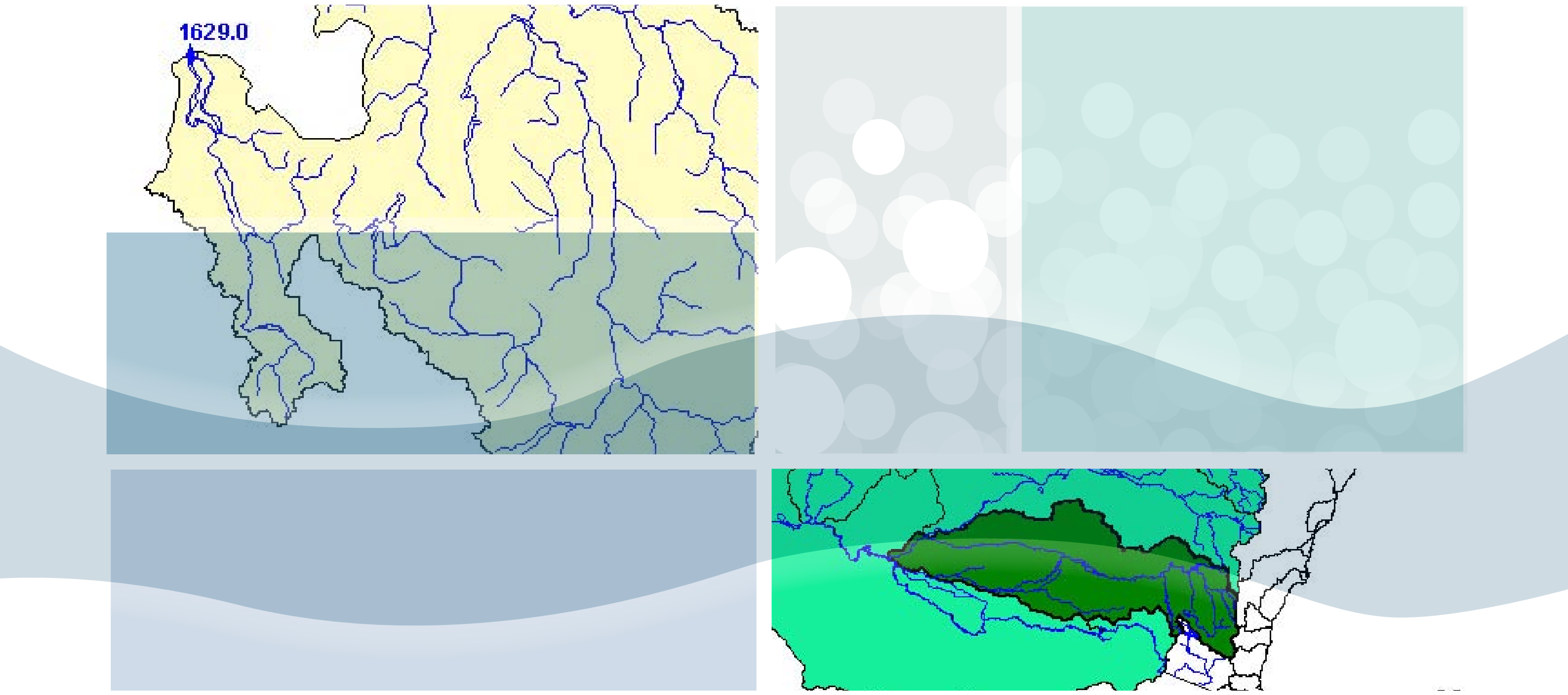
Instream salinity models of NSW tributaries in the Murray-Darling Basin

Volume 6 – Murrumbidgee River Salinity Integrated Quantity and Quality Model



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Instream salinity models of NSW tributaries in the Murray-Darling Basin Volume 6 – Murrumbidgee River Salinity Integrated Quantity and Quality Model

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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 Murrumbidgee 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 Murrumbidgee 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 Murrumbidgee 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 Murrumbidgee 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 1.3.7 respectively.

1.2.4. 2006 Salinity Audit

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

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

1.3. CURRENT POLICY FRAMEWORK

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

1.3.1. MDBC Integrated Catchment Management

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

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

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

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

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

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

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

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

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

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

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

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

1.3.3.1. Schedule C of the Murray-Darling Basin Agreement

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

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

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

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

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

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

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

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

1.3.4. Catchment Action Plans

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

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

1.3.5. NSW Water Sharing Plans

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

1.3.6. NSW Salinity Strategy

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

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

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

1.3.7. NSW Environmental Services Scheme

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

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

1.3.8. CMA Incentive schemes

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

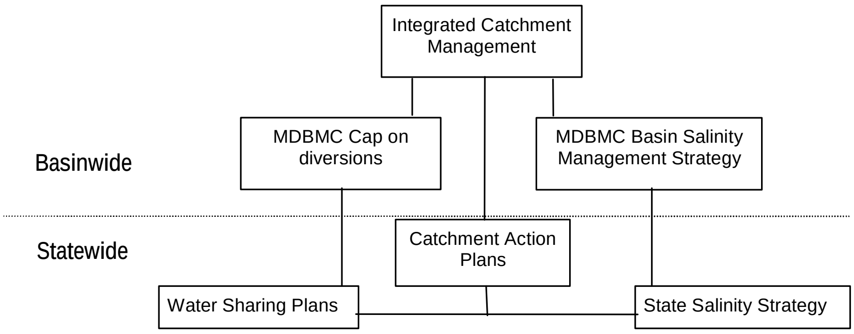


Figure 1.1. Relationship of Basinwide and Statewide policies and plans

1.4. DWE MODEL FRAMEWORK

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

1.4.1. Objectives of modelling

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

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

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

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

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

1.4.2. Modelling requirements

The modelling had the following requirements:

- Daily predictions

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

1.4.3. Strengths and Limitations

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

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

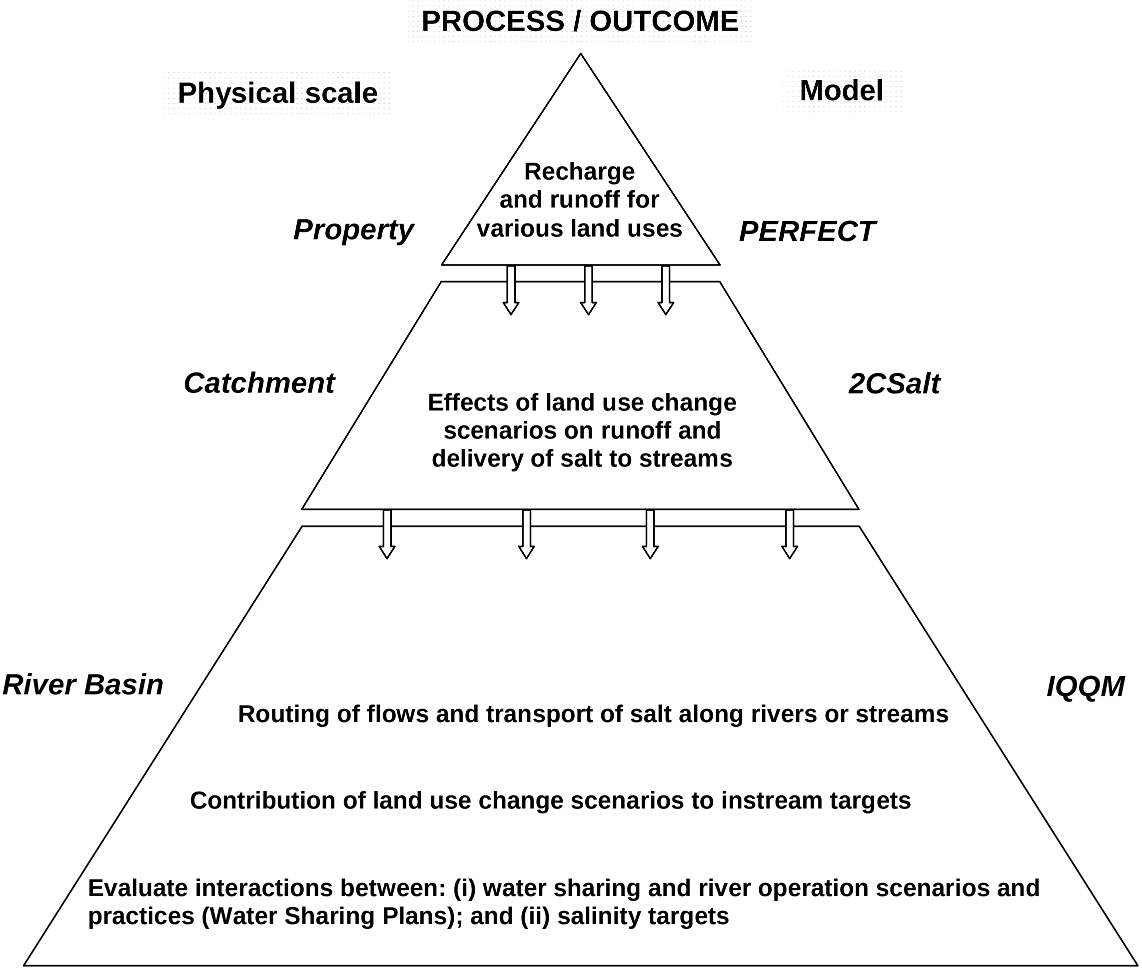


Figure 1.2. Applications and linkages of DECC and DWE models at different scales

Staged Model Development

The work reported here was developed in logical stages as shown in Figure 1.4. 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.

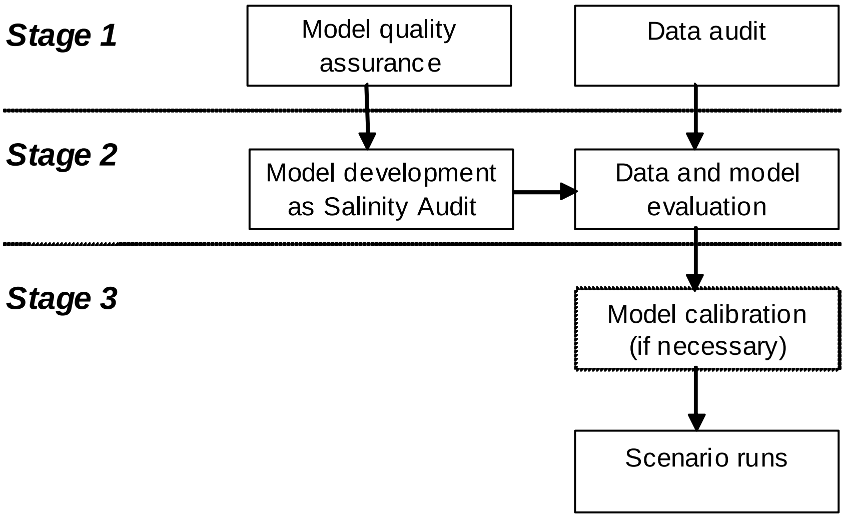


Figure 1.4. Stages of model development

1.4.4. Stage 1: Model QA and Data Audit

The existent IQQM that had been configured and calibrated for the Murrumbidgee 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.

1.4.5. 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.

1.4.6. 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 Murrumbidgee System

2.1. PHYSICAL FEATURES OF THE CATCHMENT

2.1.1. General

The Murrumbidgee system in southwestern NSW is one of the major sub-catchments of the Murray-Darling Basin (Figure 2.1). It is bounded by the Great Dividing Range to the east, the Lachlan River Valley to the north and the Murray Valley to the south. The Murrumbidgee River runs for nearly 1,600 km from its source in the Snowy Mountains to its junction with the Murray River near Balranald and drains an area of about 84,000 km^2.

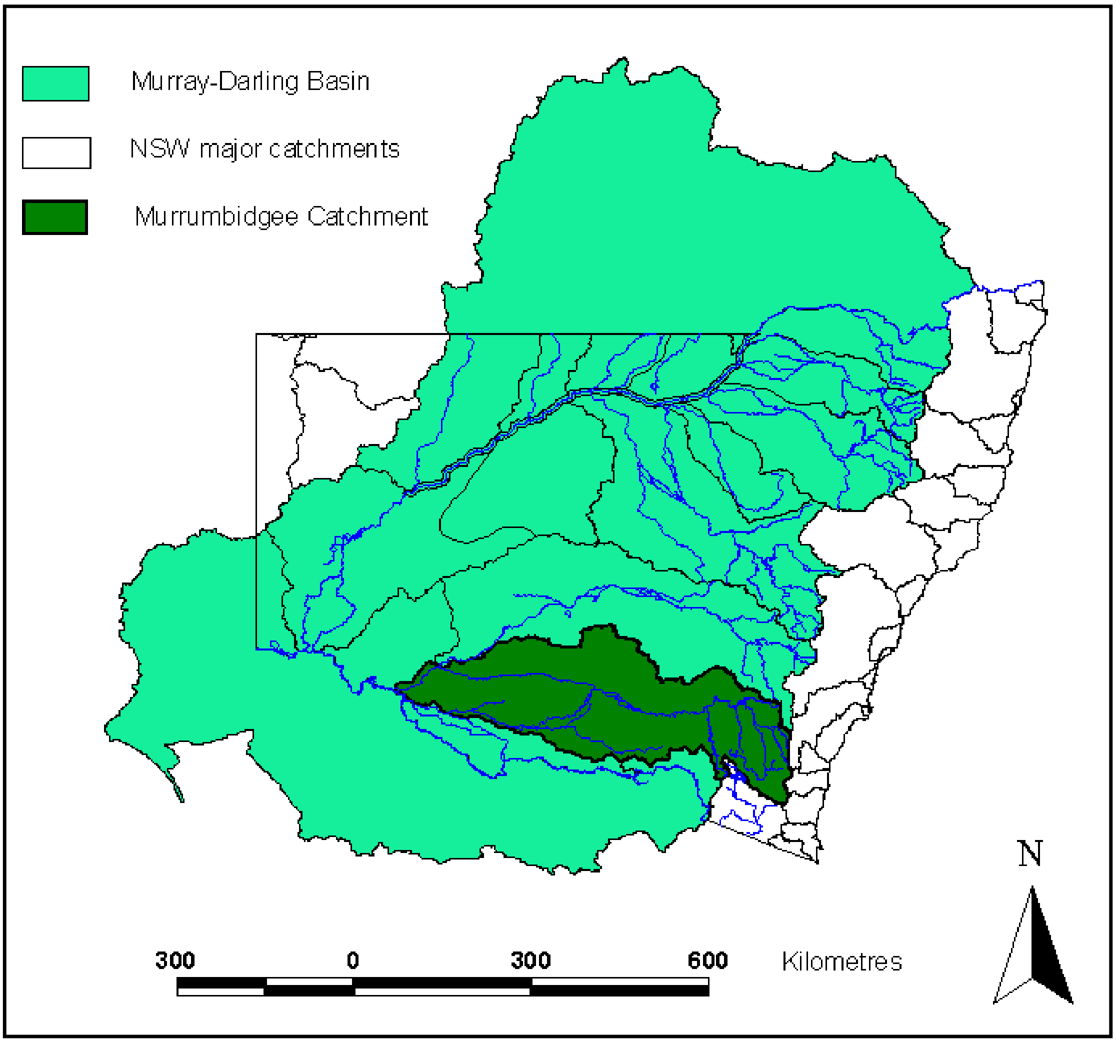


Figure 2.1. Relationship of the Murrumbidgee catchments to Murray-Darling Basin

The Murrumbidgee catchment includes Australia's capital, Canberra, with a population of 314,000 and NSW's largest inland city, Wagga Wagga, with a population of 57,000 as well as numerous smaller cities and towns (Figure 2.2). The total urban population in the Murrumbidgee catchment is approximately 520,000.

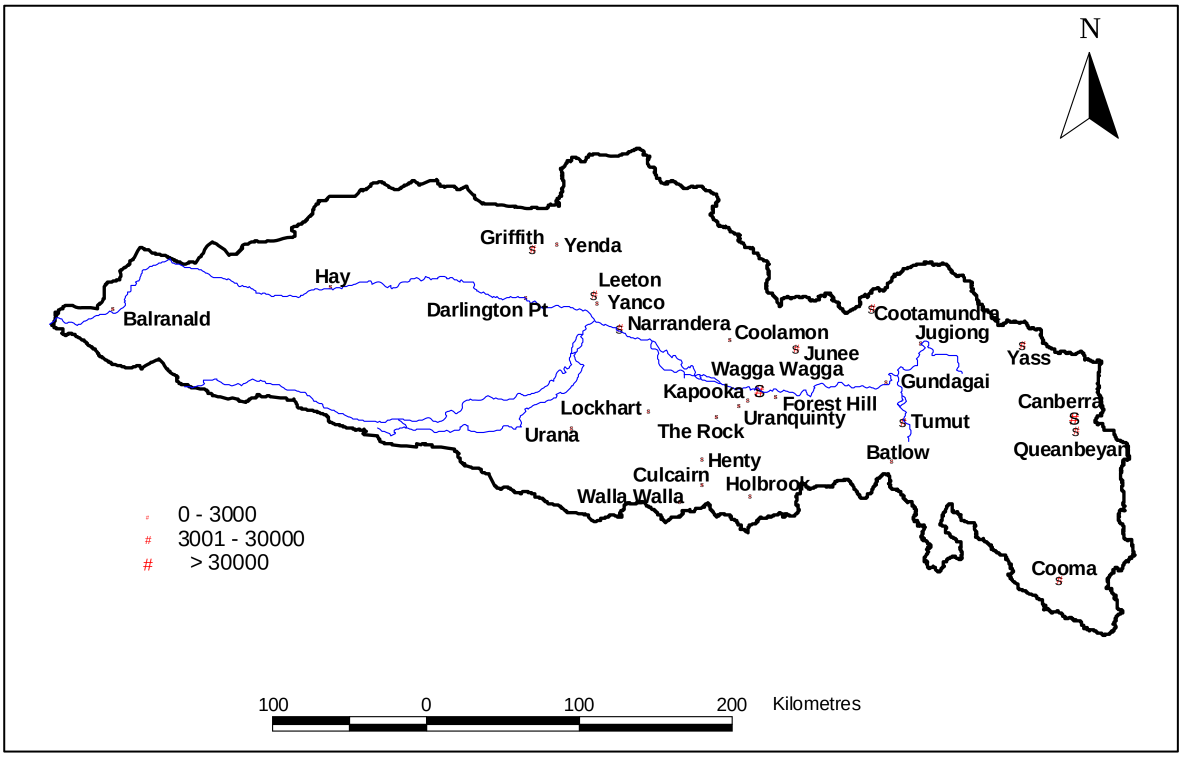


Figure 2.2. Cities and towns in the Murrumbidgee catchment

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

(i) Burrinjuck and Blowering Dam catchments (source region);

(ii) Murrumbidgee and Tumut Rivers from the dams to Wagga Wagga (source & extraction region); and

(iii) Murrumbidgee River from Wagga Wagga to Balranald and the Yanco-Colombo-Billabong system (extraction region).

The latter includes the Murrumbidgee Irrigation Area (MIA), Coleambally Irrigation Area (CIA) and the Lowbidgee Irrigation District which are highlighted in Figure 2.3(b).

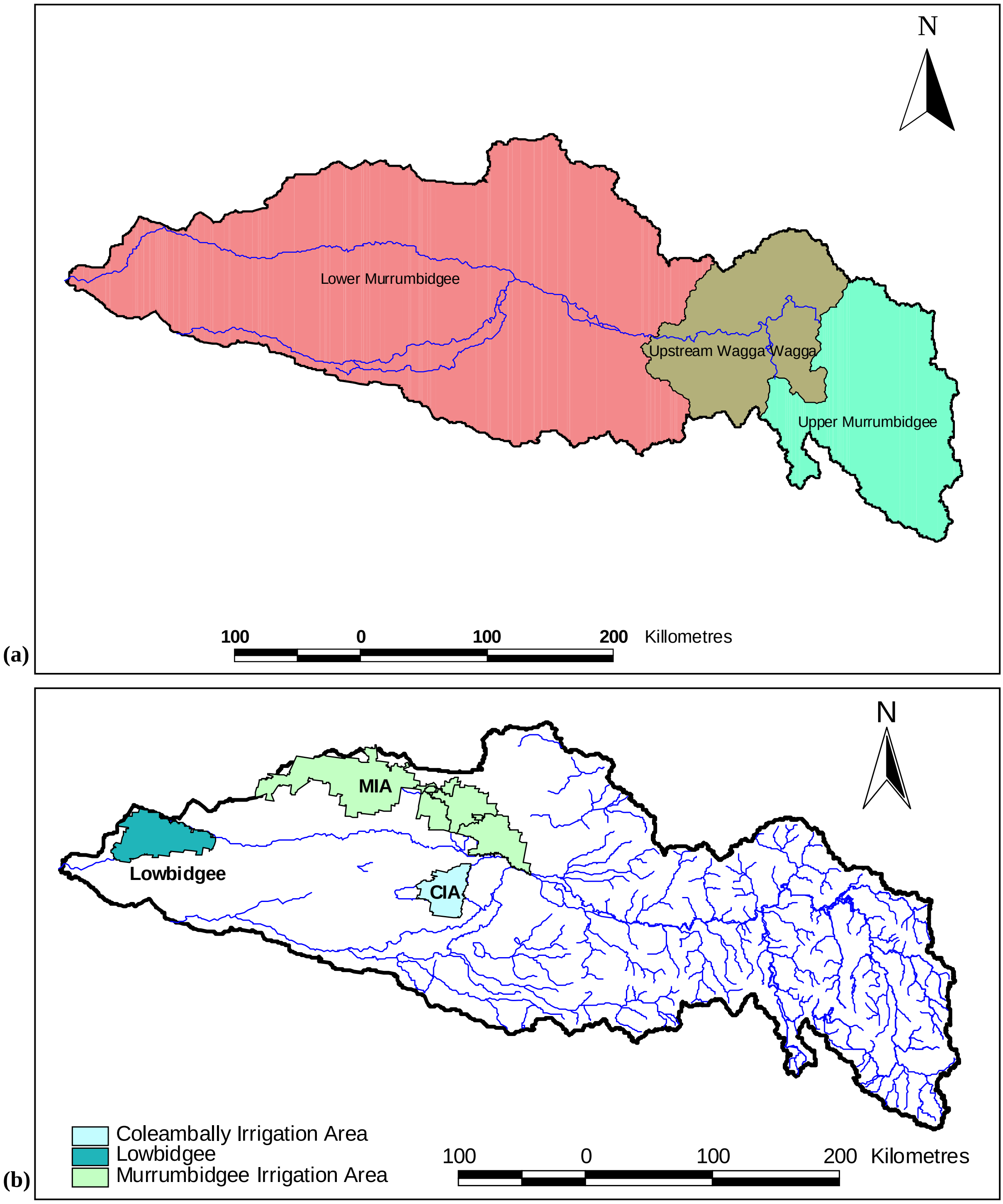


Figure 2.3. (a) Major regions of the Murrumbidgee Catchment, and (b) Major irrigation areas of the Murrumbidgee Catchment

2.1.2. Stream network

2.1.2.1. Burrinjuck and Blowering Dam catchments

Burrinjuck Dam lies on the Murrumbidgee River and has a total catchment area of is 13,100 km^2. The Murrumbidgee River rises on the Monaro Plateau, an area of elevated plains averaging 1,200 m with occasional peaks of up to 1800 m. The river initially flows southeast then turns abruptly north near Cooma and is joined by the Numeralla and Bredbo Rivers. It then swings north northwest through the ACT towards Yass before veering west into Burrinjuck Dam. The major tributaries in this reach are the Cotter, Molonglo and Yass Rivers. Another tributary, the Goodradigbee River, drains the rugged area between the Fiery and Brindabella Ranges before flowing north directly into the storage.

Blowering Dam on the Tumut River has a catchment area of only 1,630 km^2. However, in addition to the pristine inflows from its mountainous and largely forested catchment, it also receives water from the Snowy Scheme via a 22 km tunnel from Lake Eucumbene.

