R @ Prossers Crossing	34.1444	148.8097	Discrete	1968-2001	283
412029	Boorowa R @ Prossers Crossing	34.1444	148.8097	continuous	2000-2002	565
412030	MandageryCk u/s Eugowra	33.3778	148.4431	Discrete	1976-1986	53
412031	Hovells Ck (Jerringomar)	34.0458	148.8889	Discrete	1971-1978	28
412033	Belubula R @ Helensholme	33.5856	148.4808	Continuous	1999-2001	700
412034	Lachlan R @Condobolin Weir	33.0944	147.1444	Discrete	1986-1986	1
412036	Lachlan R @ Jemalong Weir	33.4028	147.7736	Discrete	1969-1987	113

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
412037	Jemalong Ck @Offtake	33.4025	147.7775	Discrete	1977-1977	4
412038	Lachlan R @ Willandra Weir	33.3500	145.8750	Discrete	1969-2002	177
412038	Lachlan R @ Willandra Weir	33.3500	145.8750	continuous	2000-2002	783
412039	Lachlan R @ Hillston Weir	33.4886	145.5031	Discrete	1970-2002	262
412039	Lachlan R @ Hillston Weir	33.4886	145.5031	continuous	1999-2002	880
412041	Borre Ck @ Cudal	33.3069	147.7389	Discrete	1968-1970	11
412042	Willandra Ck@ Willandra Homestead	33.1972	145.1208	Discrete	1971-1987	76
412043	Goobang Ck @ Darby's Dam	33.1569	147.4500	Discrete	1971-1982	56
412044	Island Ck above Wallamundry Offtake	33.2333	147.3375	Discrete	1972-1977	22
412045	Lachlan R @ Corrong	34.2194	144.4611	Discrete	1970-2002	222
412045	Lachlan R @ Corrong	34.2194	144.4611	continuous	1999-2002	800
412046	Wallaroi Ck @Worrongorra Weir	33.1042	146.8472	Discrete	1970-1987	80
412047	Lachlan R @ Lake Brewster outlet	33.3833	145.9014	Discrete	1970-1987	97
412048	Lachlan R @ L Brewster Weir	33.4097	145.4889	Discrete	1969-2000	34
412050	Crookwell R @ Narrawa N	34.3122	149.1642	Discrete	1969-1987	93
412050	Crookwell R @ Narrawa N	34.3122	149.1642	continuous	2000-2002	585
412054	Bolong R @Golspie	34.2750	149.6194	Discrete	1974-1980	12
412055	Belubula Ck @ Bangaroo Bridge	33.5828	148.4864	Discrete	1968-1987	104
412056	Belubula R @ the Needles	33.5819	148.8472	Discrete	1969-1989	101
412057	Lachlan R @ Nanami	33.5750	148.4167	Discrete	1970-2002	178
412057	Lachlan R @ Nanami	33.5750	148.4167	continuous	2000-2002	712
412058	Lachlan R @Island Creek Offtake	33.2639	147.4944	Discrete	1969-1986	82
412059	Nerathong Ck @Lake Cargelligo Road	33.1017	147.0756	Discrete	1976-1987	31
412061	Lachlan R @ Hillandale	34.0603	149.0339	Discrete	1969-1977	10
412063	Lachlan R @ Gunning	34.7403	149.2917	Discrete	1971-1987	96
412064	Bolong R @Golspie (refer 412054)	34.2744	149.6189	Discrete	1967-1980	63
412065	Lachlan R @ Narrawa	34.3972	149.0931	Discrete	1970-2002	165
412065	Lachlan R @ Narrawa	34.3972	149.0931	Continuous	1999-2002	784
412066	Abercrombie R @Hadley NO.2	34.1139	149.5972	Discrete	1967-1987	102
412067	Lachlan R d/s Wyangala Dam	33.9833	148.9347	Discrete	1967-2002	244
412068	Goonigal Ck @Gooloogong	33.5975	148.3750	Discrete	1974-1986	25
412069	Boorowa R @ Boorowa	34.4233	148.7639	Discrete	1968-1981	72
412070	Cadiangullong Ck @Panuara	33.5167	148.9778	Discrete	1968-1981	70
412071	Canomodine Ck @ Canomodine	33.5097	148.7889	Discrete	1968-1987	107
412072	Back Ck @ Koorawatha	34.0292	148.5431	Discrete	1968-1987	77
412073	Nyrang Ck @Nyrang	33.5431	148.5486	Discrete	1976-1986	18