2.1.2.2. Murrumbidgee and Tumut Rivers from the dams to Wagga Wagga

From Burrinjuck Dam, the Murrumbidgee River flows through a rugged narrow gorge and is joined by Jugiong and Muttama Creeks from the north and the Tumut River from the south, before emerging onto the western plains near Gundagai. Flowing west to Wagga Wagga, it is joined by Adelong, Billabung, Hillas, Tarcutta and Kyeamba Creeks.

The Tumut River is the largest tributary of the Murrumbidgee, with a total catchment of 4,000 km^2. The major tributaries of the Tumut River below Blowering Dam are Gilmore, Brungle and Adjungbilly Creeks and the Goobarragandra River.

2.1.2.3. Murrumbidgee River from Wagga Wagga to Balranald and the Yanco-Colombo-Billabong system

Murrumbidgee River from Wagga Wagga to Balranald

With the exception of Houlaghans Creek, the few remaining tributaries of the Murrumbidgee are small and ephemeral (eg. Bullenbung and Burkes Creeks which enter the Murrumbidgee via Old Man Creek). The Lachlan River joins the Murrumbidgee just upstream of Redbank Weir but it flows rarely leave the Great Cumbung Swamp at the end of the Lachlan Valley.

This part of the river is characterised by a diminishing channel capacity due to the deposition of alluvium. For example, channel capacity drops from 30,000 ML/d at Hay to a mere 7,000 ML/d at Balranald. The main features of the Murrumbidgee River between Wagga Wagga and Balranald are the Weirs that provide the head needed to supply major irrigation areas. These include:

- Berembed Weir, 60 km downstream of Wagga Wagga, which supplies the MIA’s Main Canal (capacity: 6,700 ML/d)
- Yanco Weir, about 15 km downstream of Narrandera, which controls flows into the Yanco-Colombo-Billabong system (capacity: 1,400 ML/d)
- Gogeldrie Weir, about 30 km further downstream, which controls flows into the MIA’s Sturt Canal and the Coleambally Canal that supplies the CIA and helps fill the Tombullen off-river storage.
- Hay Weir, which buffers downstream users against supply timing problems as water takes up to thirty days to reach Hay from the headwater storages

- Maude Weir, which facilitates flows into Lowbidgee's Nimmie-Caira system.
- Redbank Weir, which facilitates flows via five regulators into the Redbank Forest system.
- Balranald Weir, about 30 km upstream of the confluence with the Murray River.
- Other major features are Tombullen Storage and private diverter irrigators. Tombullen of river storage, located off the Coleambally Canal, captures rain rejections and other supplementary flows. Captured water is released to supply private diverters downstream of Gogeldrie weir. A large proportion of private diversion takes place in this reach, especially between Darlington Point and Maude Weir.

Yanco-Colombo-Billabong system

Yanco Weir controls flows into Yanco Creek, a natural high-flow effluent of the Murrumbidgee River. Yanco Creek flows south to Morundah then south-west to join Billabong Creek at Conargo. At Morundah, Tarabah Weir diverts some water into Colombo Creek which flows south-east through open plain country to joins Billabong Creek upstream of Jerilderie.

Apart from the Yanco and Colombo Creek inflows, Billabong Creek is actually a separate system from the Murrumbidgee, with its catchment in the Holbrook/Culcairn region. Flows are regulated by Hartwood Weir near Conargo which sends water down Forest Creek as far as Warriston Weir, below which the channel becomes choked by cumbungi before entering Wanganella Swamp. Only high flows pass through the swamp and back into Billabong Creek which eventually joins the Edwards River on its way to the Murray River

2.1.2.4. Coleambally Irrigation sub-system

Under the 1997 corporatisation agreement, the Coleambally Irrigation Corporation was made responsible for the supply to irrigators in the Kerabury region and the western Outfall Drain. The CIA consists of a series of supply and drainage channels. It receives water from the Murrumbidgee River via the Coleambally Canal and is drained by three major channels: the Coleambally Outfall Drain which heads west to join Billabong Creek just upstream of Darlot; DC800 which heads south to join Yanco Creek; and the Catchment Drain which heads in east to join Yanco Creek. All three drains, but primarily the DC800 and the Catchment Drain are used by State Water as supply channels for the river pumpers within DIPNR's area of operation.

2.1.3. Hydrometeorology

2.1.3.1. Rainfall

Average annual rainfall in the Murrumbidgee catchment ranges from well over 1200 mm east of Blowering Dam to less than 350 mm in the west (Figure 2.4). Wagga Wagga, although upstream of the major irrigation areas, has a good rainfall record to describe the long term rainfall characteristics of the valley. Rainfall at Wagga Wagga is fairly uniform throughout the year (Figure 2.5), but is slightly higher in winter.

A residual mass curve of the rainfall from 1890 to the present (Figure 2.6) shows that the first half of the nineteenth century had extended periods of lower than average rainfall whilst the third quarter had extended periods of higher than average rainfall. The BSMS Benchmark Climatic period (the fourth quarter) has above average rainfall overall, with some wet and dry periods. This can also be seen in Figure 2.7 which shows the annual rainfall over the BSMS Benchmark Climatic period at Wagga

Wagga. Within this period, annual rainfall varied from about 0.5 to 1.5 times the average and the catchment experienced an extended drought from 1979-1982. Other dry years were 1987, 1991, 1994 and 1997.

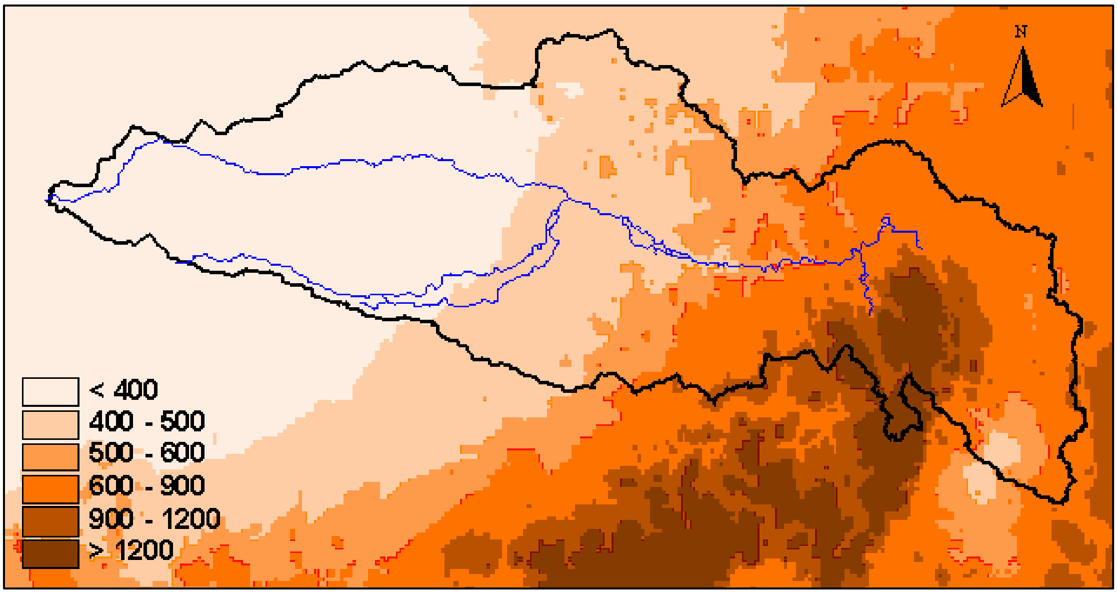


Figure 2.4. Average annual rainfall in the Murrumbidgee catchment.

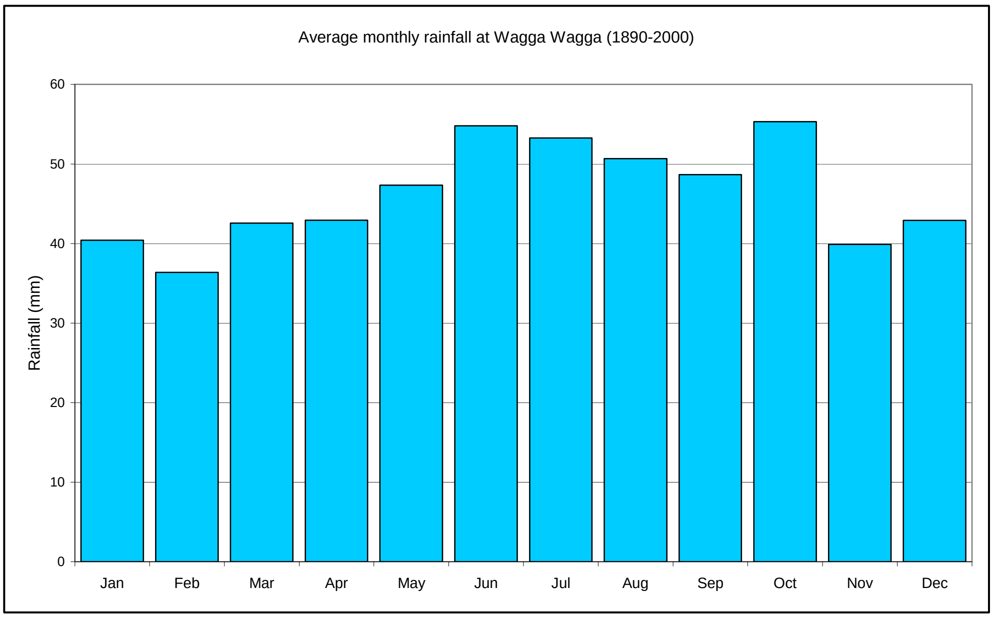


Figure 2.5. Average monthly rainfall at Wagga Wagga

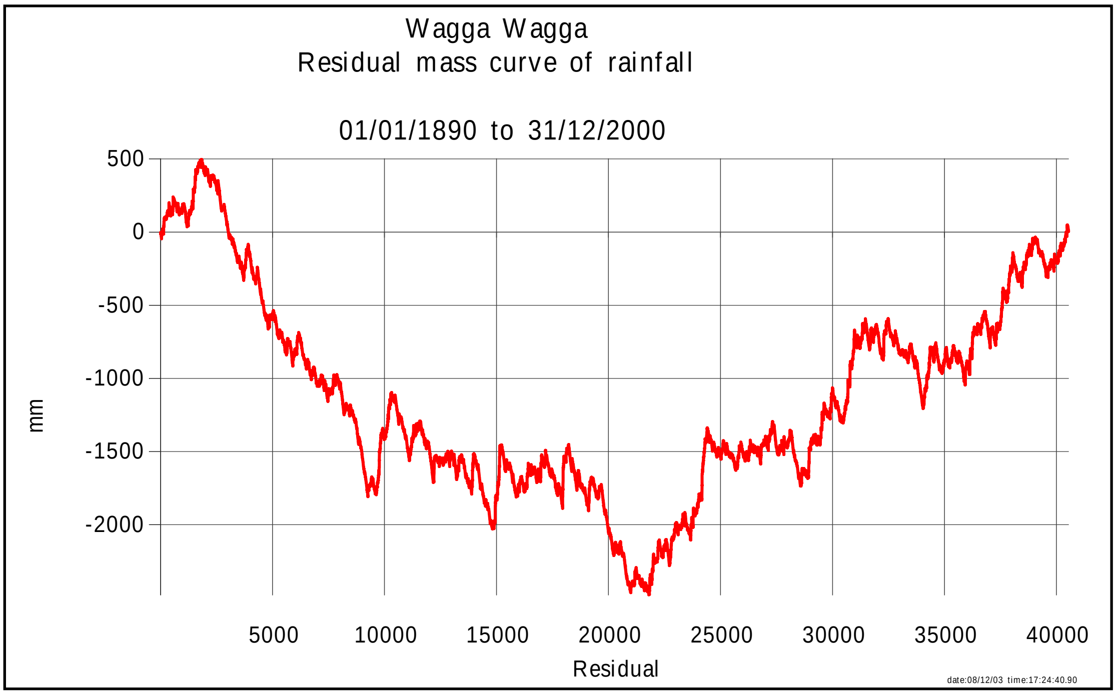


Figure 2.6. Residual mass curve of rainfall at Wagga Wagga 1890-2000.

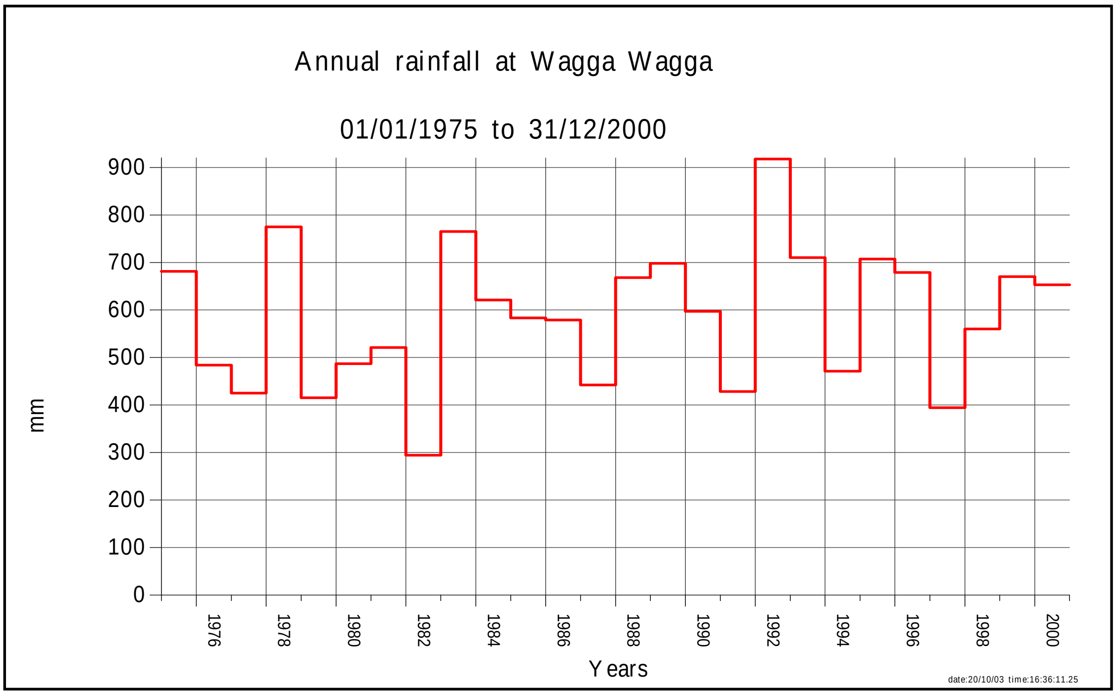


Figure 2.7. Annual rainfall at Wagga Wagga 1975-2000

2.1.3.2. Evaporation

Pan evaporation in the Murrumbidgee catchment has a strong east-west gradient (Figure 2.8). Average Class A pan evaporation varies from less than 1100 mm/year in the south-east, to around 2000 mm/year in the west. Pan evaporation is also strongly seasonal, varying from 1.2 mm/d during July at Wagga Wagga to 9.6 mm/d during January.

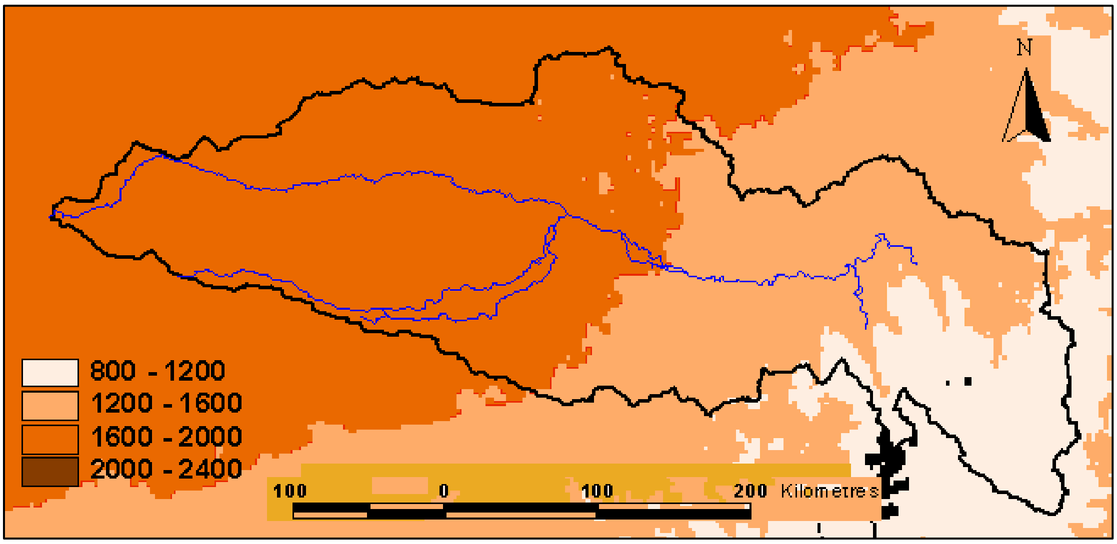
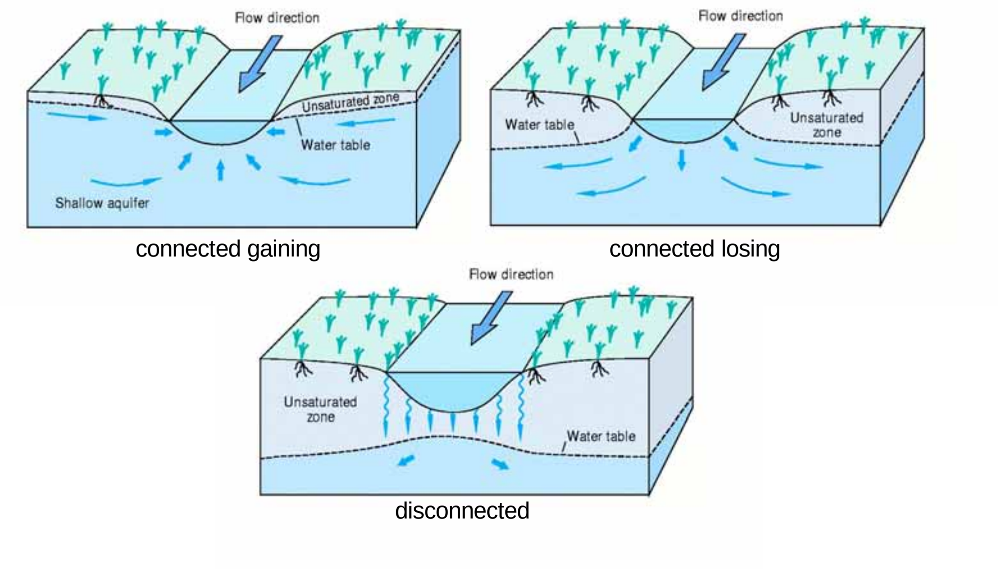


Figure 2.8. Average annual Class A Pan evaporation in the Murrumbidgee valley (1973-1995)

2.1.4. Groundwater interactions.

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

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.



connected gaining

connected losing

disconnected

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

(after Braaten and Gates, 2002)

Generally, whether a river section is hydraulically connected has a geographic distribution as shown in the Murrumbidgee Valley in Figure 2.10. Most upland streams are hydraulically connected, receiving flow from fractured rock aquifers. However, upstream of Gundagai, the Murrumbidgee lies in a confined gorge and the groundwater system is too narrow to have any significant impact.

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 floods and periods of high regulated flow will recharge the aquifer, which may then drain back to the river when the flow is lower. This situation occurs in the area of shallow alluvial water tables between Gundagai and Narrandera, which gains significant quantities of water from the aquifer for many months following major flood events.

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 Murrumbidgee River between Narrandera and just upstream of Balranald.

Although Figure 2.10 shows that the southern reaches of the Yanco-Colombo-Billabong system are disconnected, salinity rises along the regulated parts of Billabong Creek. This may be attributable to rising groundwater levels (not indicated on the map) due to the introduction of rice-growing in the late 1980s.

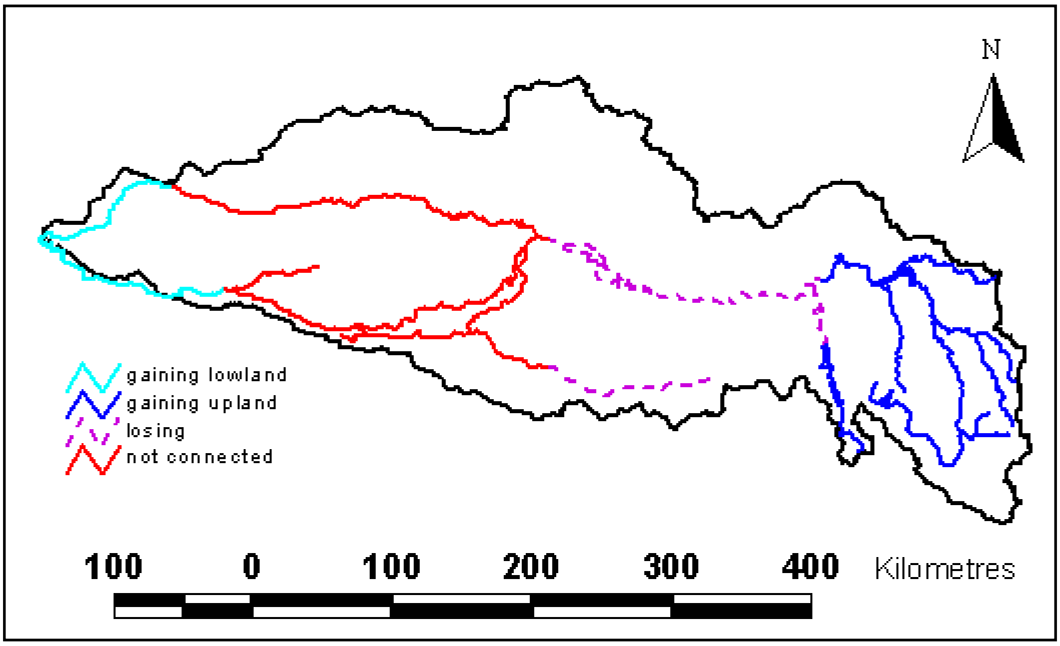


Figure 2.10. River-groundwater interaction in Murrumbidgee catchment

2.1.5. Vegetation and Land Use

Land use in the Murrumbidgee catchment is dominated by extensive agriculture (Table 2.1). Nearly 60% of the catchment is used for grazing and much of the remainder for dryland crops. Irrigated crops, while economically important, cover just 3.6% of the catchment area, whilst forests and conservation areas cover about nine percent.

The grazing land is distributed throughout the catchment and features heavily in all the regions (Figure 2.11). Dryland agriculture occurs mostly downstream of Burrinjuck and Blowering Dams, predominantly in the mid-Murrumbidgee region between Gundagai and Narrandera. The larger irrigation areas are located downstream of Narrandera, with some areas to the south of Billabong Creek (in the Murray Valley). The largest areas of conservation land and non-conservations forest are in the east of the catchment, upstream of Burrinjuck and Blowering Dams.