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
412074	Isabella River @ Ballyroe	34.0333	149.6000	Discrete	1971-1981	50
412075	Mandagery Ck @Manildra	33.1903	145.3028	Discrete	1976-1982	42
412076	Bourimbla Ck @Cudal	33.3292	148.7139	Discrete	1976-1986	42
412077	Belubula R @ Carcoar	33.6153	149.1431	Discrete	1968-1991	121
412078	Lachlan R @ Whealbah	33.6533	145.2514	Discrete	1969-1987	96
412079	Belubula R @ Mandurama	33.6375	149.0944	Discrete	1968-1989	49
412080	Flyers Ck @ Beneree	33.5125	149.0408	Discrete	1969-1987	99
412081	Rocky Bridge Ck	33.8000	149.1847	Discrete	1976-2002	128
412082	Phils Ck @Fullerton	34.2306	149.5514	Discrete	1976-1984	49
412083	Tuena Ck @ Tuena	34.0194	149.3306	Discrete	1970-1987	87
412084	Lachlan R @ u/s Blakney Creek	34.5958	149.1625	Discrete	1971-1982	54
412085	Ooma Ck @Henry Lawson Way Br	33.5653	148.0514	Discrete	1976-1986	17
412086	Goobang Ck @Parkes	33.1764	148.1764	Discrete	1970-1987	83
412087	Merrowie Ck at Merrowie Homestead	33.3692	145.5300	Discrete	1976-1986	15
412088	Lachlan R @ Numby	34.1964	149.0561	Discrete	1969-2002	234
412089	Cooks Vale Ck @ Peelwood	34.0681	149.4597	Discrete	1961-1987	103
412090	Boree Ck @Cudal No.2	33.2806	148.7458	Discrete	1971-1990	106
412091	Waugoola Ck U/S Cowra	33.8236	148.7208	Discrete	1971-1987	85
412092	Coombing Ck @naer Neville	33.6625	149.2083	Discrete	1971-1987	55
412093	Naradhan @ Naradhan	33.6264	146.3181	Discrete	1983-1991	12
412096	Pudmans Ck @Kennys Ck Rd	34.4458	148.7917	Discrete	1976-1987	57
412097	Island Ck @ Offtake	33.2542	147.4944	Discrete	1971-1986	27
412099	Manna Ck near Lake Cowal	33.3611	147.3861	Discrete	1976-1987	14
412100	Jemalong Main Canal @Offtake	33.4028	147.7722	Discrete	1976-1981	10
412101	Lake Cargelligo Intake @	33.2031	146.4561	Discrete	1973-2002	112
412102	Lake Brewster Intake @	33.4028	145.9778	Discrete	1973-2002	106
412103	Bland Creek @Morangarell	34.1481	147.6811	Discrete	1976-1986	23
412104	Belubula River @U/S Blayney	33.5103	149.2750	Discrete	1989-1991	86
412105	Belubula River @D/S Blayney	33.5500	149.2625	Discrete	1977-1991	233
412107	Lake Cargelligo @Storage Gauge	33.3017	146.3800	Discrete	1999-2000	5
412108	Lake Brewster @Storage Gauge	33.4567	145.9483	Discrete	1999-2002	74
412109	Lake Brewster Conduit @Lake Brewster	33.3964	145.9842	Discrete	1951-1986	45
412110	Bolong River @U/S Giddigang Creek	34.3014	149.6242	Discrete	1977-1987	37
412112	Lachlan River @Savilles	33.2319	146.3833	Discrete	1999-2000	12
412115	Willandra Creek @Booligal-Ivanhoe Road	33.1847	144.5667	Discrete	1980-1985	7
412116	Willandra Creek @Hillston-Roto Road	33.2028	145.4850	Discrete	1980-1985	19