Table 2.1. Land use statistics for Murrumbidgee catchment

Land use description	Total extent ('000 Ha)	Total extent (%)
Nature conservation	460.2	5.6
Other protected areas including indigenous uses	1.0	0.0
Minimal use	440.3	5.4
Livestock grazing	4812.3	58.9
Forestry	297.6	3.6
Dryland agriculture	1751.4	21.5
Irrigated agriculture	292.3	3.6
Built environment	67.4	0.8
Waterbodies not elsewhere classified	42.1	0.5

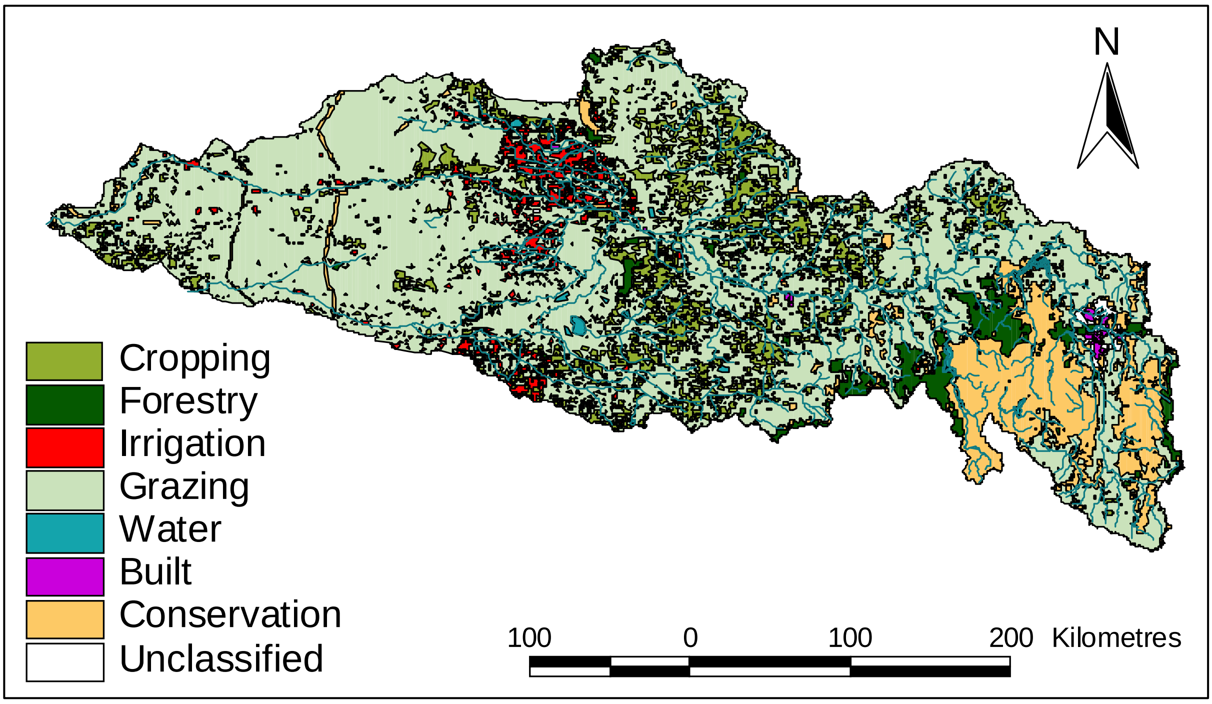


Figure 2.11. Landuse in the Murrumbidgee valley

2.2. WATER RESOURCE MANAGEMENT

The Murrumbidgee Valley has a complex water resource management structure due to its interaction with the Murray & Snowy systems. Also adding to the complexity are multiple classers of licence holders including groundwater users, regulated and unregulated surface water users, and environmental requirements. More detailed information can be found in the gazetted Murrumbidgee Regulated Water Source Plan and the Murrumbidgee (Lower) Groundwater Sources Plan. Other references include the unregulated plans for the Adelong, Tarcutta and Upper Billabong systems. All plans are available on the DIPNR web site. A brief summary of the major features of the regulated system is given below.

The regulated Murrumbidgee Valley system operates on an annual accounting system with a 10% capped carryover limit (in 1999/2000, currently 15%), unlike other parts of the state which use a continuous accounting system. Access to supplementary water from reservoir spills, pre-releases or tributary events is granted first to regulated Murrumbidgee general security users, then regulated Murray users (via Balranald) and finally Lowbidgee users. Murrumbidgee regulated users have an annual “history of use cap’ which applies to supplementary access after announced allocation reaches or exceeds 70%.

A complex set of accounts applies to the environmental allocation, which can be used to create or supplement events by releases from Burrinjuck or Blowering dams. In essence, the environment gets a set amount of allocation once a certain allocation threshold is reached, as well as an amount related to inflow. There are carryover rules for environmental water as well as rules for transparent/translucent releases from Burrinjuck. These determine how much of the inflow to Burrinjuck is released depending on the time of year, catchment conditions, storage volume and the need to stay within the Gundagai flow limit.

2.3. SALINITY IN CATCHMENT

Figure 2.12 shows occurrences of dryland salinity in the Murrumbidgee Valley identified from aerial photo interpretation.

The most significant areas of dryland salinity occur in the Jugiong Creek catchment, in the upper Yass River catchment, from the headwater storages to Wagga Wagga and, to a lesser extent, in the upper Billabong Creek catchment.

Salt loads from catchments in the upper Murrumbidgee region were estimated as part of the Salinity Audit (Beale et al., 1999). Figure 2.13 shows that the highest salt loads on a per unit area basis occur in the Kyeamba, Hillas and Adelong Creek catchments, which all lie to the south of the Murrumbidgee River upstream of Wagga. The Audit also showed quite high salt loads in the Jugiong Creek, Muttama Creek and Tumut River catchments.

The high salt loads exported from the Tumut River catchment are due to its relatively high flow per unit area as it has very few occurrences of dryland salinity compared with the Jugiong Creek catchment. Therefore, a high salinity concentration isn’t necessary to produce high salt loads.

2.4. DATA FILLING

Rainfall and evaporation data was gap filled in the standard IQQM way (See Methods report). Missing Inflows were estimated using Sacramento models (Synthesis of Daily Flow Sequences, Murrumbidgee River System, HydroTechnology, April 1995).

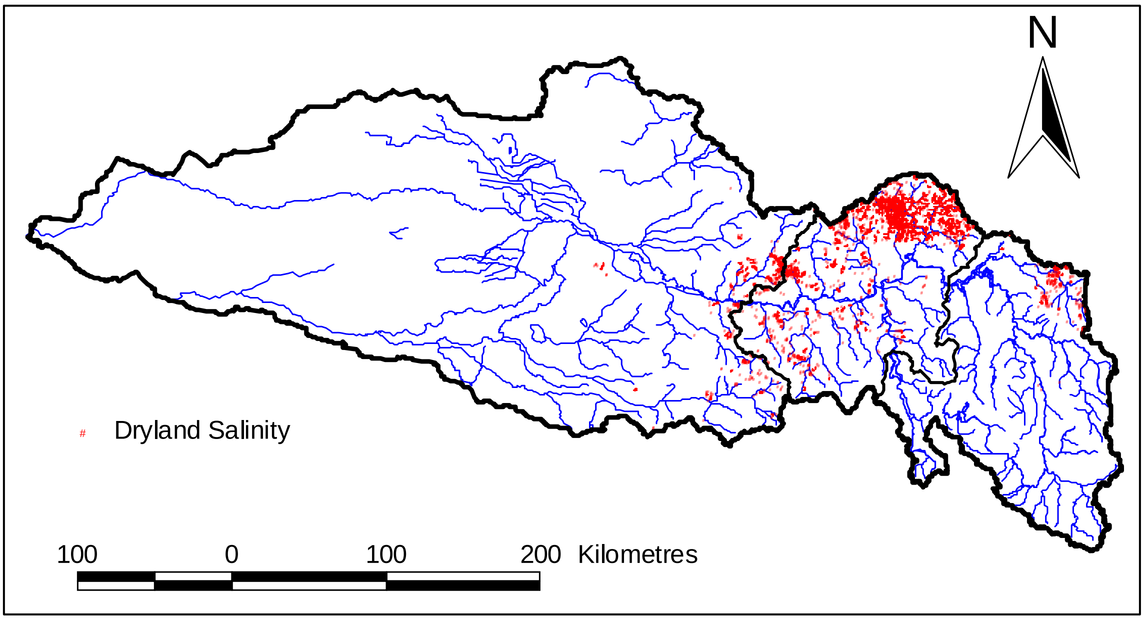


Figure 2.12. Dryland salinity occurrences in Murrumbidgee catchment (mapped pre-1999)

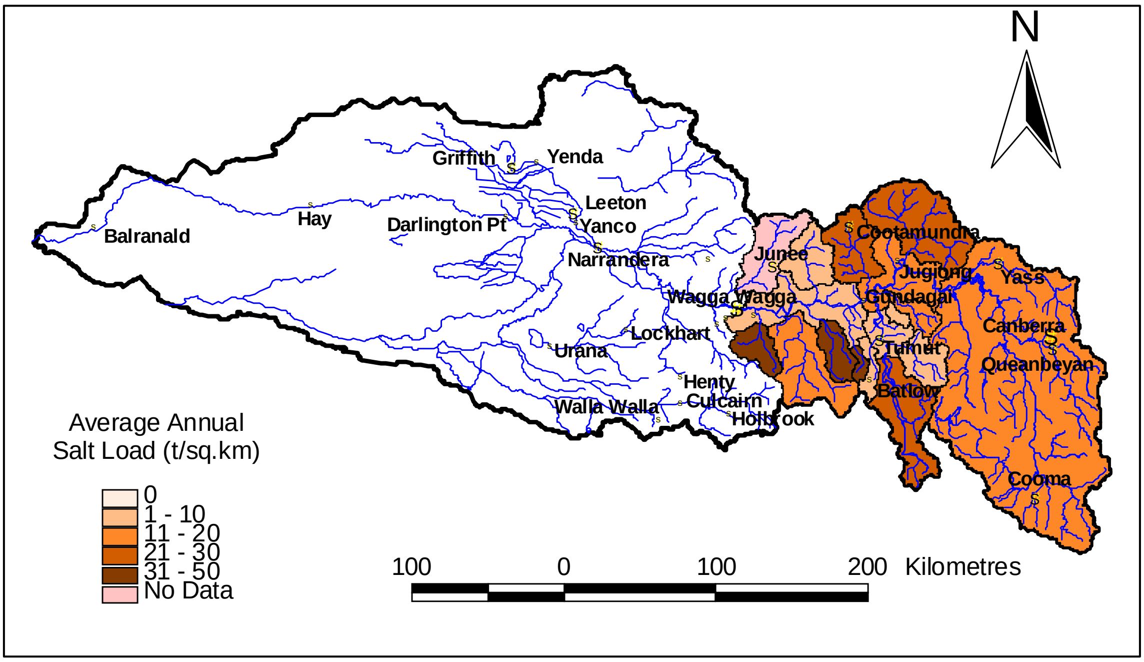


Figure 2.13. Modelled average annual salt export rates (tonnes/km^2) from Murrumbidgee River catchments

3. Salinity data

3.1. AVAILABLE DATA

All the data for the Murrumbidgee valley catchment was extracted from the DIPNR databases. A station list appears in Appendix A. The distribution and relative length of the data is shown in Figure 3.1 for discrete EC data stations, and Figure 3.2 for continuous EC data stations.

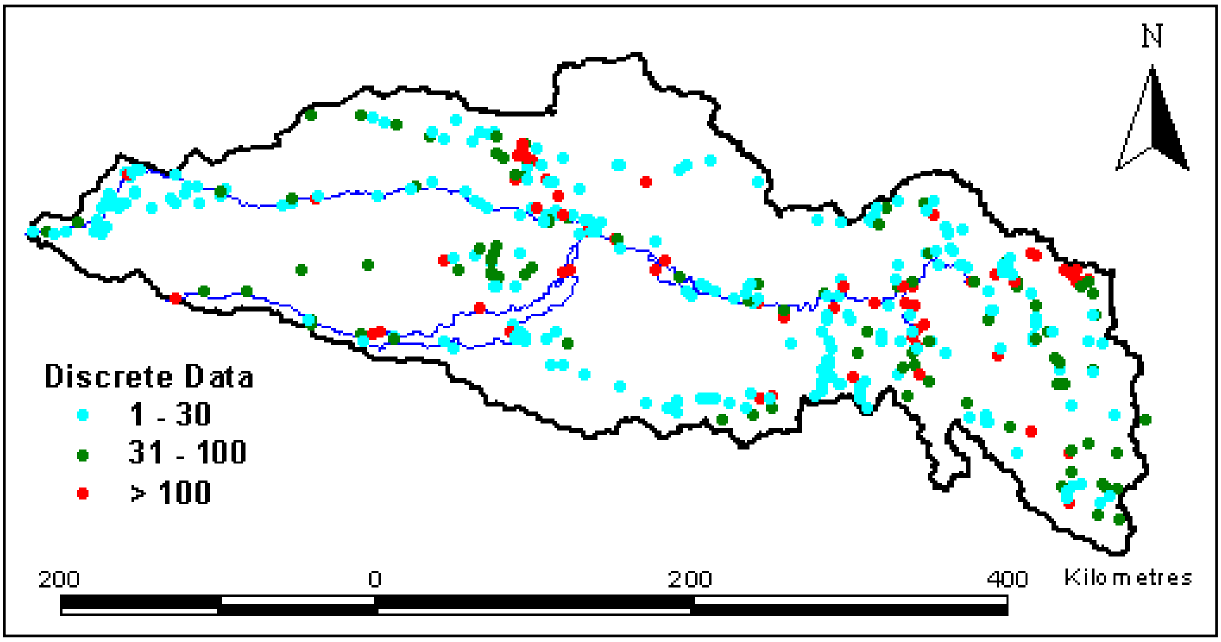


Figure 3.1. Location and record length size for discrete EC data stations

The legends used in Figure 3.1 and Figure 3.2 are indicative of the usefulness of the data for modelling purposes. A discrete data set with < 30 data points is of little value, from 30-100 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. These classes are based on experience; a more rigorous approach to determining how well these data sets describe the salinity regime is discussed in Volume 2, Chapter 5.

A feature of the discrete data sets is that of the 487 total reported in Appendix A, 54% have less than 30 data points, and 23% have more than 100 data points. Intense sampling has occurred in the MIA where salinity is an operational problem and the choice between water sources is governed by their salinity. Yanco Creek below the Coleambally DC800 canal and the Coleambally's Outfall Drain are also sampled frequently due concern over their high salinity levels.

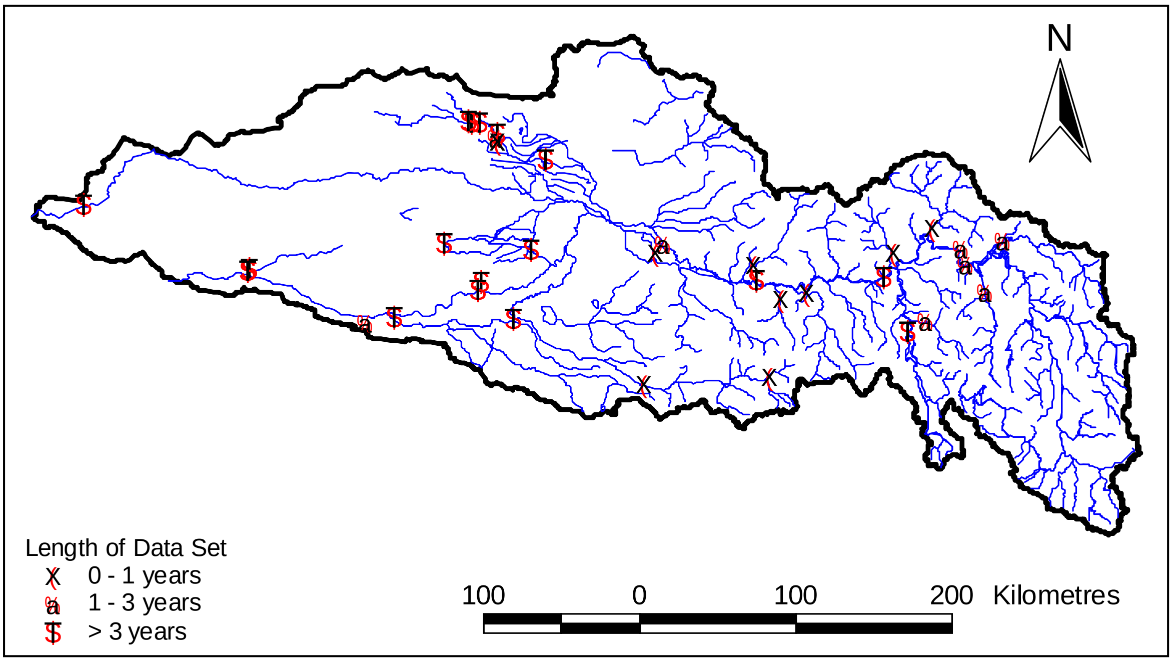


Figure 3.2. Location and record length for continuous EC data stations

The Murrumbidgee River System has a good coverage of continuous stations compared with most other NSW MDB valleys, reflecting the level of salinity management activity in the catchment. Of the thirty-five stations: nine have between eight and ten years of data; seventeen have between three and seven years of data; and ten have less than one year. As for the discrete data, the continuous data stations are concentrated in the MIA and the Yanco-Colombo-Billabong system.

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. Fifty-three stations, fifty-one with discrete data and twenty-one with continuous data, can potentially be used for these purposes.

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

3.2.1. Exploratory analysis of data

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

A plot of median salinity against median inflow (Figure 3.3) indicates that the Muttama Creek catchment (410044) contributes small volumes of high salinity water whilst the Jugiong Creek catchment (410025) produces significant volumes of moderately high salinity water. At the other end of the spectrum, the Tarcutta Creek and Goobarragandra River catchments (410047 and 410057) contribute large volumes of moderately low and very low salinity water respectively.

The longitudinal overview of median salinities (Figure 3.4) shows a significant difference between the median salinities of Burrinjuck and Blowering Dam outflows. The very low median salinity (20 mg/L) downstream of Blowering Dam occurs despite high salt export rates from the Tumut River catchment due to the large volume of flow. Salinity remains very low in the Tumut River after it is joined by the Goobarragandra River. The relatively high median salinity (in the order of 110 mg/L) downstream of Burrinjuck Dam is probably due to its extensive catchment which contains significant areas of dryland salinity.

Below the Murrumbidgee-Tumut confluence, the median salinity drops to about 65 mg/L then rises slightly to about 75 mg/L at Wagga Wagga. There is very little salinity data between Wagga Wagga and the end of system at Balranald where the median salinity is still only 106 mg/L. The highest main stream median salinities in the valley are in the Yanco-Colombo-Billabong system. This is probably due to the high salinity drainage flows from the Coleambally area. The occurrences of dryland salinity in the upper Billabong Creek catchment are unlikely to be significant as the areas contributes relatively little flow to the system.

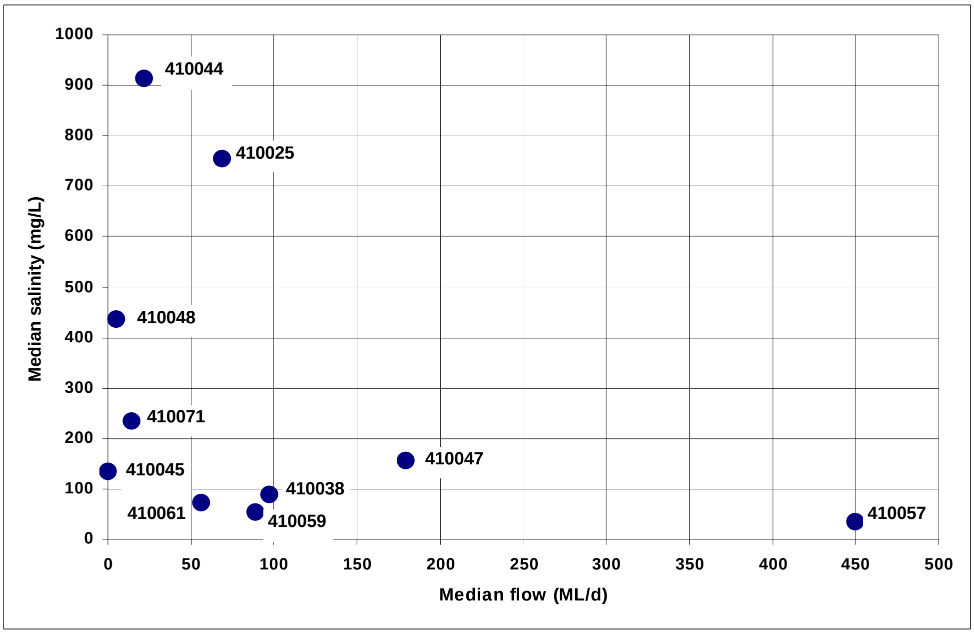


Figure 3.3. Median salinity versus median flow for inflow sites with discrete EC data

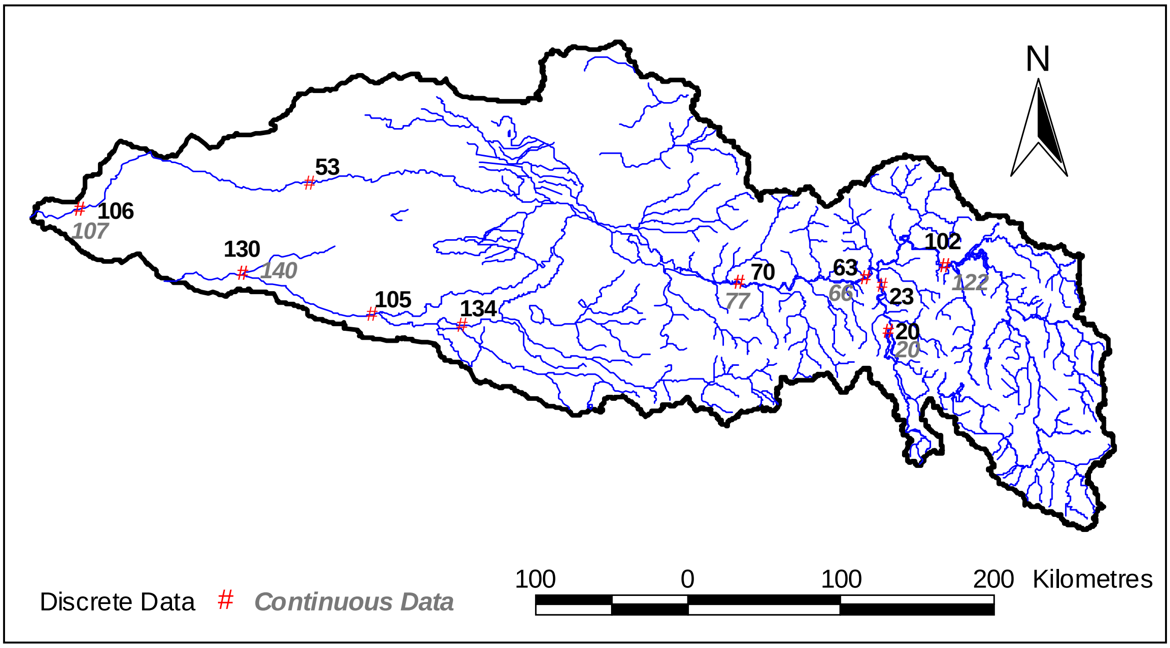


Figure 3.4. Median salinity along main stream

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

Station Number	Station Name	Data use	Data points removed			Final data days
			<15 µS/cm	*zero or missing flow*	*outliers*	
410008	Murrumbidgee River @ d/s Burrinjuck Dam	Inflow	0	0		154
410008	*Murrumbidgee River @ d/s Burrinjuck Dam*	*Inflow*	*0*	*0*	*0*	*377*
410025	Jugiong Creek @ Jugiong (Inverlockie)	Inflow	0	28		230
410025	*Jugiong Creek @ Jugiong (Inverlockie)*	*Inflow*	*0*	*0*	*0*	*216*
410038	Adjungbilly Creek @ Darbalara	Inflow	0	14		144
410044	Muttama Creek @ Coolac	Inflow	0	26		197
410044	*Muttama Creek @ Coolac*	*Inflow*	*0*	*0*	*0*	*208*
410045	Billabung Creek @ Sunny side	Inflow	0	6		13
410047	Tarcutta Creek @ Old Borambola	Inflow	0	22		285
410047	*Tarcutta Creek @ Old Borambola*	*Inflow*	*0*	*0*	*0*	*158*
410048	Kyeamba Creek @ Ladysmith	Inflow	0	80		83
410048	*Kyeamba Creek @ Ladysmith*	*Inflow*	*0*	*0*	*0*	*348*
410057	Goobarragandra River @ Lacmalac	Inflow	0	0		120

Station Number	**Station Name**	**Data use**	**Data points removed**			**Final data days**
			<15 μS/cm	*zero or missing flow*	*outliers*	
410057	*Goobarragandra River @ Lacmalac*	*Inflow*	*0*	*0*	*0*	*990*
410059	Gilmore Creek @ Gilmore	Inflow	1	76		74
410061	Adelong Creek @ Batlow Road	Inflow	0	0		129
410071	Bungle Creek @ Red Hill	Inflow	0	14		91
410073	Tumut River @ Oddys Bridge	Inflow	4	17		208
410073	*Tumut River @ Oddys Bridge*	*Inflow*	*0*	*0*	*0*	*3226*
410091	Billabong Creek @ Walbundrie	Inflow	0	81		133
410091	*Billabong Creek @ Walbundrie*	*Inflow*	*0*	*0*	*0*	*104*