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
412117	Willandra Creek @Balranald-Ivanhoe Road	33.1097	144.1044	Discrete	1982-1982	1
412118	Nerathong Creek @Condobolin-West Wyalong Road	33.1292	147.1292	Discrete	1986-1987	3
412119	Lachlan River @West Condobolin Weir	33.0875	147.0750	Discrete	1986-1987	4
412121	Merrimajeel Creek @U/S Murrumbidgil Swamp	33.8653	143.6389	Discrete	1977-1978	14
412124	Muggabah Creek @Cobb Highway	33.7722	144.9211	Discrete	1977-1978	13
412134	Wattle Creek @Dudauman	34.5964	147.8642	Discrete	1988-1988	1
412136	Abattoir Creek @St Joseph's College	33.5278	149.2556	Discrete	1989-1991	141
412137	Abattoir Creek @Palmer Street	33.5222	149.2403	Discrete	1989-1991	235
41210001	Wyangala Dam Station 1 – Dam Wall	33.9731	148.9522	Discrete	1977-2003	64
41210002	Wyangala Dam Station 2 – Grabine Station	33.9489	149.0192	Discrete	1979-1994	15
41210003	Wyangala Dam Station 3 – Lachlan River	34.0003	149.0606	Discrete	1979-2002	16
41210004	Wyangala Dam Station 4	34.0478	149.0467	Discrete	1987-1988	3
41210005	Wyangala Dam Station 5 – Abercrombie	33.8892	149.1178	Discrete	1979-2002	14
41210006	Wyangala Dam Station 6	33.9544	149.1436	Discrete	1988-1988	1
41210021	Carcoar Dam Station 1	33.6194	149.1789	Discrete	1971-2003	222
41210022	Carcoar Dam Station 2	33.6069	149.1967	Discrete	1977-1995	186
41210023	Carcoar Dam Station 3	33.5922	149.2144	Discrete	1977-1995	171
41210024	Carcoar Dam Station 4	33.5839	149.2289	Discrete	1977-1995	132
41210041	Lake Cargelligo Abattoir Point	33.2706	146.3975	Discrete	1978-1979	5
41210042	Lake Cargelligo (Town Water Supply)	33.2944	146.3817	Discrete	1979-2000	7
41210043	Lake Cargelligo (Main Swimming Area)	33.3017	146.3786	Discrete	1979-1989	3
41210044	Lake Cargelligo (Tullibigeal Pump)	33.3067	146.3972	Discrete	1995-2000	6
41210045	Lake Cargelligo (Centre of Main Lake)	33.2889	146.3964	Discrete	1989-2002	90
41210046	Lake Cargelligo Boat Ramp @ Apex Park	33.2983	146.3783	Discrete	1979-1979	2
41210061	Lake Brewster Storage at Outflow	33.4258	145.9411	Discrete	1989-2002	91
41210062	Lachlan River D/s Belubula River Conf	33.6028	148.4714	Discrete	1999-1999	1
41210067	Lachlan River @ Murrin Bridge	33.2050	146.3606	Discrete	1999-2002	79
41210101	Belubula River at Dungeon Road Crossing	33.4711	149.3247	Discrete	1989-1991	28
41210102	Side Creek Upper Belubula Catchment)	33.4769	149.3250	Discrete	1989-1990	9
41210103	Belubula River at Newbridge Road Bridge	33.5342	149.2561	Discrete	1989-1990	54
41210104	Belubula River at CTCC Pipeline	33.5778	149.2428	Discrete	1989-1991	41
41210105	Chain of Ponds Creek Midway Carcoar Reservoir	33.6139	149.2206	Discrete	1990-1990	13
41210106	Belubula River at V-notch Weir Downstream of Carcoar Dam	33.6239	149.1797	Discrete	1989-1991	65