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

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

Station Number	**Station Name**	**Data use**	**Data points removed**			**Final data days**
			<15 μS/cm	*zero or missing flow*	*outliers*	
410001	Murrumbidgee River @ Wagga Wagga	Evaluation	*0*	*6*		177
410002	Murrumbidgee River @ Hay	Evaluation	*0*	*3*		165
410004	Murrumbidgee River @ Gundagai	Evaluation	*1*	*7*		191
410016	Billabong Creek @ Jerilderie	Evaluation	*0*	*19*		222
410017	Billabong Creek @ Conargo	Evaluation	*0*	*1*		164
410039	Tumut River @ Brungle Bridge	Evaluation	*0*	*1*		117
410130	Murrumbidgee River d/s Balranald Weir	Evaluation	*9*	*12*		740
410134	Billabong Creek @ Darlot	Evaluation	*0*	*34*		765

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

Station number	**Station name**	**Data use**	**Data days**		**Comments for data errors**	**Final data days**
			Missing flow	*Data errors*		
410001	Murrumbidgee River @ Wagga Wagga	Evaluation	0	0		3,121
410004	Murrumbidgee River @ Gundagai	Evaluation	0	0		3,043
410023	Murrumbidgee River @ d/s Berembed Weir	Evaluation	0	0		750
410085	Little Mirrool Creek Drain @ d/s Gogeldrie Main Drain	Evaluation	0	0		1,267
410093	Old Man Creek @ Kywong (Topreeds)	Evaluation	0	0		351

Station number	Station name	Data use	Data days		Comments for data errors	Final data days
			Missing flow	*Data errors*		
410108	Drainage Canal 800 @ Outfall	Evaluation	0	0		2,881
410110	Drainage Canal 500 @ Outfall	Evaluation	0	47	Spikes representing groundwater baseflow were unrealistically capped.	2,654
410130	Murrumbidgee River @ d/s Balranald Weir	Evaluation	0	2	Spike during very constant flow period	3,258
410133	Coleambally Outfall Drain @ near Bundy	Evaluation	0	0		2,652
410134	Billabong Creek @ Darlot	Evaluation	0	0		3,183
410135	Coleambally Catchment Drain @ Farm 544	Evaluation	0	0		2,481
410148	Forest Creek @ Warriston Weir	Evaluation	0	0		1,087

Table 3.4. Cumulative distribution statistics of screened EC data sets

Station Number	Station name	Data type	Data use	Salinity statistics mg/L			Q_{50} ML/d
				C_{25}	C_{50}	C_{75}	
410001	Murrumbidgee River @ Wagga Wagga	Discrete	Evaluation	118	70	51	10,885
410001	Murrumbidgee River @ Wagga Wagga	Continuous	Evaluation	130	77	57	
410002	Murrumbidgee River @ Hay	Discrete	Evaluation	74	53	44	2,016
410004	Murrumbidgee River @ Gundagai	Discrete	Evaluation	99	63	47	10,035
410004	Murrumbidgee River @ Gundagai	Continuous	Evaluation	120	66	49	
410008	Murrumbidgee River d/s Burrinjuck Dam	Discrete	Inflow	116	102	89	1,801
410008	Murrumbidgee River d/s Burrinjuck Dam	Continuous	Inflow	132	122	115	
410016	Billabong Creek @ Jerilderie	Discrete	Evaluation	188	134	87	308
410017	Billabong Creek @ Conargo	Discrete	Evaluation	140	105	81	493
410023	Murrumbidgee River d/s Berembed Weir	Continuous	Evaluation	128	64	53	5,298
410025	Jugiong Creek @ Jugiong	Discrete	Inflow	930	756	572	69
410025	Jugiong Creek @ Jugiong	Continuous	Inflow	987	939	682	
410038	Adjungbilly Creek @ Darbalara	Discrete	Inflow	113	90	68	97
410039	Tumut River @ Brungle Bridge	Discrete	Evaluation	32	23	20	6,443
410044	Muttama Creek @ Coolac	Discrete	Inflow	1,032	915	666	22
410044	Muttama Creek @ Coolac	Continuous	Inflow	1,139	1,095	1,044	
410045	Billabung Creek @ Sunnyside	Discrete	Inflow	198	135	110	0

Station Number	Station name	Data type	Data use	Salinity statistics mg/L			Q_{50} ML/d
				C_{25}	C_{50}	C_{75}	
410047	Tarcutta Creek @ Old Borambola	Discrete	Inflow	191	156	131	179
410047	Tarcutta Creek @ Old Borambola	Continuous	Inflow	206	199	183	
410048	Kyeamba Creek @ Ladysmith	Discrete	Inflow	600	438	285	5
410048	Kyeamba Creek @ Ladysmith	Continuous	Inflow	874	722	628	
410057	Goobarragandra River @ Lacmalac	Discrete	Inflow	39	34	28	450
410057	Goobarragandra River @ Lacmalac	Continuous	Inflow	36	29	24	
410059	Gilmore Creek @ Gilmore	Discrete	Inflow	60	54	45	89
410061	Adelong Creek @ Batlow Road	Discrete	Inflow	87	72	63	56
410071	Brungle Creek @ Red Hill	Discrete	Inflow	267	234	201	14
410073	Tumut River @ Oddys Bridge	Discrete	Inflow	22	20	18	5,182
410073	Tumut River @ Oddys Bridge	Continuous	Inflow	29	20	17	
410085	Little Mirrool Creek Drain d/s Gogeldrie Weir	Continuous	Evaluation	310	258	222	146
410091	Billabong Creek @ Walbundrie	Discrete	Inflow	1,131	754	384	87
410091	Billabong Creek @ Walbundrie	Continuous	Inflow	1,372	951	538	87
410093	Old Man Creek @ Kywong (Topreeds)	Continuous	Evaluation	129	68	59	613
410108	Drainage Canal 800 @ Outfall	Continuous	Evaluation	210	163	127	140
410110	Drainage Canal 500 @ Outfall	Continuous	Evaluation	378	278	216	196
410130	Murrumbidgee River d/s Balranald Weir	Discrete	Evaluation	137	106	80	818
410130	Murrumbidgee River d/s Balranald Weir	Continuous	Evaluation	143	107	81	
410133	Coleambally Outfall Drain near Bundy	Continuous	Evaluation	374	262	208	40
410134	Billabong Creek @ Darlot	Discrete	Evaluation	150	130	107	575
410134	Billabong Creek @ Darlot	Continuous	Evaluation	167	140	116	
410135	Coleambally Catchment Drain @ Farm 544	Continuous	Evaluation	91	70	57	51
410148	Forest Creek @ Warriston Weir	Continuous	Evaluation	195	148	108	171

4. The Murrumbidgee IQQM

4.1. QUANTITY MODEL

The history of the Murrumbidgee IQQM started with its monthly time step predecessor. The monthly 'Murrumbidgee Valley Irrigation Model' was first developed in the late 1970s by predecessors to the Department of Infrastructure, Planning and Natural Resources (DIPNR) and was still in use in the late 1990s. At that time, the Murrumbidgee River Management Committee (RMC) was devising the environmental flow rules (EFRs) which are still basically in use today. Those rules included a set of very complex environmental accounts and Burrinjuck Dam translucent dam release rules where the minimum dam release is a function of dam inflow. The complexity was required to achieve an environmental outcome, which minimised high year diversion impacts with the consequent severe socio-economic impact. The monthly model proved to be good at assessing the resource implications of the EFRs but the monthly time-step limited analysis of peak flood flow inundation analysis and other inter-month attributes.

Planning for a Murrumbidgee IQQM started in the mid-1990s but serious development did not begin until 1999 due to higher priority work. The completed model was used in the Murrumbidgee Water Sharing Plan (WSP) process which required the Murrumbidgee RMC to recommend a set of irrigation/environment resource sharing rules to the NSW Government. These rules would remain unaltered for ten years to give farmers a greater degree of certainty in their investment decisions. The Murrumbidgee RMC recommendations were largely accepted by government and the Murrumbidgee WSP was gazetted in December 2002. The plan is due to come into effect on 1 July 2004.

4.1.1. Murrumbidgee System

The Murrumbidgee IQQM is able to simulate scenarios and is capable of handling emerging water management modelling needs. Further refinements were anticipated during the course of this project to improve its capacity to reliably model salt transport. The overall structure of the Murrumbidgee System IQQM is shown in Figure 4.1.

The upstream boundaries of the model are the inflows to Burrinjuck and Blowering Dams. Inflows into Blowering Dam are based on a model developed by SnowyHydro for the period up to November 1975. After this, inflows are calculated by means of a water balance. The SnowyHydro model is fairly old and doesn't address Snowy corporatisation issues. Burrinjuck Dam inflows are derived by water balance means for the entire benchmark period. No effort has been made to de-trend the data for landuse changes or urban development changes.

River flow, evaporation and rainfall data used in the model will be fully described in the Murrumbidgee Cap Report (due for completion in 2004). In brief, all rainfall and evaporation data were obtained from the Bureau of Meteorology, except for Griffith ETO which was obtained directly from the CSIRO. Rainfall and evaporation data were gap filled according to standard methods used for IQQM. All flow data was obtained from the DIPNR HYDSYS database. Missing inflow values were estimated using Sacramento Rainfall-Runoff models (HydroTechnology ,995).

Downstream of the dams, the model covers the areas described in Sections 2.1.2.2 to 2.1.2.4 as well as the Murrumbidgee Irrigation Area and Lowbidgee Irrigation District described below.

4.1.1.1. The Murrumbidgee Irrigation Area.

This sub-system is modelled in some detail. Its boundaries are the Murrumbidgee River inputs from the Main and Sturt Canals and the natural inflows from Mirrool and Little Mirrool Creeks. It includes Main Drain J, Brays Dam, Willow Dam and Barren Box Swamp. Irrigation is represented by thirty IQQM irrigation nodes. The sub system model includes the generation of drainage flows from supply and on farm escapes, on-farm rainfall-runoff and irrigation washoff. Although salinity is also modelled, no attempt has been made to evaluate it as no water returns from the MIA.

4.1.1.2. The Lowbidgee Irrigation District

Lowbidgee Irrigation District is made up of two sub-systems. The Redbank Forest system, which is modelled as an off-river pond hydraulically connected to the river, and the Nimmie-Caira system, which consists of numerous bays modelled as a series of connected storages. Although the latter returns water to the Murrumbidgee River, there is little flow data and even less salinity data.

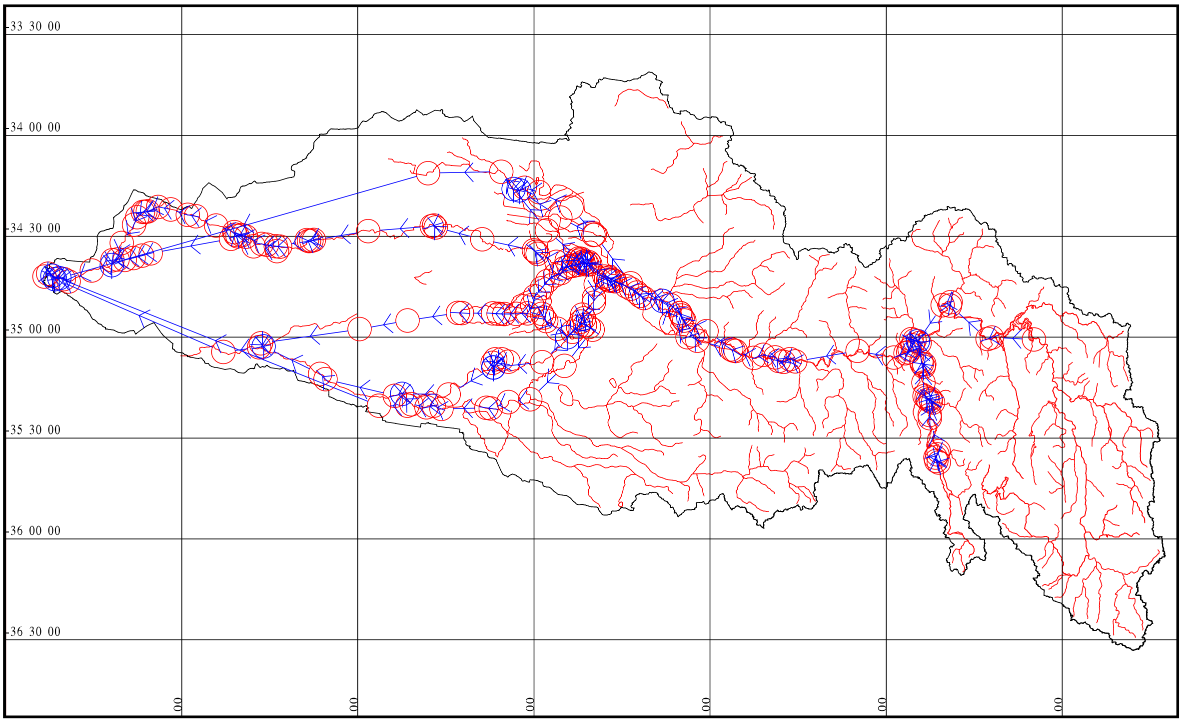


Figure 4.1. Schematic Murrumbidgee System IQQM

Figure 4.1 is only meant to present an overview of the Murrumbidgee System IQQM. The complexity of the Murrumbidgee System IQQM, with over 350 nodes, is such that the detail cannot be presented on a single A4 page. This limitation has been addressed by presenting the major types of nodes as separate figures, showing the geographic location and relative magnitude, where possible, of:

- inflows (Figure 4.2 to Figure 4.4)
- storages (Figure 4.5)
- irrigation demands (Figure 4.6 to Figure 4.7), and
- instream and environmental nodes (Figure 4.8)

These features of the Murrumbidgee IQQM are discussed in sections 4.1.2 to 4.1.5.

4.1.2. Inflows

The Murrumbidgee IQQM has fifteen stream inflow nodes and twenty-seven flow calibration gauge nodes. The magnitude and distribution of these inflows, along with returning effluent nodes, is shown in Figure 4.2 to Figure 4.4.

The largest single inflow in the Murrumbidgee System IQQM is the Blowering Dam inflow, followed closely by the Burrinjuck Dam inflow. The remaining inflows occur between the dams and Wagga Wagga, with the exception of Billabong and Houlaghans Creeks.

Each river section is defined by an upstream and downstream gauge node and usually contains one or more loss nodes. However, upstream of Gundagai, the loss nodes are set to zero as there is little net loss in this reach.

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 Murrumbidgee Valley Cap calibration report (in preparation). 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.

4.1.3. Storages

Eight actual storages (some storages in the model are conceptual) are modelled in the Murrumbidgee System IQQM. Their locations and sizes are shown in Figure 4.5.

The headwater dams, Burrinjuck and Blowering, meet most of the regulated demand. Most of the time Blowering Dam meets as much as possible of any order at the Tumut-Murrumbidgee confluence, allowing for the 9,000 ML/d capacity constraint on regulated flows in the Tumut River. Burrinjuck Dam then meets the remaining part of the order.

Further downstream, Berembed and Gogeldrie Weirs have very limited operating ranges as their main function is to provide sufficient head to get water into the canal systems of the Murrumbidgee and Coleambally Irrigation Areas. The model ‘passes’ orders coming to these storages on to the headwater storages.

Tombullen off-river storage is filled by rain rejections and tributary flow events. In the model, Tombullen Storage meets as much of any orders downstream of the irrigation areas as its limited volume and outlet capacity allows. The practice of releasing extra water from Tombullen (above the downstream requirements) to address water quality problems within the storage is not modelled.

Hay Weir has a capacity of about 13 GL and is about eighteen days downstream of the headwater storages. It acts as a buffer against the unpredictable variations in downstream demands. Maude Weir is used to further buffer demands in the Maude to Redbank reach and to provide head for the Nimmie-Caira sub-system in Lowbidgee. Redbank Weir provides head for the regulators supplying the Redbank Forest sub-system in Lowbidgee.

4.1.4. Extractive demands

As with other regulated river systems, allocation of water to irrigators in the Murrumbidgee River System occurs under a volumetric allocation system. The total active licence entitlement in the regulated river system is 2,750,025 ML. This can be broken down into:

- 2,043,432 ML of general security entitlement, including the general security component of the Murrumbidgee Irrigation and Coleambally Irrigation bulk licences.
- 298,021 ML of high security entitlement, most of which is used for horticulture (although town water supplies account for 23,403 ML);
- 35,572 ML of stock & domestic entitlement; and
- 373,000 ML conveyance, or transmission loss, allowance (243,000 M for Murrumbidgee Irrigation and 130,000 ML for Coleambally Irrigation).

Figure 4.7 shows how general and high security water usage is distributed throughout the river system.

4.1.4.1. Supplementary water usage

Supplementary water access in the Murrumbidgee Valley is governed by a complex set of rules, all of which have been incorporated into the Murrumbidgee IQQM.

These rules are very different from those used in the northern valleys of NSW where supplementary water access provides opportunities to pump large volumes of water into on-farm storages. The only time this sort of usage occurs in the Murrumbidgee is at the start of the season when the Irrigation Corporation fills its canals. In general, due to the lack of on-farm storages in the regulated parts of the Murrumbidgee Valley, supplementary water is simply ‘substituted’ for regulated water. Regulated licence holders divert the same amount of water as they would if supplementary access had not been declared, the difference is that it is not counted against their volumetric licence limits.

The complexity arises from the legislated priorities for supplementary water usage between the Murrumbidgee regulated water users, NSW Murray regulated users and Lowbidgee users (there is a ranking amongst these as well). Supplementary water usage is also subject to annual ‘history of use’ caps, which are applied to individual licence holders after allocations have reached 70% (before 70% is reached, all users have unlimited access to any available supplementary water), as well as a total cap of 220,000 ML for the valley.

4.1.5. In-stream demands

In-stream regulated demands are simulated at six locations in the Murrumbidgee IQQM using Type 9.0, and Type 10 nodes (Figure 4.8). The purpose of each node is described in Table 4.1.

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

Node type	In-stream ordering node name	Purpose
10.6	Burrinjuck Dam transparency / translucency EFR Requirement	Minimum release from Burrinjuck Dam as a function of inflow, time of year, dam level, Gundagai flow constraint and catchment conditions. Includes an Environmental Flow Rule for the Murrumbidgee River between Burrinjuck Dam and the Murrumbidgee-Tumut River confluence.
9.0	Blowering Dam minimum release	Minimum release from Blowering. Designed to maintain flows in the Tumut River between Blowering Dam and the Murrumbidgee-Tumut River confluence.
9.0	Balranald minimum flow	Sets end of valley minimum flow requirement depending on allocation levels. Can be either 200 ML/d or 300 ML/d.
9.0	D/S Hay Weir minimum flow requirement	Operational requirement
9.0	Darlot minimum flow target	Operational minimum flow target of 50 ML/d originating from the 1988 Salinity and Drainage Strategy.
9.0	Minimum flow requirement at Warriston Weir on Forest Creek	Operational requirement mainly for Stock & Domestic replenishment. Normally set at a 100 ML/d.

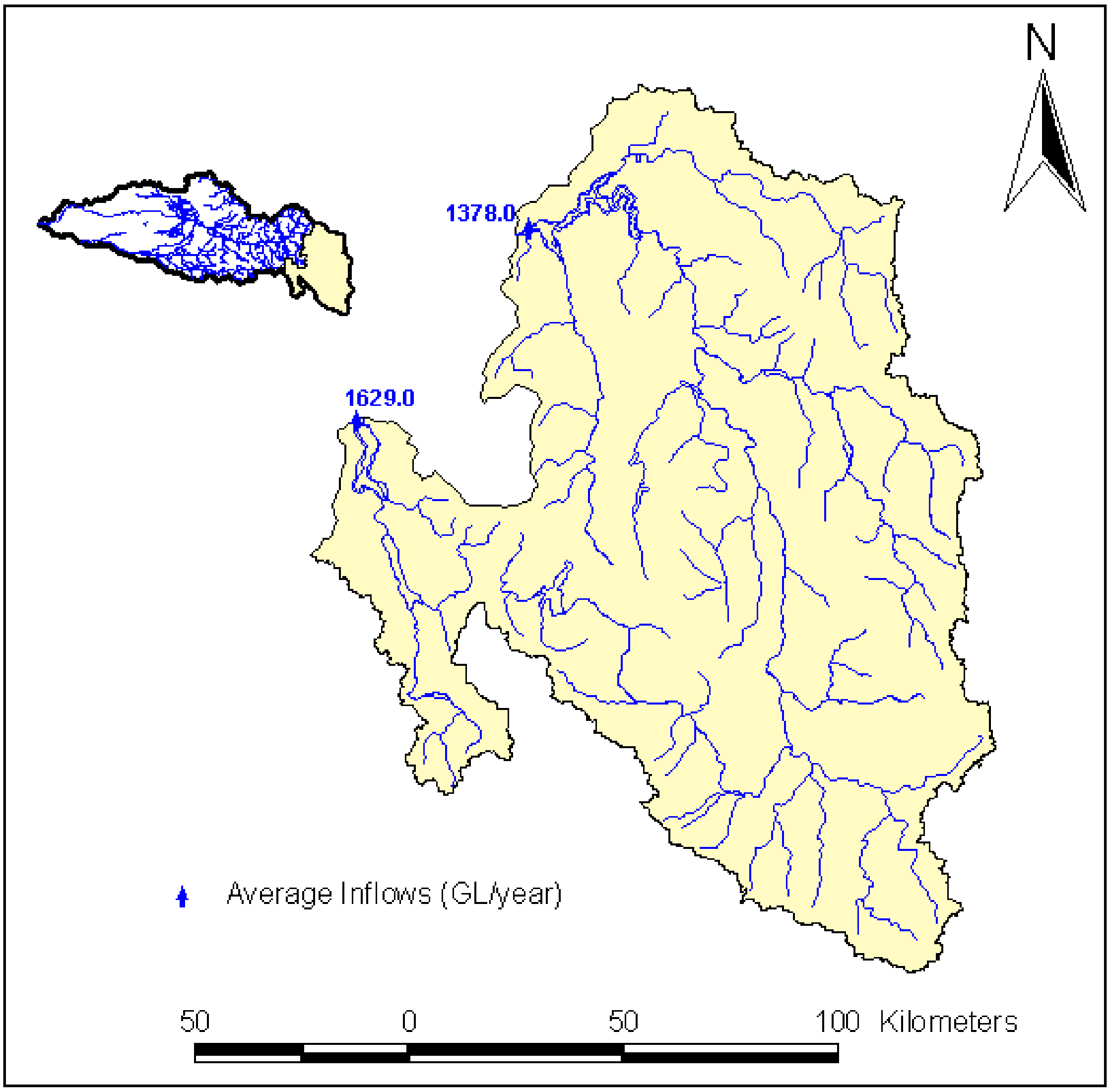


Figure 4.2. Distribution of modelled annual average (1975-2000) inflows in upstream of Burrinjuck and Blowering Dams region of Murrumbidgee Valley.

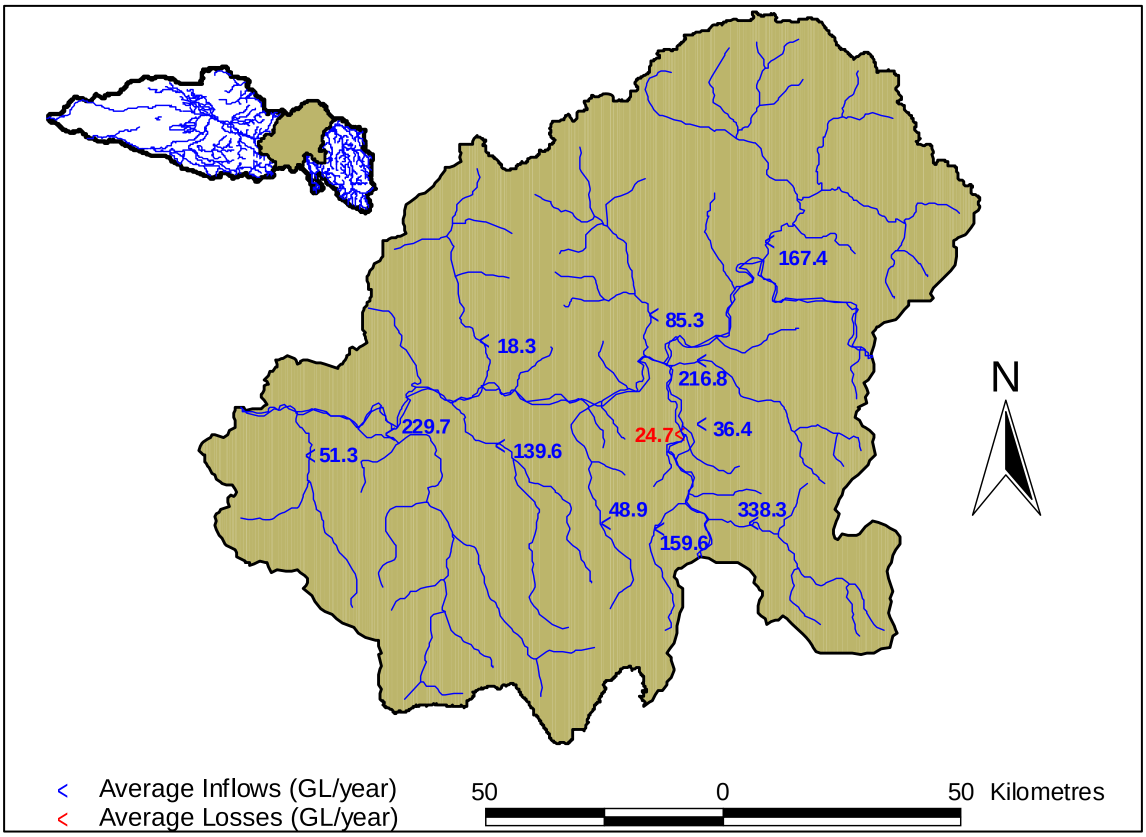


Figure 4.3. Distribution of modelled annual average (1975-2000) inflows and losses in Burrinjuck and Blowering Dams to Wagga Wagga region of Murrumbidgee Valley

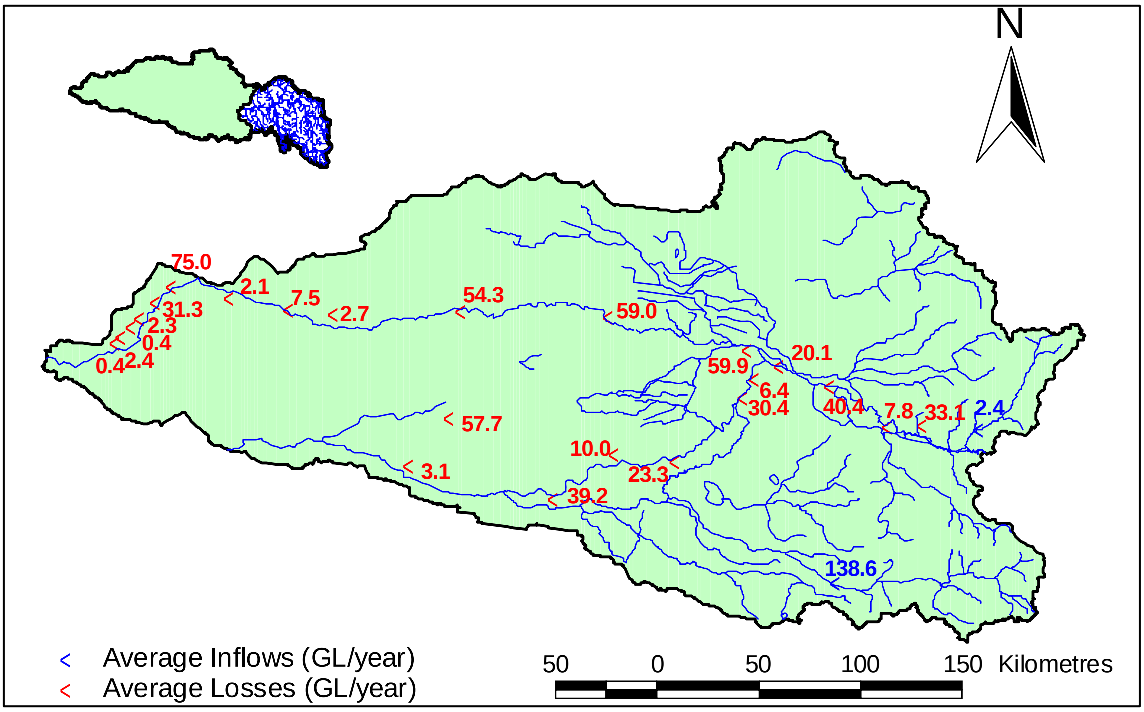


Figure 4.4. Distribution of modelled annual average (1975-2000) inflows and losses in downstream of Wagga Wagga region of Murrumbidgee Valley.

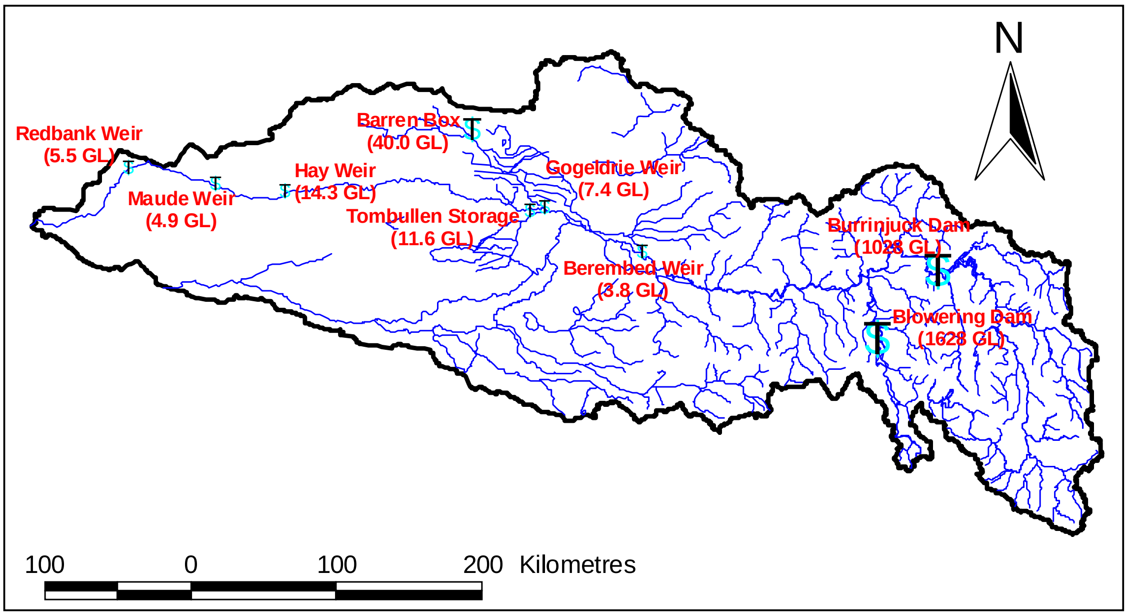


Figure 4.5. Modelled storages in the Murrumbidgee System IQQM.

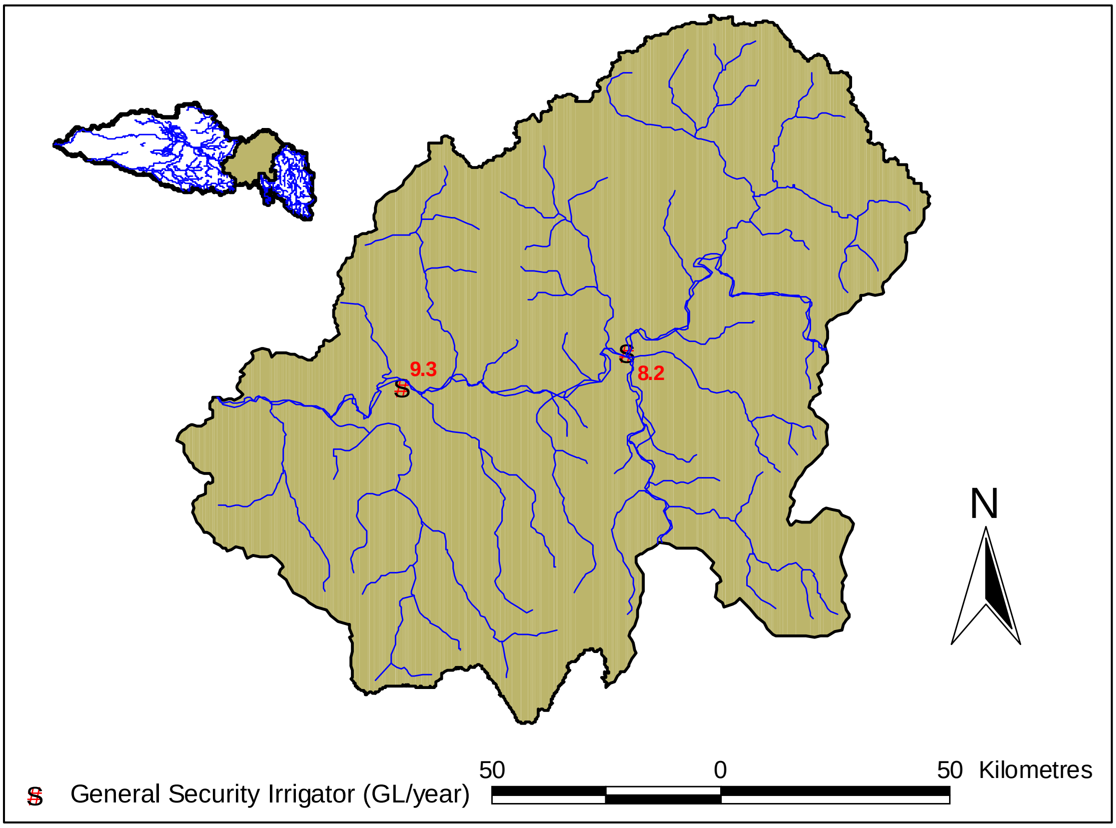


Figure 4.6. Modelled average annual irrigation diversions (GL/year; 1975-2000) for Burrinjuck and Blowering Dams to Wagga Wagga region.

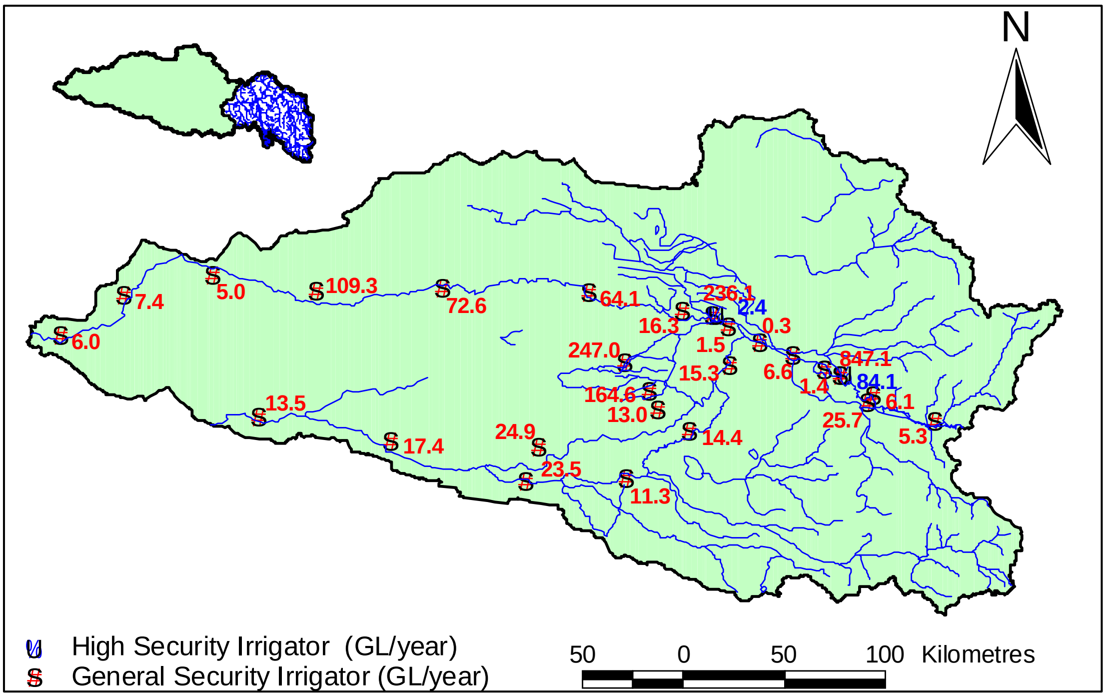


Figure 4.7. Modelled average annual irrigation diversions (GL/year, 1975-2000) for downstream of Wagga Wagga Region

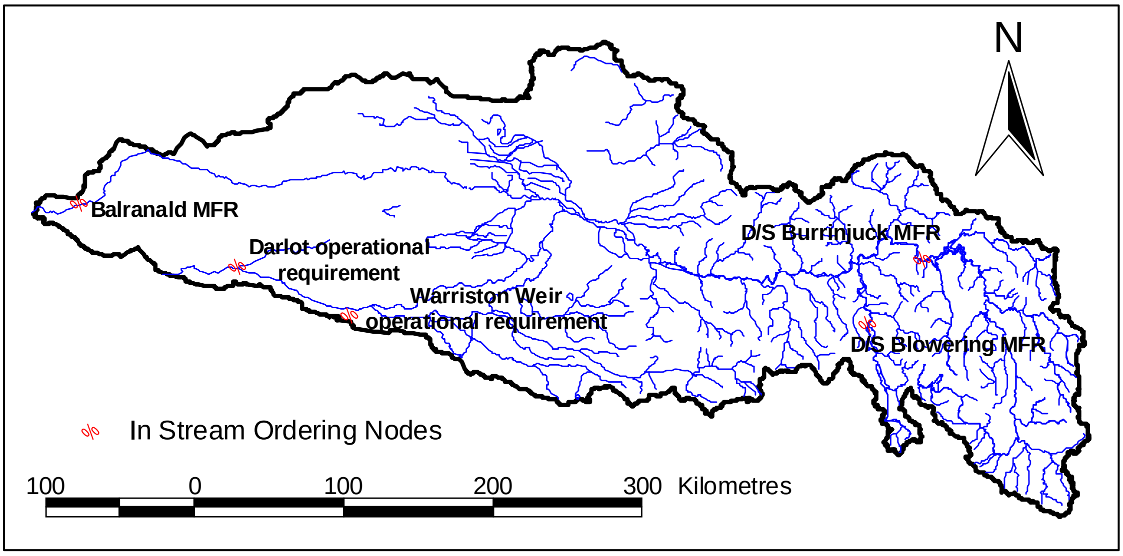


Figure 4.8. Distribution of nodes for ordering in-stream and environmental flow requirements

4.2. QUALITY ASSURANCE OF QUALITY MODEL

4.2.1. QA Test 1: Update base quantity model

The results of the mass balance check for the major water balance components of the base quantity model over the simulation period 1975-2000 (see Volume 2, Section 3.1.1) are shown in Table 4.2. The total error over the period of simulation is 11 ML, out of a total inflow of $69*10^6$ ML, or 0.00001 %. The magnitude of these results is typical of the order of magnitude that would be expected from rounding errors in the calculations, and we can conclude that there are effectively no flow mass balance errors in the IQQM software.

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

Water balance component	Sum over simulation period (ML)
Inflows	27,153
Losses	12,027
Extractions	13,985
Storage change	1,140
Error	0

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

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

The results for the quantity mass balance comparison reported in Table 4.3 show changes for the water balance components in the order of 0.007-0.351%. These differences are due to the introduction of surface areas in reaches with routing parameters (the original model contained reaches with a surface area of ‘zero’ - this will not work when modelling quality so dummy areas were entered). However, the differences are small enough that the remainder of the work can continue with some confidence that the software is working well enough. The salt mass balance report is shown in Table 4.4, and the results show that there are no numerical sources or sinks of salt introduced in the software.

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

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

Water balance component	QA Test 1 Sum over simulation period (ML)	QA Test 2 Sum over simulation period (ML)
Inflows	27,153	27,155
Losses	12,027	12,029
Extractions	13,985	13,989
Storage change	1,140	1,136
Error	0	0

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

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

4.2.3. QA Test 3: Constant flow and concentration

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

The result aimed for at the end of system was ($\mu \pm \sigma$) 100.0 ± 0.0 mg/L. The actual result was 100.0 ± 0.4 mg/l, with very little deviation occurring after the start up period.

4.2.4. QA Test 4: Variable flow and constant concentration

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

The result aimed for at the end of system was ($\mu \pm \sigma$) 100.0 ± 0.0 mg/L. The actual result was 99.8 ± 0.9 mg/l. A time series inspection of the salinities indicate that the deviations from 100.0 only occur at very low flows after almost all the mass has gone through..

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 as described in Volume 2, Section 3.1.5, with constant salinity concentration of 100 mg/L. All other inflow nodes had zero flow and concentration, and all storages, diversions, and effluents were modified to have no effect on water balance.

The results are shown at Figure 4.9. 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. This result was achieved.

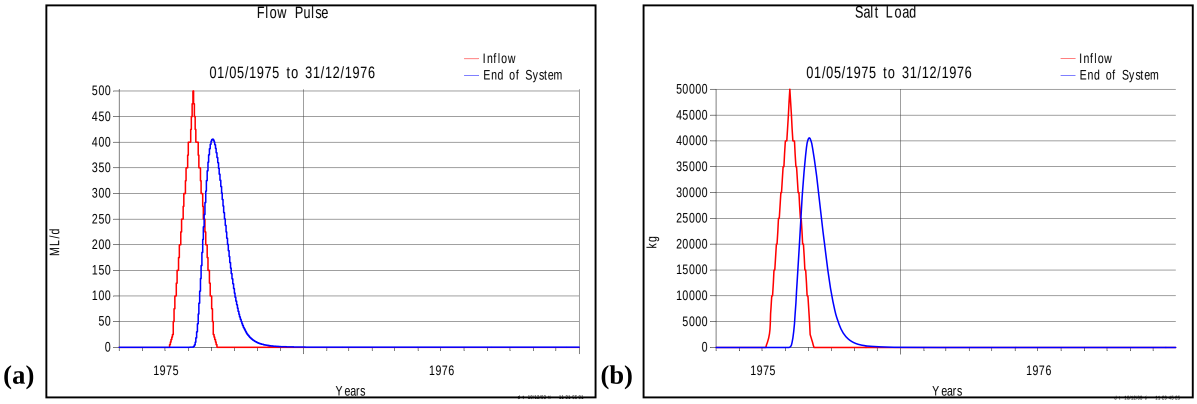


Figure 4.9. (a) Inflows and resultant EOS flows; (b) Salt load inflows and EOS salt loads

4.2.6. QA Test 6: Salt pulse with constant flow

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

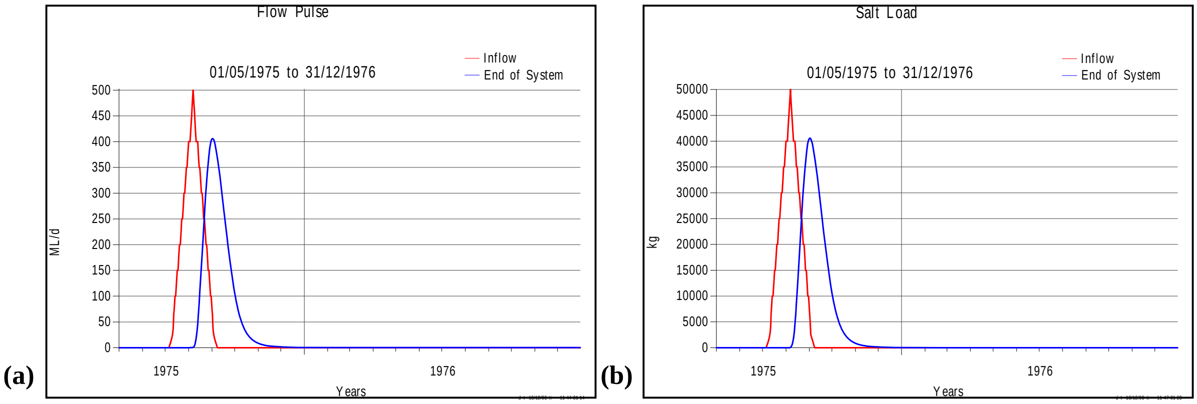


Figure 4.10. (a) Salt load inflows and EOS salt loads; (b) Concentration inflows and EOS concentration

4.3. QUALITY MODEL DEVELOPMENT

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

5. Salt inflow estimates and evaluation

5.1. INITIAL ESTIMATE

Salt loads were input to the model at all the inflow nodes as discussed in Volume 2, Section 3.2. The initial estimates for the salt load inflows were based on the relationships documented in Table 5.11 of the Salinity Audit (Beale et al, 1999). These relationships are the basis of the 'first cut' models. The flow and salt load results from the 'first cut' model are firstly tested for consistency with the Salinity Audit results (Appendix B) before being evaluated against in-stream concentration data.

The schematisation of the salt load inflows and balance points from Figure 5.13 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 5.11 in the Salinity Audit were modified in the following ways as explained in Volume 2:

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

(ii) Replaced model forms IIA and IIB with model form IID;

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

(iv) Concentration capped to highest observed;

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

The relationship between the IQQM network structure and the Salinity Audit inflows referred to in point (i) above is listed in Table 5.1 for gauged catchments and Table 5.2 for residual catchments. In accordance with point (ii), new (model form IID) relationships had to be derived for all inflows in the Murrumbidgee model. This also provided an opportunity to use all of the available discrete salinity data (much of which was not used for the Audit). Tabular flow-salinity relationships were calibrated for the IQQM inflows to Burrinjuck and Blowering Dams as the Audit had started at their outflows rather than inflows. As there was no way to derive model IID relationships for the residual catchments, they were given the same inflow salinity as their respective upstream catchments (the residual inflows generally represent the lower reaches of gauged catchments). The concentration cap adopted for point (iv) above is also shown in Table 5.1 and Table 5.2.

In the Murrumbidgee model, no attempt was made to calibrate the salt inflow estimates to match the observed in-stream concentration data due to the unresolved issues of trend determination and editing of continuous salinity data editing (see Section 7.2.1).

However, some additional work was also carried out on water quantity aspects of the Murrumbidgee IQQM to improve the model's ability to simulate salinity in the valley. This work is described in more detail later in this chapter and includes:

- re-calibration of some losses in the system; and
- an attempt to better the represent the operation of the Yanco offtake.