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41210107	Kings Plain Creek at Dungeon Road	33.4867	149.3125	Discrete	1991-1991	2
41210108	Highway Culvert near Blayney Showgroud	33.5178	149.2653	Discrete	1989-1991	59
41210109	Saleyard Creek at Blayney ICR Engineering	33.5261	149.2533	Discrete	1989-1991	58
41210110	Marshall Road Culvert near Blayney Ta	33.5111	149.2522	Discrete	1989-1991	87
41210111	New Culvert near Blayney MS&LC	33.5144	149.2550	Discrete	1991-1991	3
41210112	Drain Pipe from Blayney Linen Service	33.5125	149.2522	Discrete	1991-1991	1
41210113	Runoff from Log Treatment Plant, Blayney	33.5144	149.2544	Discrete	1990-1991	6
41210114	Ewin St. Drain, South of Blayney Abattoir	33.5261	149.2461	Discrete	1991-1991	3
41210115	Culvert Cnr Boust and Carcoar Sts, Blayney	33.5281	149.2494	Discrete	1991-1991	7
41210116	Drain near Blayney Goldfields Motel	33.5414	149.2547	Discrete	1991-1991	1
41210117	Outlet at Blayney Sewage Treatment Works below Wetland	33.5497	149.2631	Discrete	1990-1990	1
41210118	Prices Culvert Crossing	33.5692	149.2667	Discrete	1991-1991	1
41210120	Abattoir Creek at Blayney Abattoir Carpark	33.5267	149.2494	Discrete	1989-1991	86
41210123	Abercrombie Rv at Camping Area	33.9564	149.3192	Discrete	1993-2002	111
41210154	Lake Cargelligo Intake DS Sheet of Water	33.2406	146.4508	Discrete	1999-2002	79
41210155	Lake Cargelligo Intake DS Curlew Water	33.2675	146.4389	Discrete	1999-2002	79
41210156	Lake Cargelligo Site A near Inlet	33.2683	146.4256	Discrete	1999-2002	79
41210157	Lake Cargelligo Site C nr Outlet	33.2642	146.4117	Discrete	1999-2002	79
41210158	Lake Brewster Intake @ Lake	33.4361	145.9572	Discrete	1999-2002	81
41210159	Lake Brewster Site A - open water	33.4556	145.9564	Discrete	1999-2001	59
41210160	Lake Brewster Site B - open water	33.4664	145.9550	Discrete	1999-2001	57
41210161	Lachlan River DS Lake Cargelligo Weir	33.2233	146.4275	Discrete	2000-2002	65
41210162	Lachlan River DS Lake Brewster Weir	33.3903	145.9339	Discrete	2000-2002	63
41210163	Lake Brewster - Dead Storage	33.4808	145.9650	Discrete	2000-2001	28

Appendix B. Comparison with Salinity Audit

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. This test for consistency is necessary for confidence in the Lachlan 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, e.g., Belubula River @ Bangaroo Bridge 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 were subtracted to produce net flow and salt load for that catchment.

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

Table B.2 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*
412065	Lachlan R @ Narrawa	*166*	167	169	*42*	44	45	42	38
412050	Crookwell R @ Narrawa North	*88*	88	90	*15*	15	15	15	14
412083	Tuena Ck @ Tuena	*37*	37	36	*6*	7	7	6	5
412028	Abercrombie R @ Abercrombie	*291*	299	292	*32*	33	32	30	29
R1*	Ungauged Lachlan River u/s Wyangala Dam	*288*	209	207	*35*	19	18	17	23
412067	**Lachlan R at Wyangala**	***821***	**780**	**765**	***127***	**119**	**117**	**110**	**109**
412029	Boorowa R @ Prossers Crossing	*90*	91	94	*32*	22	22	21	18
R2*	Ungauged Lachlan River between Wyangala Dam and Cowra	*219*	90	90	*32*	22	22	21	18
412002	**Lachlan River @ Cowra**	***988***	**953**	**942**	***205***	**161**	**159**	**149**	**143**
412072	Back Ck @ Koorawatha	*24*	24	23	*9*	11	10	10	10
412009	**Belubula R @ Canowindra**	*194*	198	201	*57*	50	50	47	42
412055	**Belubula R @ Bangaroo Bridge**	*199*	194	197	*57*	46	46	43	40
R3*	Ungauged Lachlan River between Cowra and Nanami	*267*	21	19	*13*	4	4	3	2
412057	**Lachlan River @ Nanami**	***1208***	**1183**	**1174**	***247***	**220**	**218**	**204**	**194**
412030	Mandagery Ck @ U/S Eugowra	*80*	78	78	*29*	29	29	28	27
R5	Ungauged Lachlan River between Nanami and Forbes	*170*	56	56	*33*	16	16	15	14
412004	**Lachlan River @ Forbes**	***1140***	**1135**	**1126**	***238***	**230**	**229**	**215**	**205**
R6	Ungauged Lachlan River between Forbes and Condobolin	*32*	23	25	*14*	5	5	5	5
412043	Goobang Ck @ Darby's Dam	*67*	74	74	*26*	29	28	26	15
412034/006	**Lachlan River @ Condobolin Bridge**	***806***	**794**	**787**	***171***	**166**	**164**	**154**	**143**

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

- *These residuals have losses included in their calculation.*

  R1* = inflow (4) – loss (5) in U/S Wyangala system file

  R2* = inflow (5) – loss (10) in D/S Wyangala system file

  R3* = inflow (31) – loss (32) in D/S Wyangala system file

The Salinity audit did not have a separate loss node at this location. All other residuals had separate loss nodes