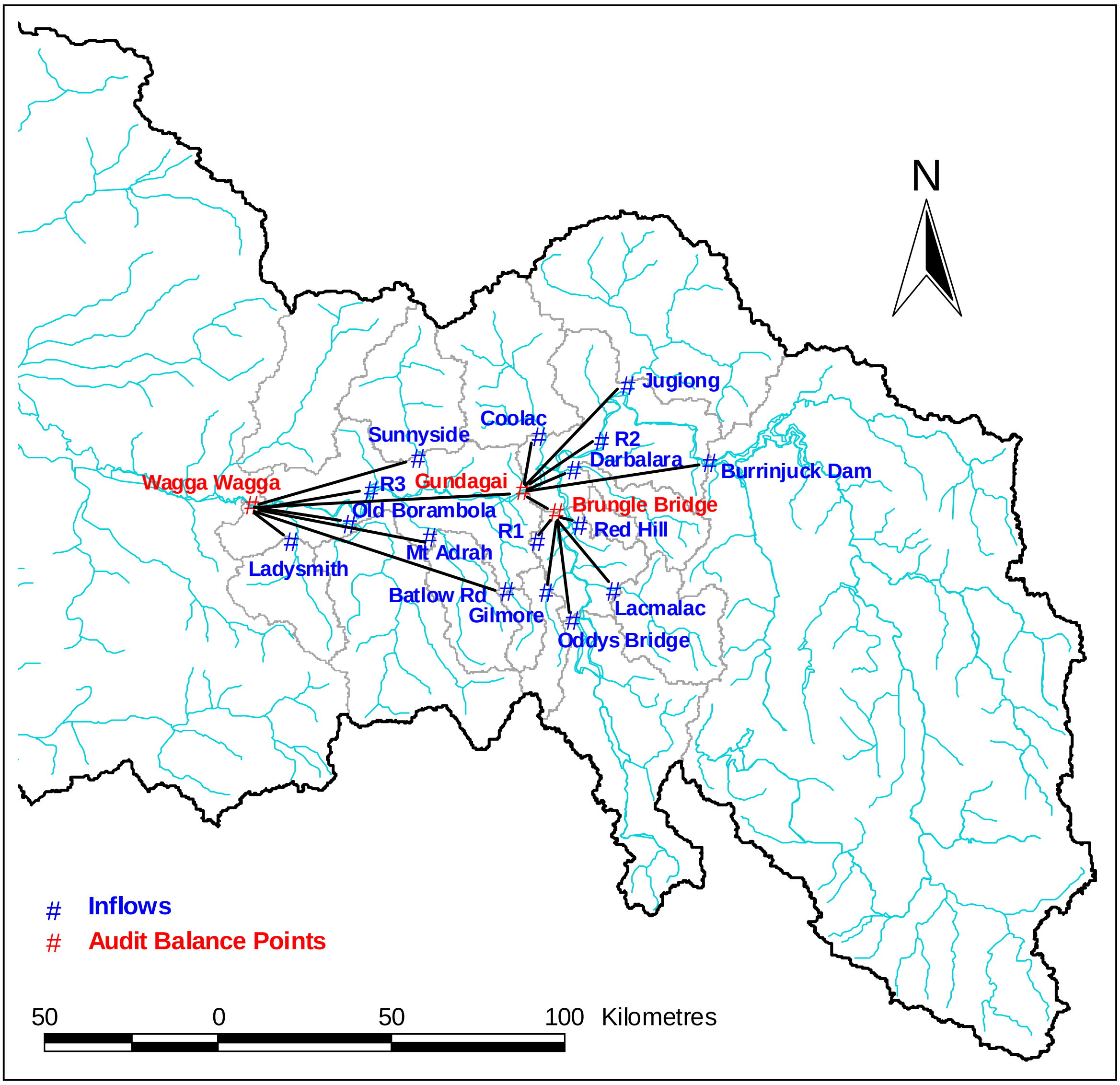


Figure 5.1. Geographic representation of 1999 Salinity Audit schematic of inflows and balance points

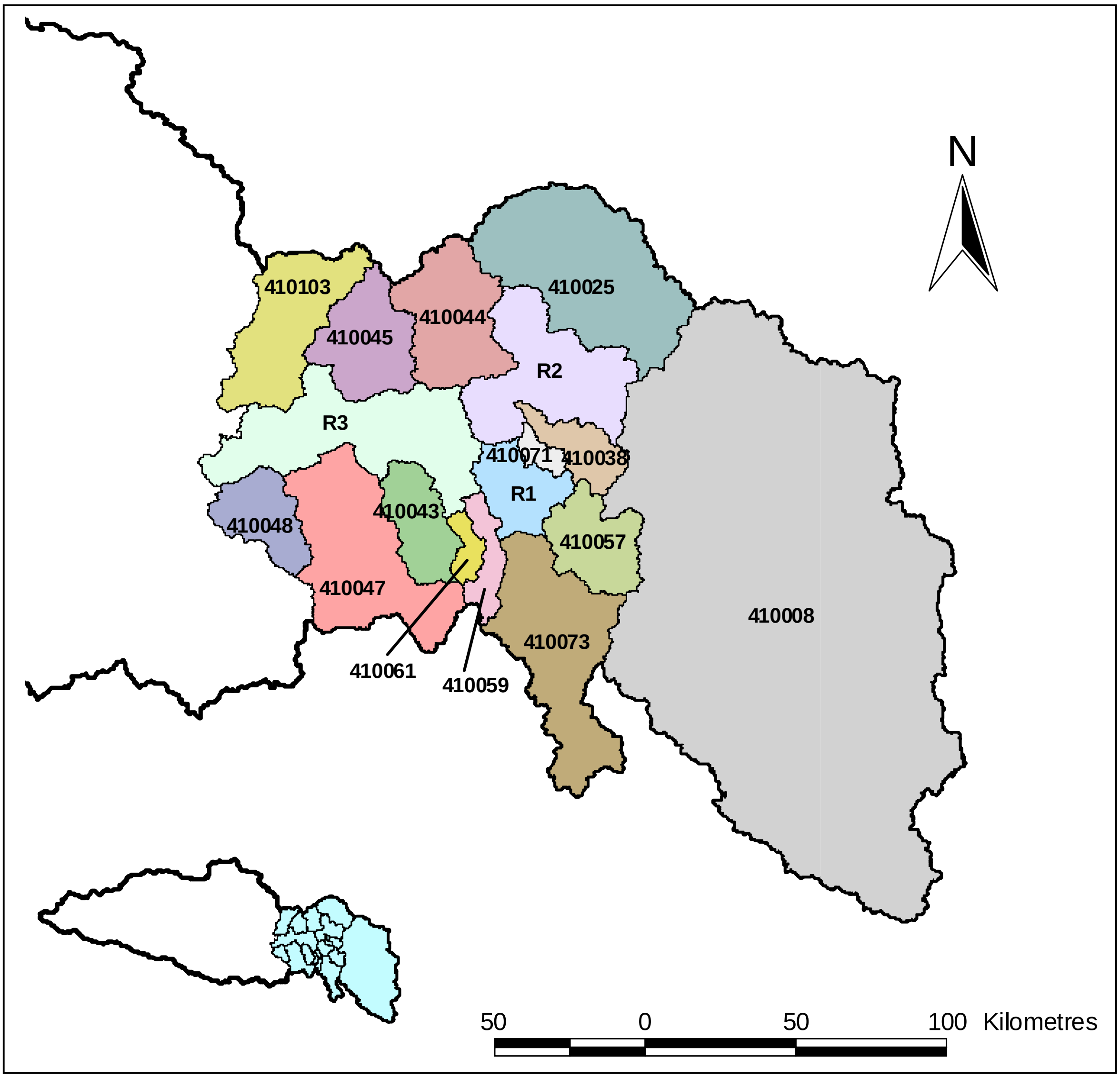


Figure 5.2. Inflow catchments used for 1999 Salinity Audit

Table 5.1. Salt inflow model parameters for gauged catchments

	Subcatchment		**Audit load flow model**			
Gauge number	**Station name**	**IQQM inflow node number**	*Type*	η	λ	C_{max} *(mg/L)*
410073	Tumut River @ Oddys Bridge	312	IIA	-6.7	1.56	
	Blowering Dam inflow	*310*	*Constant salinity input*			*22*
410057	Goobarragandra River @ Lacmalac	313	IIA	-6.7	4.9	
			IID	*1.3065*	*0.8519*	*127*
410059	Gilmore Creek @ Gilmore	318	IIA	-6.7	5.2	
			IID	*1.4457*	*0.8954*	*204*
410071	Brungle Creek @ Red Hill	320	IIA	-11.5	8.39	
			IID	*2.6880*	*0.8173*	*918*
410038	Adjungbilly Creek @ Darbalara	324	IIA	-11.5	6.0	
			IID	*2.0379*	*0.7970*	*414*
410008	Murrumbidgee River d/s Burrinjuck Dam	303	IIA	-11.5	8.39	
	Burrinjuck Dam inflow	*301*	*Flow-salinity table*			*250*
410025	Jugiong Creek @ Jugiong	305	IIB	4.19	0.69	
			IID	*4.0696*	*0.9078*	*1980*
410044	Muttama Creek @ Coolac	327	IIA	-45.6	22.0	
			IID	*4.0513*	*0.8534*	*1543*
410061	Adelong Creek @ Batlow Road	332	IIA	3.31	5.7	
			IID	*1.7780*	*0.8442*	*168*
410045	Billabung Creek @ Sunnyside	333	IIA	-45.9	80	
			IID	*2.5135*	*0.9440*	*480*
410043	Hillas Creek @ Mount Adrah	443	IIA	3.31	6.0	
			Set to same salinity as 410047			
410047	Tarcutta Creek @ Old Borambola	444	IIB	2.79	0.783	
			IID	*2.7173*	*0.8783*	*642*
410048	Kyeamba Creek @ Ladysmith	334	IIA	-34.9	33.2	
				3.2186	*0.8479*	*1086*
410012*	Billabong Creek @ Cocketgedong	178	IID	4.1160	0.5827	

* *Not in Salinity Audit as downstream of the last Balance Point at 410001. Flow-load relationship derived from data for 410091 Billabong Creek @ Walbundrie.*

Table 5.2. Salt inflow model parameters for residual catchments

Subcatchment		IQQM inflow	Audit load flow model			
Number	**Description**	**node number**	*Type*	η	λ	C_{max} (mg/L)
R1	Ungauged Tumut River u/s Brungle Bridge	213, 214, 215	IIA	-6.7	6.5	n/a
	Goobarragandra River residual catchment	213	*Set to same salinity as 410057*			
	Gilmore Creek residual catchment	214	*Set to same salinity as 410059*			
	Brungle Creek residual catchment	215	*Set to same salinity as 410071*			
R2	Ungauged Tumut and Murrumbidgee Rivers u/s Gundagai	216, 212, 217	IIA	-45.6	22.0	n/a
	Adjungbilly Creek residual catchment	216	*Set to same salinity as 410038*			
	Jugiong Creek residual catchment	212	*Set to same salinity as 410025*			
	Muttama Creek residual catchment	217	*Set to same salinity as 410044*			
R3	Ungauged Murrumbidgee River between Gundagai and Wagga Wagga	218, 219, 272, 232, 273	IIA	Parameters not given in Salinity Audit Report		
	Adelong Creek residual catchment	218	*Set to same salinity as 410061*			
	Billabung Creek residual catchment	219	*Set to same salinity as 410045*			
	Hillas Creek residual catchment	272	*Set to same salinity as 410047*			
	Tarcutta Creek residual catchment	232	*Set to same salinity as 410047*			
	Kyeamba Creek residual catchment	273	*Set to same salinity as 410048*			

5.2. EVALUATION METHOD

The salt transport models have to be developed to the point where they are fit for the intended purposes, which are:

(i) estimating a time series of flows and salt loads under baseline conditions at valley target locations for the benchmark climatic period; and

(ii) simulating the impact of salinity management interventions and other actions on salinity targets.

The extent to which the salt transport model is fit for purpose can be tested by comparing how well the model reproduces observed data of flow and concentration. A satisfactory performance, matching model results against observed data, provides some confidence that the model can reliably simulate scenarios that differ from the observed. Appropriate methods to measure performance have to be developed to be able to reach this conclusion. These performance measures need to be robust and the use of multiple measures helps to ensure this. The use of inappropriate methods to calibrate a model (eg. setting parameter values outside reasonable ranges) may achieve a satisfactory result for one performance measure but will probably fail others.

The quantity part of the model has not had a formal peer review process. Informal review has taken place through regular discussions with DIPNR's river operators who probably have the greatest all-round knowledge of the Murrumbidgee system.

Appropriate performance measures are being developed for salinity. Initially they will be similar to some of those used for flow calibration although modified to account for the characteristics of salinity data. These are described in Sections 5.2.3 and 5.2.4.

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, the result will be an incorrect estimate of simulated concentration at the gauge location (C_{obs}).

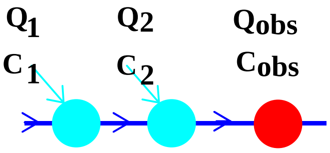


Figure 5.3. Calculating resultant concentration from two tributaries

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

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)

Inflows to the Murrumbidgee IQQM headwater storages are derived by means of a water balance and are reasonably accurate. Downstream of storages, observed flows depend a lot on regulation (ie. how much water was released from the storage). No single configuration of the model estimates these releases well over the period when data was collected, because levels of irrigation development and storage operation policies changed within this period.

A good match of the flows downstream of the storages was achieved by forcing the releases from the storages to observed releases. This method works reasonably well except when diversions are a significant proportion of the flow in the river. Simulated diversions in the Murrumbidgee System IQQM used to evaluate results are based on 1993/4 levels of development, and any errors in estimating diversions would contribute to errors in the simulated flow compared with observed. In other valleys, these errors may not significantly effect simulated concentrations as most of the inflows have already entered the major rivers upstream of most of the diversions. However, in the Murrumbidgee, water is regularly diverted from one part of the system to another, mixed with run-off from irrigation areas, then returned to the main river via drainage canals. This mixing of water from different sources within and downstream of the major irrigation areas, combined with the relatively large volumes used for irrigation, make it much more important to accurately model irrigation diversions in the Murrumbidgee Valley.

The installation of a new Yanco Creek offtake structure in the mid-1990s meant that flows from the Murrumbidgee River into Yanco Creek and from Yanco Creek into Colombo Creek also had to be forced to observed values in the model. A final Murrumbidgee variation was not to force any flows by running the cap or current condition models without any constrain or forcing.

5.2.2. Selection of evaluation sites

A total of thirty-two locations have data that could be used for model evaluation (

Table 3.2) and fourteen of these have continuous data (Table 3.3). Model results were only evaluated at locations of interest such as:

- NSW Catchment Blueprint target sites;
- ‘end of system’ sites where water flows into the Murray River;
- sites where the model performance has a significant effect on the performance at the above-mentioned sites;
- sites with sufficient data to carry out a meaningful evaluation.

The Murrumbidgee Catchment Blueprint target is:

(i) Station 410130: Murrumbidgee River downstream Balranald Weir

The last station on the Murrumbidgee River before it joins the Murray River. Balranald has a good long-term continuous EC record and a good, densely sampled discrete record going back even further.

Based on the criteria decribed above, the following sites were also chosen for evaluation,:

(ii) Station 410073: Tumut River at Oddys Bridge

Station immediately downstream of Blowering Dam.

(iii) Station 410039: Tumut River at Brungle Bridge

Pristine flows associated with this site have a dilution effect on the rest of the system

(iv) Station 410008, Murrumbidgee River downstream Burrinjuck Dam

Station immediately downstream of Burrinjuck Dam. Low salinities here have a significant dilution effect on the downstream parts of the system.

(v) Station 410004: Murrumbidgee River at Gundagai

The higher salinity tributary inflows between the dams and Gundagai effect the rest of the system. Gundagai has a good discrete EC data set and is the most upstream long-term continuous salinity station.

(vi) Station 410001: Murrumbidgee River at Wagga Wagga

This station summarises the salinity contribution of nearly all the tributary inflows. The salinities at this station are indicative, after routing effects are taken into account, of salinities entering the Yanco Creek. The station has a long-term continuous record and a good discrete record.

(vii) Station 410136: Murrumbidgee River d/s Hay Weir

The river is connected to the groundwater system between Wagga and Narrandera. Most of the irrigation diversions on the Murrumbidgee River take place between Wagga and Hay so this station is a good indicator of the model's ability to represent the major diversions. It is also a good point to assess the impact of not modelling surface-groundwater interaction.

(viii) Station 410016: Billabong Creek at Jerilderie

This station measures the interaction of the inflows and salinities coming from the upper Billabong Creek and those coming from the Murrumbidgee River via Yanco and Colombo Creeks. Jerilderie has a good, dense discrete sample record.

(ix) Station 410017: Billabong Creek at Conargo

(later replaced by Station 41010997: Billabong Creek at Conargo Bridge)

This station measures the interaction between water from Yanco Creek (which includes Coleambally DC800 drainage water) and water from Conargo. A large proportion of the Yanco-Colombo-Billabong diversions has also taken place at this point in the system.

(x) Station 410134: Billabong Creek at Darlot

The last station on Billabong Creek before it joins the Murray River. Darlot has good, long-term continuous and discrete EC records.

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

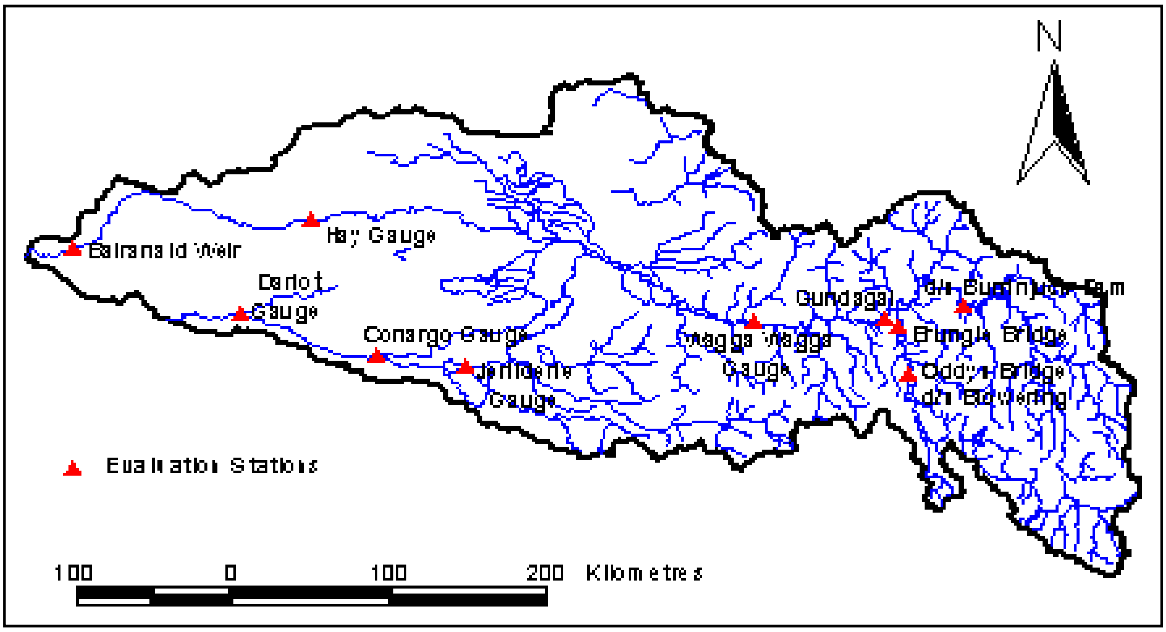


Figure 5.4. Location of evaluation sites

5.2.3. Data quality performance measures

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

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

(i) how many data points there are;

(ii) what period the data represents;

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

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

Graphs of the full set of screened salinity data (

Table 3.2) and observed flow at evaluation locations are shown in Appendix B. Performance measures (i), (ii), and (iii) from above are reported as shown in Table 5.3. 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).

. Performance measures (i), (ii), and (iii) are reported as shown in Table 5.3 and performance measure (iv) from above is reported in Table 5.4.

5.2.4. Model result performance measures

The performance measures have only been developed for comparing the model results with the discrete data sets at this stage. The continuous data sets are often too short and methods have yet to be derived to account of serial correlation within the data sets.

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) because evaporation decreases water volume without changing the salt load. Wet periods will usually result in abrupt changes in concentration because the volume of water in storage and the inflow are a similar size, and the high flows usually have relatively low concentrations. IQQM explicitly simulates all these processes.

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

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. The perfect result for performance measures (i-iv) is zero, whilst for performance measure (v) it is one.

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

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

$$E = \frac{\left| \sum_i S_i - \sum_i O_i \right|}{\sum_i O_i} \tag{5.5}$$

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

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

5.2.4.2. In-stream

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

(i) mean;

(ii) standard deviation;

(iii) maximum; and

(iv) minimum.

In addition, the following are reported for concentration:

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

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

Lastly, mean simulated loads are compared with mean observed loads for each flow range. An example with these results is shown in Table 5.5.

5.3. EVALUATION OF MODEL RESULTS

The model was evaluated at ten sites along the Murrumbidgee River and Billabong Creek. The basis for selecting these sites is discussed in Section 5.2.2. Discussion of the results, as well as performance measures, is presented in Sections 5.3.1 to 0. The run numbers which the following refers to are bidgev19.sqq – forced cap model, bidgev20.sqq – non-forced cap model and bidgcu25.sqq – baseline model.

The Murrumbidgee salinity modelling effort involved only minimal recalibration from the first cut model as discussed in Section 5.2. Some main river loss functions were recalibrated taking into account of recent season experiences. Also some Coleambally drainage parameters were re-examined.

Some model validation trials were undertaken to see test the models performance beyond its ability to route salinity flows and thereby get a feeling of the merits of the Baseline Model. This departure form the standard reporting procedure (in other valley reports) means that the format in the following sections is different from the other NSW reports. Each reported site has a one section coverage with all information pooled in that section.

In reading the following sections it is very important to appreciate the nature of changes in the Murrumbidgee Valley over the last 15 years. Without such an understanding it is easy to misinterpret the degree of mismatch between the simulated and observed values in the “forced release cap model”.

Rice was not allowed to be grown anywhere except in the Murrumbidgee and Coleambally Irrigation areas before the late 1980s. At that time, the deregulation of rice growing industry meant growth in use downstream of Darlington Point (and in the Yanco-Colombo-Billabong System). Also occurring was a change in the pattern of demand with far more of that demand being experienced in summer. The forced release Cap model extracts water from the river, for the entire 1975-2000 period, using the level of rice development seen around 1993/94.

A new Yanco Creek offtake was commissioned in the mid-1990s, giving operators partial remote control of the offtake and greater flexibility to send flows down Yanco Creek. This resulted in far greater amounts of Murrumbidgee supplementary flows being sent down the creek. This had a significant dilution effect on the Billabong Creek system. The forced release Cap model diverts water down the Yanco Creek System assuming the new weir was in operation throughout the period 1975-2000.

Finally worth noting are the changes in the Coleambally Irrigation Area. Groundwater tables rose through the 1980s to the early 1990s when they stabilised. This effected the drainage salinities, locally and ultimately at the end of the system at Darlot. Also effecting drainage flows are the actions taken by Coleambally management to minimise leaks in their canal systems. This resulted in a significant reduction in drainage flows. The forced release Cap model runs with the drainage flows throughout the 1975-2000 period.

5.3.1. Station 410073: Tumut River @ Oddys Bridge

The gauging station on the Tumut River at Oddys Bridge is the first gauge downstream of Blowering Dam. Data has been collected at this station fairly consistently every 1-2 months since 1970 (prior to completion of the Snowy Scheme). The salinity ranges from 14 mg/L after periods of high inflows relative to storage volume to a maximum of 68 mg/L after an extended period of low inflow and presumably high evaporation relative to storage volume. The median salinity is 20 mg/L.

The simulation is set up to approximately match the mean of the observed salinities. The observed data shows little variation over this period, having a mean of 22.6 mg/L and a standard deviation of only 7.5 mg/L. Therefore, a constant concentration was applied to the model inflows and no table of performance measures was deemed necessary for this dam.

Figure 5.5 shows that the salinities immediately downstream of Blowering Dam are just about constant. With the model assuming a constant concentration for Blowering Dam inflows and with insignificant net evaporations, the model manages the not too difficult task of matching the observed salinities. No reservoir calibration statistics were deemed necessary for this site.