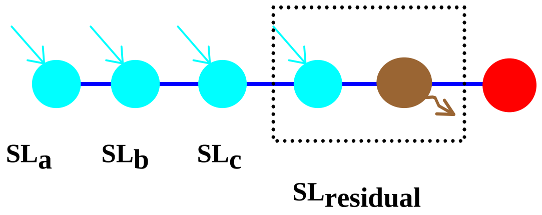

Figure A.8.1. Schematic for calculating net salt load inflow at residual catchments

B.1.1. Flow

The flow results used in IQQM compare quite closely with those used in the Salinity Audit (Table B.2.). This is expected as the Salinity Audit flows were derived from the Lachlan IQQM flows of the time.

For the majority of gauged inflow locations, the inflows are within 5% of each other for both periods of 1975-1995 and 1975-2000. These differences can be attributed to rounding off the calculations of mm runoff from ML/year. The only significant difference in these results is for catchment 412043, where the IQQM flows are 10% greater than the Audit. It is possible that the flows have been updated for IQQM since the Audit was published.

The IQQM flows for the residual catchments are generally substantially less than the Audit flows. Overall, the total residual inflow from IQQM is about 40% of the Audit residual flows. These large differences are attributable to the abnormally high amounts of runoff in the Salinity Audit residuals, except for Residual R1, (refer to Salinity Audit, Table 5.9) compared with the runoff from gauged catchments. As an example, the R3 residual in the Audit has an annual runoff of 166mm/year compared with the neighbouring gauged catchment of 412055 with 78mm/year.

The IQQM flow at the main river gauge sites (the shaded rows in Table B.2.) is still within 5% of the Salinity Audit results. The Salinity Audit results at these locations are based on observed data and not the combination of the Salinity Audit inflows and losses.

The results for the extra 5 years between 1996-2000, with the majority of the inflows having similar average annual runoff, indicates that 1996-2000 were, on average, generally representative of the last 20 years (1975-1995). This is supported by analysis of the average annual rainfall over the entire period between 1975 and 2000 (Figure 2.7).

B.1.2. Salt loads

In general, the IQQM salt loads are consistently below the Salinity Audit salt loads, by roughly 10-30%. In comparing the salt loads at main river gauge sites (the shaded rows in Table B.2.), IQQM is 79% of the Salinity Audit at 412002, but consistently improves to be roughly 97% by the gauge at 412004.

Capping the concentration had a significant affect the inflow points at 412065, 412009, 412055, 412043. At Condobolin (412006), the capping reduces the salt load by 7%. The capped salt inflows are mostly up to 10% lower than uncapped estimates.

As mentioned above, the longer benchmark climatic period between 1975-2000 is similar to period between 1975 – 1995 and there is little difference between the salt load results.

Applying the lower EC→salinity conversion factor of 0.6 rather than 0.64 (as applied in the Salinity Audit) is likely to a predictable effect of reducing salt loads to 93.75% (or 0.60/0.64) of the estimates presented in Table B.2.

B.1.3. Conclusion

The main purpose of this comparison was to demonstrate the degree of consistency with the results from the Salinity Audit and explain differences where they occur. These differences would be in part because of using a different model structure, but also to different benchmark climate period, and other modifications.

The differences between annual flows, except for residual flows, were within 5% for the majority of sites. The flows at residual sites in the Salinity Audit have uncharacteristically high runoff compared to surrounding catchments.

The salt loads for IQQM are consistently lower than the Salinity Audit estimates by 10-30%. Capping the salt loads only had a significant impact of 4 gauged site locations. The impact of the capping of inflow salinity concentrations was a 7% reduction in the salt load at Condobolin.

Overall, the results are within 10% for both flow and salt loads at the all balance points except for the salt load at Nanami (412057).

Changing the benchmark climate period from the 21 year Audit period to the 25 year BSMS period resulted in no significant changes.

Overall, the comparison of the salt loads from IQQM with those reported in the Salinity Audit gave confidence that the model was producing consistent results. The differences reported for the ungauged catchments are attributable to differences in residual catchments estimates now compared with the estimates at the time, and some possible differences in the model structure. Differences, where they exist, can be explained if required.

Appendix C. Model Details

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

- IQQM version = 6.67.1
- System file = LachBL01.sqq (all other files needed are detailed in this system file).