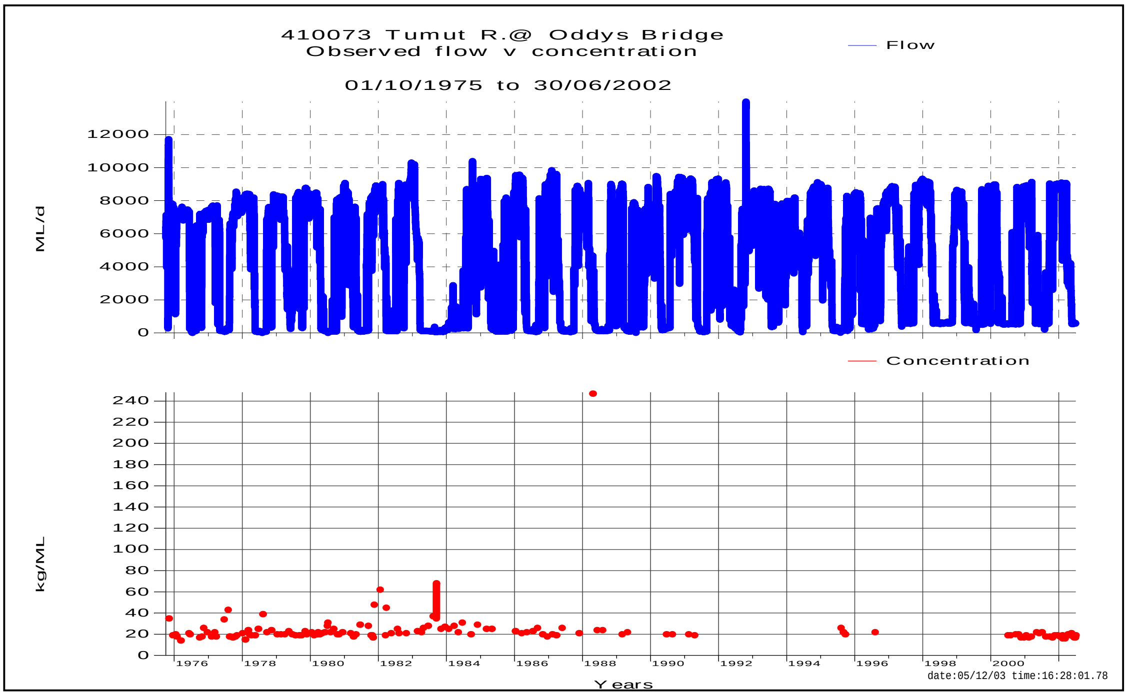


Figure 5.5. Station 410073: Tumut River @ Oddys Bridge; flow and discrete salinity data.

5.3.2. Station 410039: Tumut River @ Brungle Bridge

The gauging station along Tumut River @ Brungle Bridge has had data collected consistently every 1-2 months over the period 1970-1987. The salinity ranges from about 10-58 mg/L, with a median salinity of 23 mg/L, slightly higher than that of water released from Blowering Dam. The data is representative of all months (Table 5.3). Table 5.4 shows that EC data collected in the medium flow range tended to be in higher flow days than that for the overall period. This is because the 1970-1987 period was overall wetter than on average than the full evaluation period.

Table 5.6 shows that the forced release simulation model maintains the observed flow distribution. Not a surprise result given the proximity to the forced release point. Figure 5.7(b) shows that the salinity is well matched on an exceedance plot basis except for the very low salinities. The simulated salinities never go below 22 mg/L, the assumed salinity for Blowering Dam (most of the time). Perhaps some tributary flow load relationships could be changed to allow a better fit but some consideration would first have to be given to the validity of salinities lesser than 15 mg/L. Figure 5.6 shows the relationship between flows and salinities.

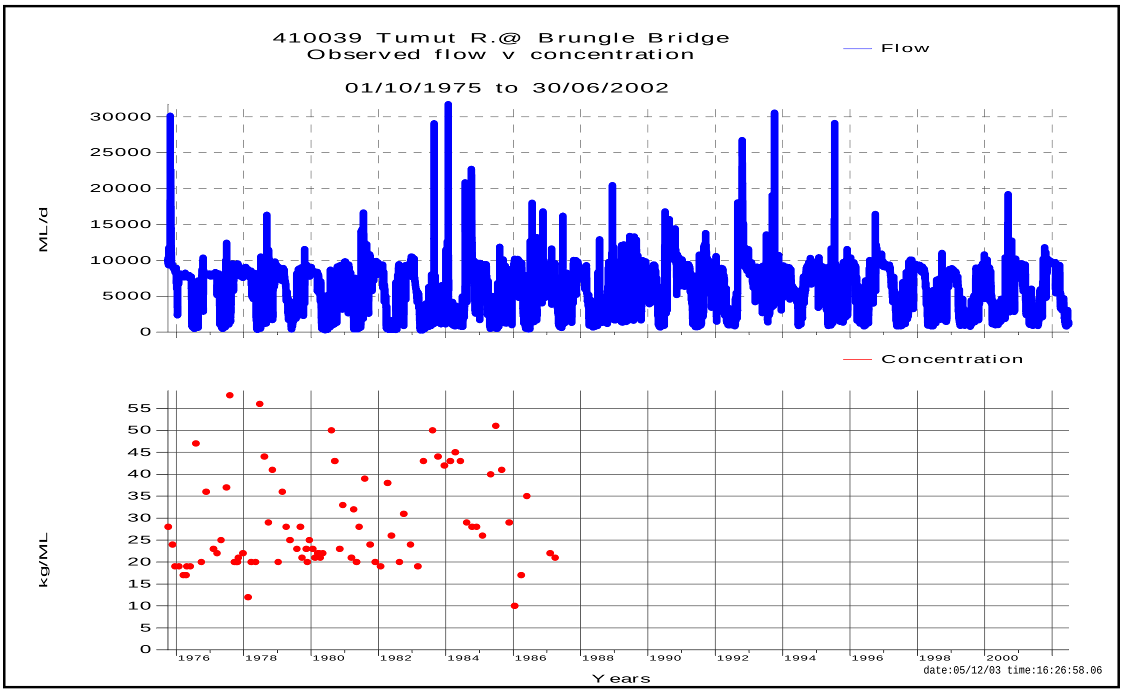


Figure 5.6. Station 410039: Tumut River @ Brungle Bridge; flow and discrete salinity data

Table 5.3. Distribution of flow with discrete EC across flow ranges and months for Station 410039: Tumut River @ Brungle Bridge

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2000	21	0	1	0	3	5	5	1	3	2	1	0	0
Medium		47	4	4	6	4	4	0	1	3	3	1	7	5
High		14	1	2	1	1	0	0	0	2	1	2	2	1
All		82	5	7	7	8	9	5	2	8	7	4	9	6

Table 5.4. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 410039: Tumut River @ Brungle Bridge

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	1,048	402	221	1,740
	With EC obs	1,056	549	360	1,735
Medium	*All*	5,970	2,454	1,741	9,201
	With EC obs	7,187	2,011	1,803	9,151
High	*All*	10,227	2,087	9,202	31,765
	With EC obs	9,900	1,140	9,212	13,748
ALL	*All*	5,807	3,593	221	31,765
	With EC obs	6,080	3,515	360	13,748

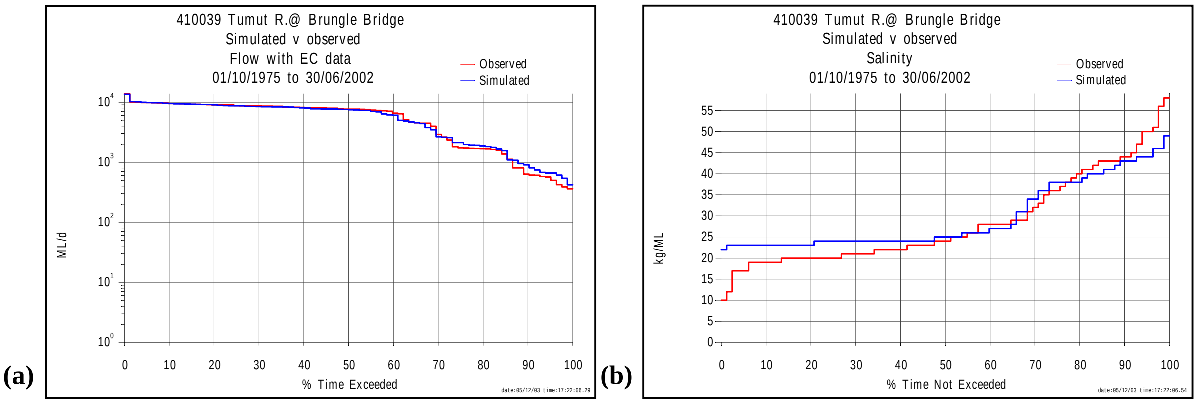


Figure 5.7. Station 410039: Tumut River @ Brungle Bridge; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.5. 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 410039: Tumut River @ Brungle Bridge

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*	1,056	549	360	1,735	41	10	22	58	6	0.434	45
	Simulated	1,227	581	421	2,126	41	4	31	49			50
Medium	*Observed*	7,187	2,011	1,803	9,151	24	7	12	44	4	0.661	170
	Simulated	7,108	1,995	2,125	9,376	26	5	22	44			178
High	*Observed*	9,900	1,140	9,212	13,748	23	5	10	29	4	0.266	229
	Simulated	9,427	2,057	3,475	13,517	26	3	23	36			239
All	*Observed*	6,080	3,515	360	13,748	28	11	10	58	4	0.756	148
	Simulated	5,998	3,416	421	13,517	30	8	22	49			155

5.3.3. Station 410008: Murrumbidgee River d/s Burrinjuck Dam

Burrinjuck Dam became operational in 1912, and salinity data has been collected generally at intervals of 1-2 months since 1976. The data was collected at Station 410008: Murrumbidgee River d/s Burrinjuck Dam (see Table 3.1). The salinity for the period 1976 to 2002 ranges from 25-163 mg/L, with a median salinity of 102 mg/L. The salinity has some variation and also has a slight upward trend over time. Figure 5.8 shows the observed relationships between Burrinjuck downstream inflows and concentrations.

The pattern of simulated salinity appears to be following the pattern of observed salinity; that is increasing during periods of stable or decreasing storage volumes, and abrupt decreasing after significant inflows (Figure 5.9). Statistically, Table 5.6 shows that the average error is quite good. A slightly poor result for the range match is caused by IQQM getting the mean about right but having not enough variation to match the peaks and troughs in the observed salinities.

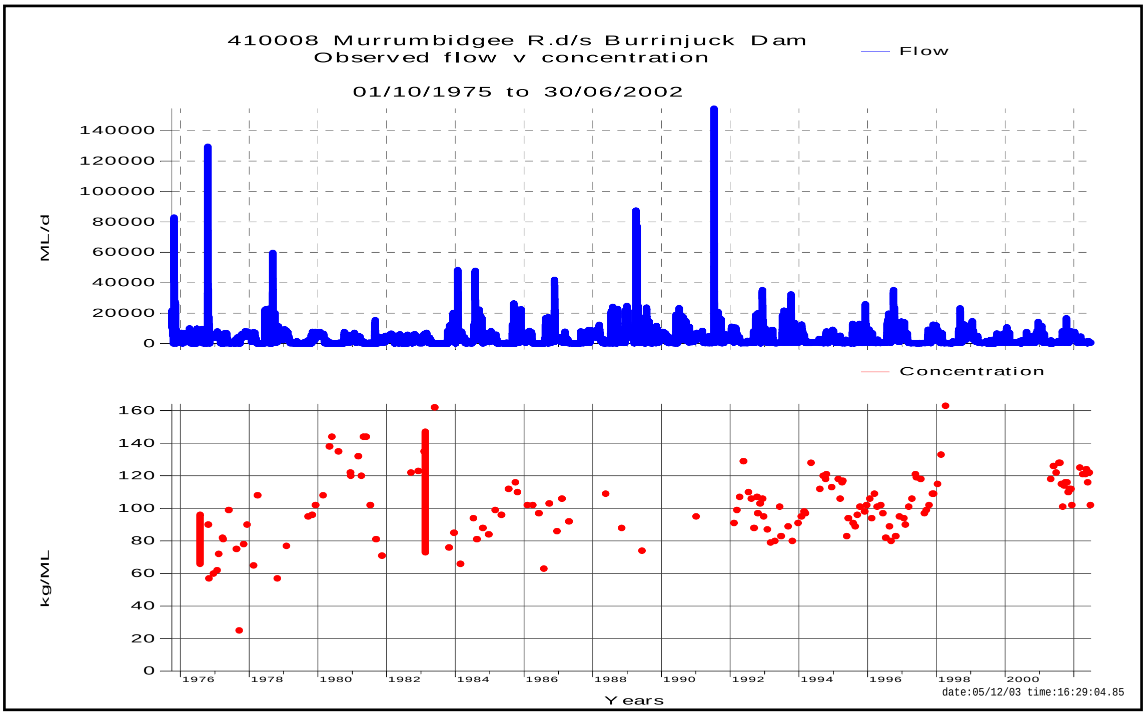


Figure 5.8. Station 410008: Murrumbidgee River d/s Burrinjuck Dam; flow and discrete salinity data.

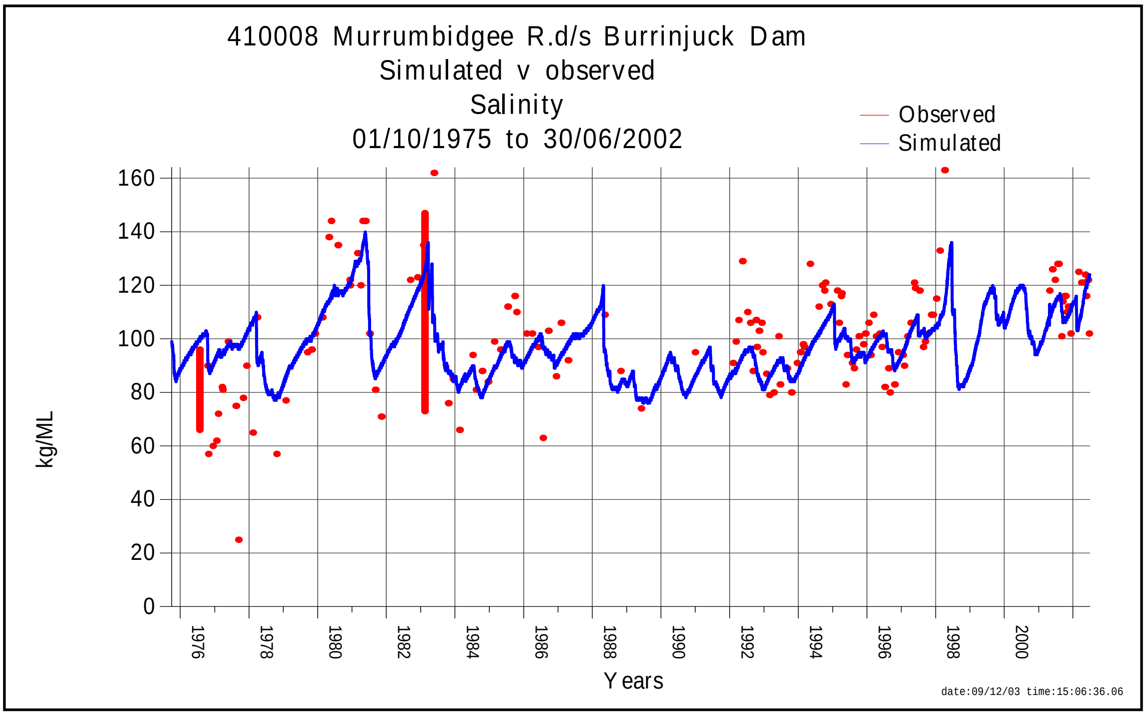


Figure 5.9. Station 410008: Murrumbidgee River d/s Burrinjuck Dam; time series plot of observed discrete versus force Cap model salinity.

Table 5.6. Results of performance measures for observed versus simulated salinities in Burrinjuck Dam using the flow-concentration table derived

Performance measure	Result
Pattern match	0.610
Mean match	0.019
Average error	0.115
Range match	0.558
R^2	0.412

5.3.4. Station 410004: Murrumbidgee River @ Gundagai

The gauging station Murrumbidgee River @ Gundagai has had data collected generally every 1-2 months from 1976 onwards. However, there are long gaps from 1988-89, 1993-94 and 1998-2000. The collection of continuous data since 1993 may explain the gaps in the discrete set. Table 5.7 shows that the discrete data is representative of all months and all flow ranges. Table 5.8 shows that EC collection is representative.

Table 5.9 shows that there is an excellent match of flow and a good overall match of observed salinities. However, the salinity match is poor in the low flow range. Figure 5.9 shows a similar story. Figure 5.11 shows that in a time series sense Gundagai salinities are well matched. A time calibration plot is shown in Figure 5.12 and Figure 5.13.

Table 5.7. Distribution of flow with discrete EC across flow ranges and months for Station 410004: Murrumbidgee River @ Gundagai

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2000	35	0	0	0	2	9	8	4	3	2	1	0	0
Medium		103	7	9	13	7	4	3	4	7	7	7	11	7
High		28	2	1	2	0	0	1	1	3	3	5	1	4
All		166	9	10	15	9	13	12	8	14	11	13	12	11

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 421004: Murrumbidgee River @ Gundagai

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	2,074	855	444	3,715
	With EC obs	1,971	899	544	3,664
Medium	*All*	9,574	3,091	3,718	14,524
	With EC obs	9,615	3,259	3,737	14,401
High	*All*	23,548	15,682	14,533	217,579
	With EC obs	22,662	9,331	14,607	60,988
ALL	*All*	10,739	10,083	444	217,579
	With EC obs	10,204	7,868	544	60,988

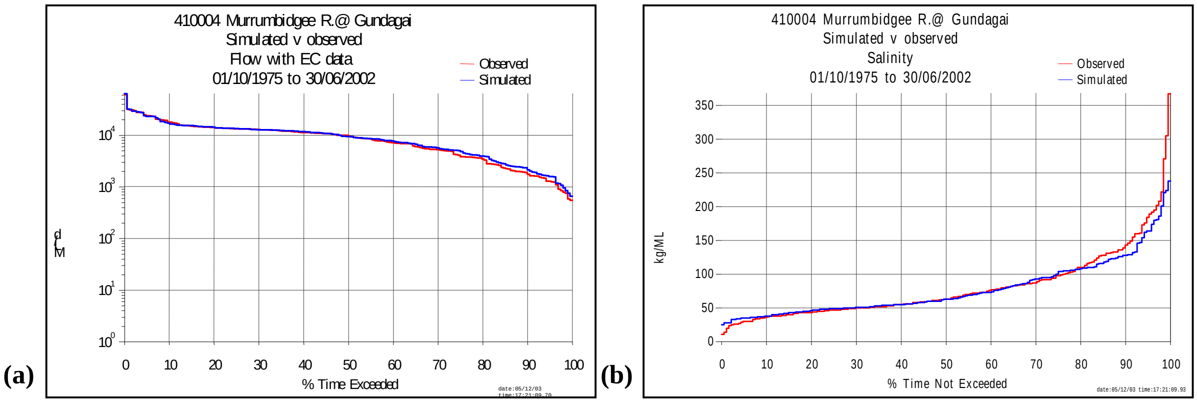


Figure 5.10. Station 410004: Murrumbidgee River @ Gundagai; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.9. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 410004: Murrumbidgee River @ Gundagai

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*	1,991	881	544	3,696	130	69	33	367	32	0.682	250
	Simulated	2,513	1,320	658	6,398	113	44	28	238			275
Medium	*Observed*	9,603	3,274	3,737	14,401	64	37	14	202	12	0.633	586
	Simulated	9,874	3,292	3,440	16,268	64	35	25	224			617
High	*Observed*	22,282	9,004	14,607	60,988	73	24	11	131	14	0.257	1,764
	Simulated	21,920	9,716	13,670	64,062	79	28	49	186			1,881
All	*Observed*	9,993	7,696	544	60,988	80	52	11	367	17	0.681	705
	Simulated	10,216	7,631	658	64,062	77	41	25	238			749

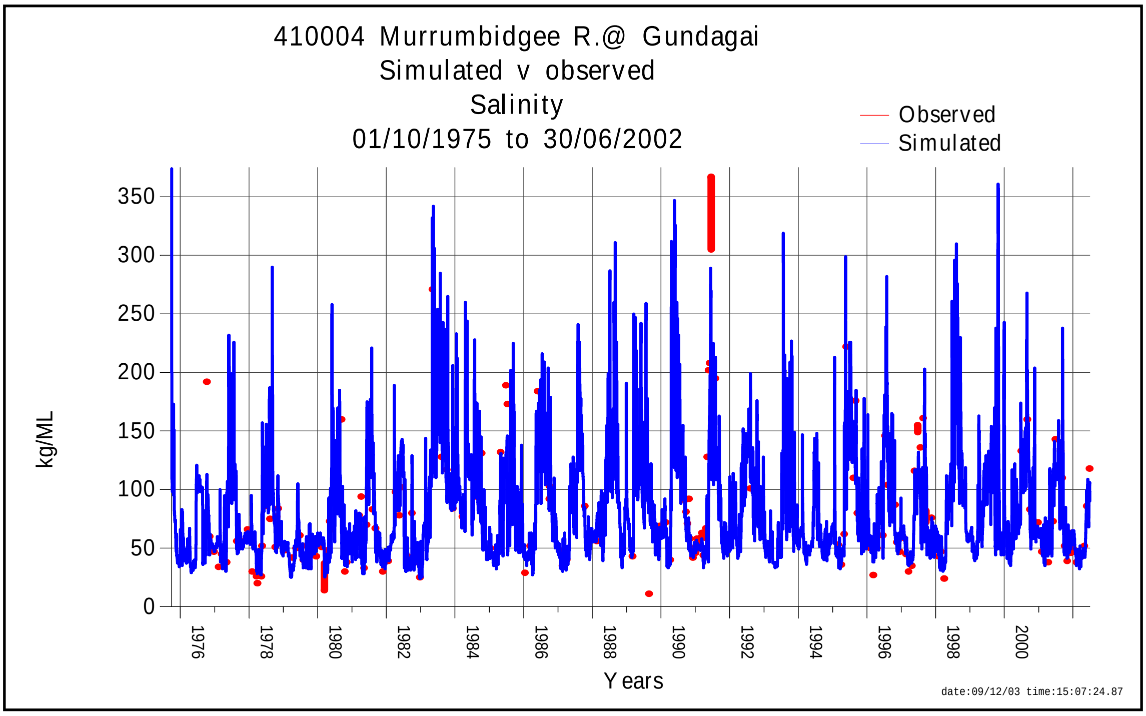


Figure 5.11. Station 410004: Murrumbidgee River @ Gundagai; time-series plot of observed discrete versus forced Cap model salinity.

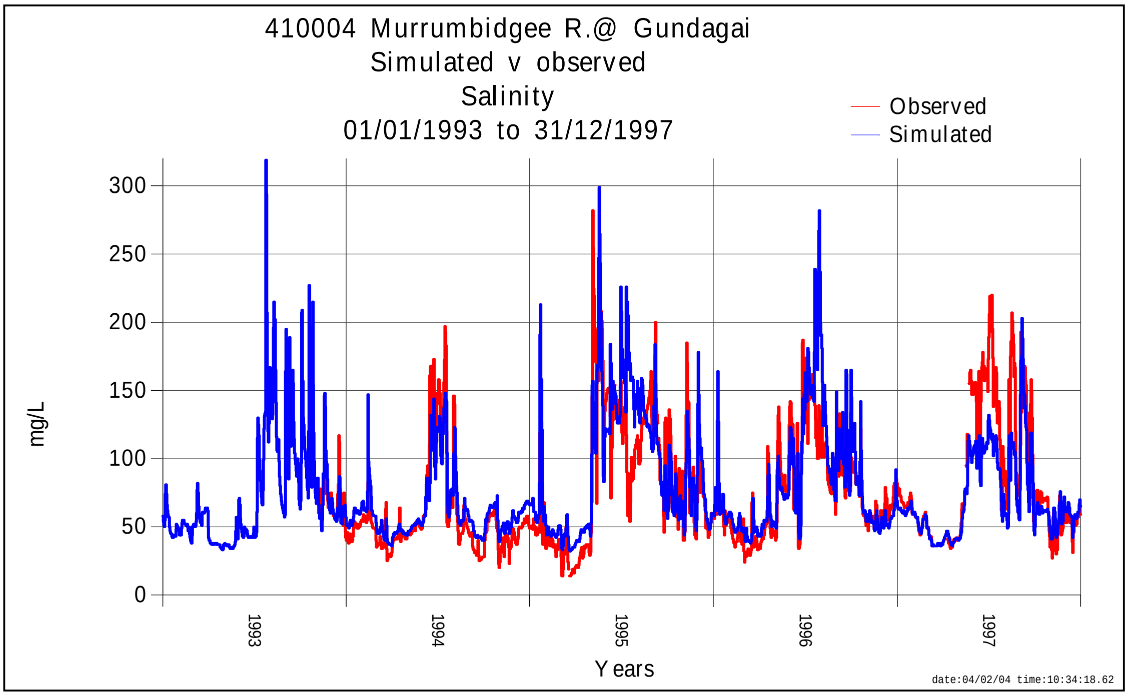


Figure 5.12. Station 410004: Murrumbidgee River @ Gundagai; time-series plot of observed continuous versus forced Cap model salinity (1993-1997).

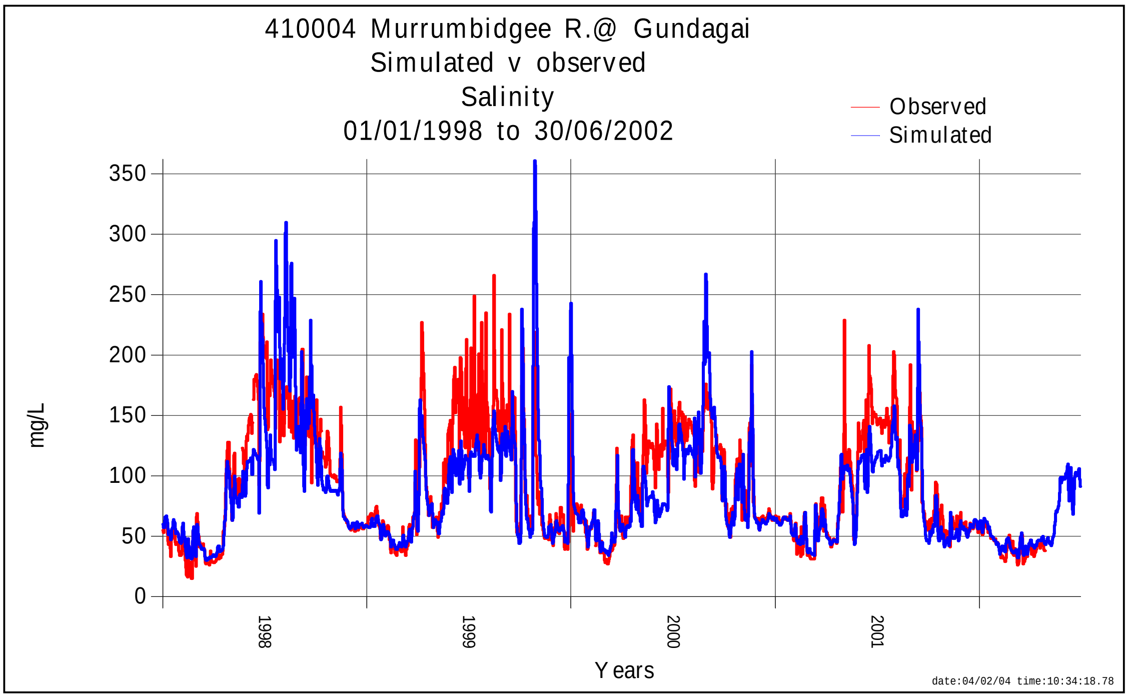


Figure 5.13. Station 410004: Murrumbidgee River @ Gundagai; time-series plot of observed continuous versus forced Cap model salinity (1998-2002).

5.3.5. Station 410001: Murrumbidgee River @ Wagga Wagga

There is discrete data at Wagga Wagga starting from 1976, which is generally at intervals of every 1-2 months. However, there was a 4-year gap from 1991-1995 and a 2-year gap from 1998-2000. The discrete EC data set is representative of all months (Table 5.10) and all flow ranges (Table 5.11). As at Gundagai, the forced simulation model gives a good overall match of salinities but does poorly in the low flow range (Table 5.12, Figure 5.14). Overall, at both Gundagai and Wagga, the performance of the unforced model (Figure 5.15) was not much worse, with an R^2 only 10% lower than the forced model.

Table 5.10. Distribution of flow with discrete EC across flow ranges and months for Station 410001: Murrumbidgee River @ Wagga Wagga

Flow range	**Period**	**Number Points**	**Number of months with data**											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2000	30	0	0	0	3	7	6	7	1	0	0	0	0
Medium		92	7	10	10	7	5	2	3	3	11	4	9	8
High		28	3	1	1	0	1	1	5	3	3	4	3	0
All		150	10	11	11	10	12	9	14	7	14	8	11	8

Table 5.11. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 410001: Murrumbidgee River @ Wagga Wagga

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	2,788	1,093	589	4,717
	With EC obs	2,455	1,150	708	4,643
Medium	*All*	10,467	2,965	4,718	15,143
	With EC obs	9,990	3,305	4,785	15,110
High	*All*	26,171	16,286	15,144	193,696
	With EC obs	28,397	28,837	15,179	157,585
ALL	*All*	11,919	10,712	589	193,696
	With EC obs	11,919	15,132	708	157,585

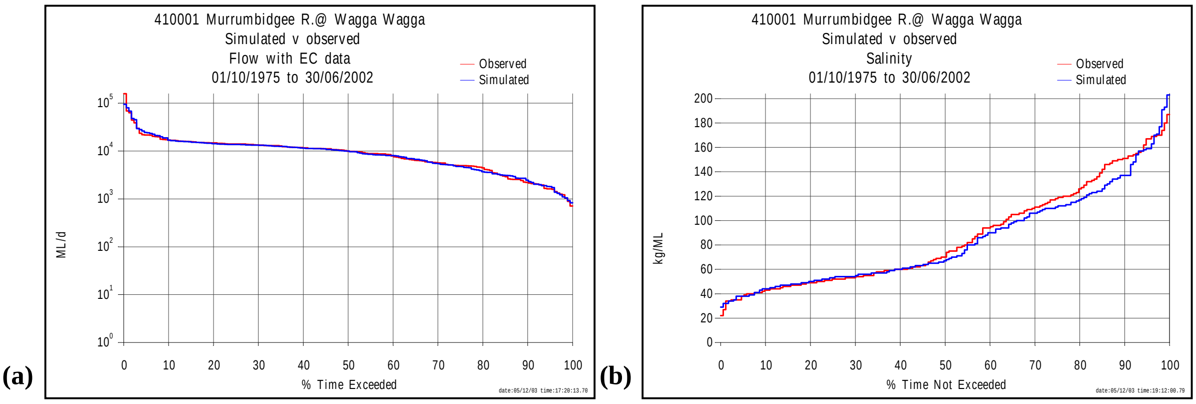


Figure 5.14. Station 410001: Murrumbidgee River @ Wagga Wagga; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity

Table 5.12. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 410001: Murrumbidgee River @ Wagga Wagga

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*	2,469	1,071	708	4,643	126	41	22	180	24	0.597	298
	Simulated	2,603	1,109	831	5,207	111	32	44	170			278
Medium	*Observed*	10,109	3,308	4,785	15,110	71	33	27	157	10	0.819	673
	Simulated	10,023	3,589	3,110	20,989	68	30	29	171			669
High	*Observed*	28,228	28,332	15,179	157,585	92	36	47	187	22	0.484	2,682
	Simulated	27,284	20,697	13,643	94,745	105	46	53	203			3,193
All	*Observed*	11,512	14,268	708	157,585	86	42	22	187	15	0.71	930
	Simulated	11,329	11,760	831	94,745	83	39	29	203			1,009

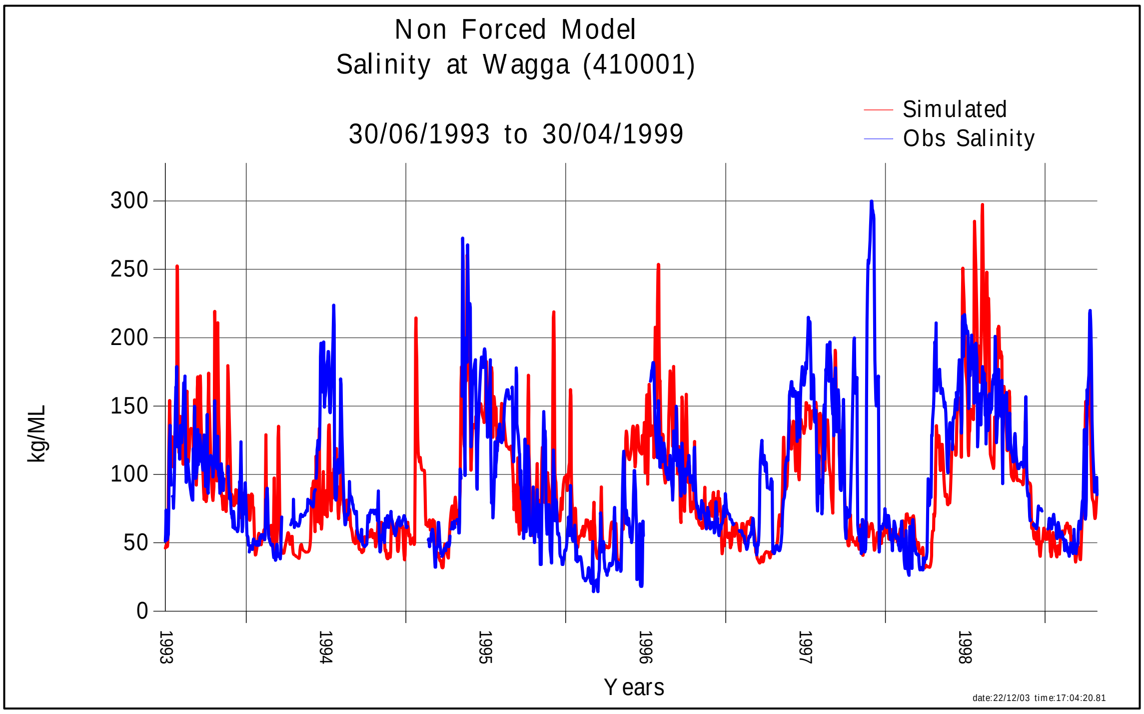


Figure 5.15 Station 410001: Murrumbidgee River @ Wagga Wagga; time series plot of observed continuous versus unforced Cap model salinity.

5.3.6. Station 410136: Murrumbidgee River d/s Hay Weir

Data collection dowmstream of Hay Weir commenced in 1982. Sampling has been consistent except for a gap in 1998-2000. The data is representative of all months and all flow ranges, despite sampling beginning five years into the evaluation period (Table 5.13, Table 5.14). The flow mismatch at Hay (Figure 5.16a) is due to the irrigation demand mismatch previously mentioned. Salinities match very well when flow is present (Figure 5.16b).

Table 5.13. Distribution of flow with discrete EC across flow ranges and months for Station 410136: Murrumbidgee River d/s Hay Weir

Flow range	Period	Number Points	Number of months with data											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Low	1975-2000	42	6	5	2	1	3	2	1	3	2	3	1	5
Medium		106	7	9	6	8	6	7	6	5	6	5	9	6
High		30	0	0	1	0	1	0	3	2	6	4	1	4
All		178	12	15	9	9	10	8	10	9	13	11	11	15

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 410136: Murrumbidgee River d/s Hay Weir

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	478	128	33	662
	With EC obs	474	129	76	661
Medium	*All*	2,288	1,593	663	6,962
	With EC obs	1,952	1,461	670	6,856
High	*All*	16,632	8,413	6,967	53,372
	With EC obs	17,039	8,808	7,492	39,844
ALL	*All*	4,754	7,119	33	53,372
	With EC obs	4,146	6,945	76	39,844

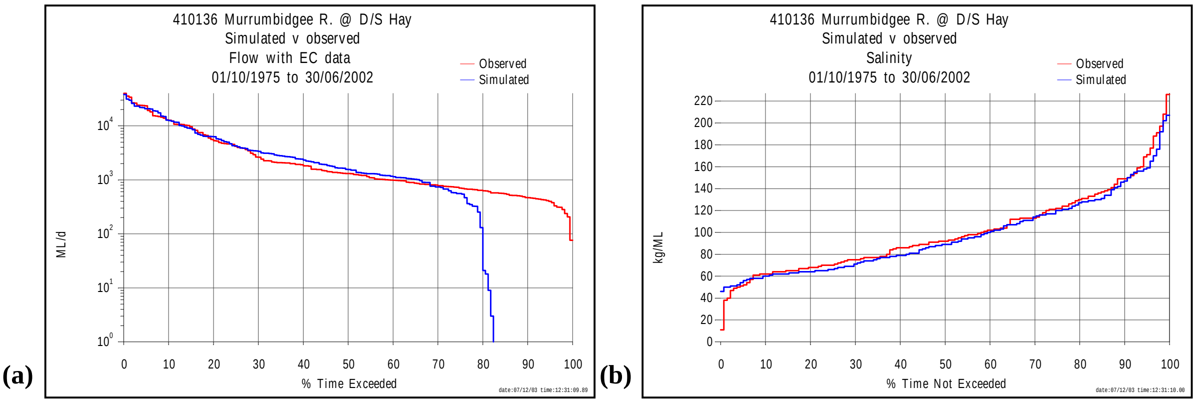


Figure 5.16. Station 410136: Murrumbidgee River d/s Hay Weir; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.

Table 5.15. Comparison of statistics within flow ranges of: (i) observed versus simulated flow; (ii) observed discrete versus simulated salinity; and (iii) observed versus simulated load for Station 410136: Murrumbidgee River d/s Hay Weir

Flow range	**Data set**	**Distributions**								**C_o versus C_s**		**Mean load (t/d)**
		Flow (ML/d)				**Salinity (mg/L)**				*Mean error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*			
Low	*Observed*	250	89	76	329	93	40	52	159	14	0.965	23
	Simulated	1,712	1,524	466	4,288	83	28	62	129			133
Medium	*Observed*	789	241	398	1,255	94	38	49	226	17	0.701	75
	Simulated	1,577	1,237	9	5,744	84	33	46	176			131
High	*Observed*	8,160	8,827	1,303	39,844	103	37	11	208	22	0.329	846
	Simulated	7,961	8,445	3	38,047	106	34	56	207			964
All	*Observed*	5,035	7,650	76	39,844	99	37	11	226	20	0.472	519
	Simulated	5,285	7,193	3	38,047	96	35	46	207			614

5.3.7. Station 410130: Murrumbidgee River @ Balranald

Table 5.16 shows that the data collected are representative of all months. Table 5.17 shows that the data collected are reasonably representative of all flow ranges, although there is more low flow sampling than high. As at Hay, the mismatch of diversions causes a mismatch of flows (Figure 5.17a). When flow is present, the salinities match well (Figure 5.17b). Low flow salinities are underestimated, as was the case upstream (Table 5.18).

The time series match of continuous data can be seen in. Figure 5.18 for 1998-2002. The match on an exceedance basis can be seen in Figure 5.19.

There are three possible explanations as to why there is an underestimation of Balranald continuous salinities. The first is related to the continuous data set being unedited. This results in it being biased as can be seen in the comparison of coincident days discrete versus continuous observed salinities shown in Figure 5.20. The second explanation relates to the apparent rising trend in the Balranald data. Although plots have not been made up for the report, it can be shown that the forced model only underestimates discrete salinities in the second part of the calibration period. That second half is where the continuous data has been collected. The third explanation relates to high salinities being associated with the periods of recessions after major flood. This is when Lowbidgee water returns from the floodplains of the Lowbidgee Redbank forest system. The models very simplistic representation of salinities generated in this system is inadequate to generate the observed high salinities.

The ability of the unforced cap model not to run out of water is shown in Figure 5.21.

Table 5.16. Distribution of flow with discrete EC across flow ranges and months for Station 410130: Murrumbidgee River @ Balranald

Flow range	**Period**	**Number Points**	**Number of months with data**											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2000	208	6	10	12	8	11	7	4	3	3	3	5	6
Medium		375	14	12	12	12	10	13	17	11	7	8	15	14
High		123	3	2	1	1	2	3	4	9	10	9	6	4
All		706	17	17	17	15	15	16	18	16	17	15	17	17

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 410130: Murrumbidgee River @ Balranald

Flow range	**Data set**	**Flow (ML/d)**			
		Mean	*SD*	*Min*	*Max*
Low	*All*	155	34	63	211
	With EC obs	155	34	70	211
Medium	*All*	1,308	1,205	212	5,102
	With EC obs	1,293	1,193	212	5,102
High	*All*	11,219	5,595	5,109	26,981
	With EC obs	11,645	6,404	5,116	26,812
ALL	*All*	3,067	4,899	63	26,981
	With EC obs	2,762	4,977	70	26,812

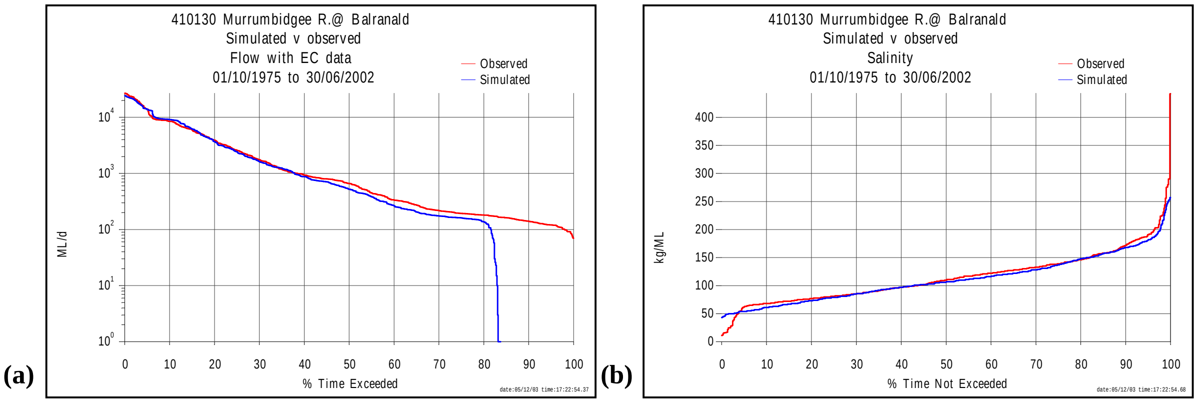


Figure 5.17. Station 410130: Murrumbidgee River @ Balranald; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.

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 Station 410130: Murrumbidgee River @ Balranald

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*	160	35	70	211	112	52	15	442	39	0.016	18
	Simulated	442	456	1	3,166	102	36	45	186			43
Medium	*Observed*	1,348	1,220	213	5,102	115	48	16	290	35	0.169	161
	Simulated	1,436	1,805	1	9,142	106	42	43	257			181
High	*Observed*	11,645	6,404	5,116	26,812	118	30	11	195	31	0.119	1400
	Simulated	11,088	6,226	252	24,227	137	35	68	246			1498
All	*Observed*	3,163	5,263	70	26,812	115	46	11	442	35	0.106	379
	Simulated	3,165	5,087	1	24,227	111	41	43	257			416

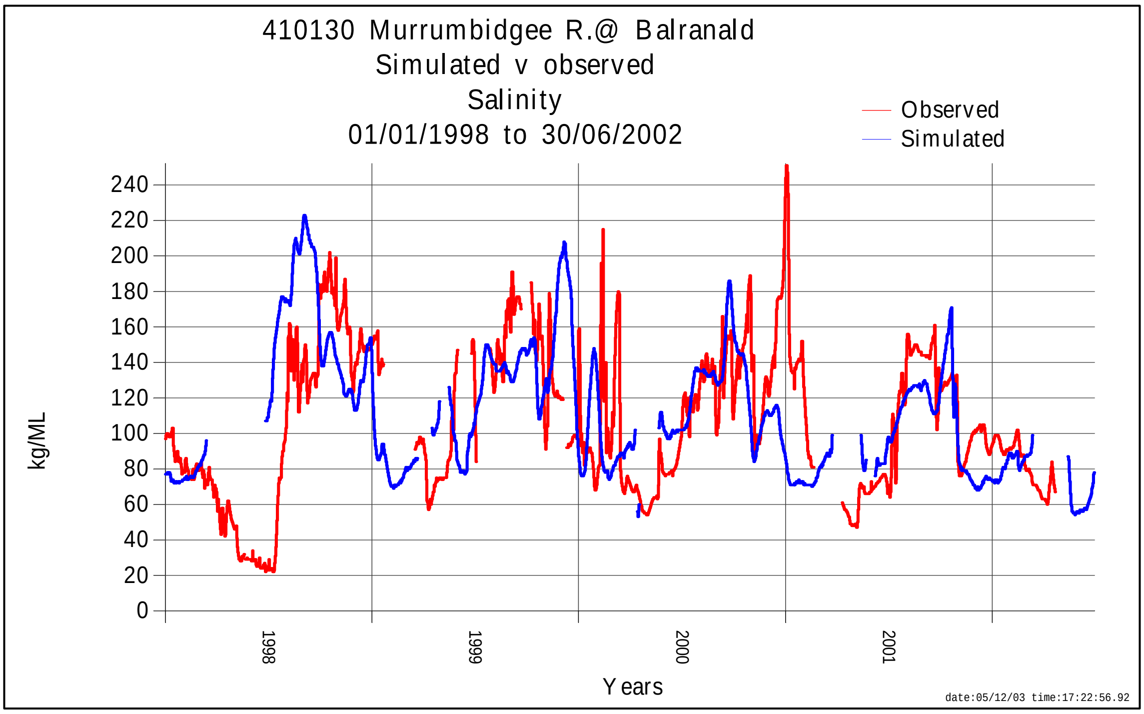


Figure 5.18. Station 410130: Murrumbidgee River @ Balranald: time series plot of observed continuous versus forced Cap model salinity.

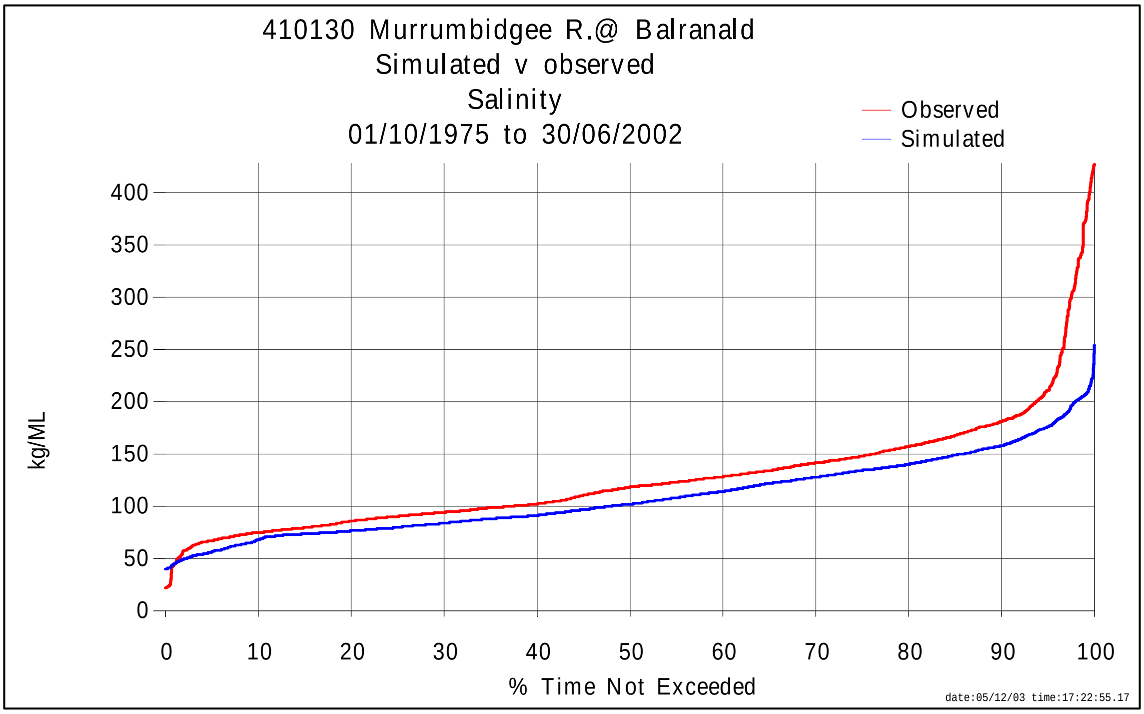


Figure 5.19. Station 410130: Murrumbidgee River @ Balranald: exceedance curve for observed continuous versus forced Cap model salinity.

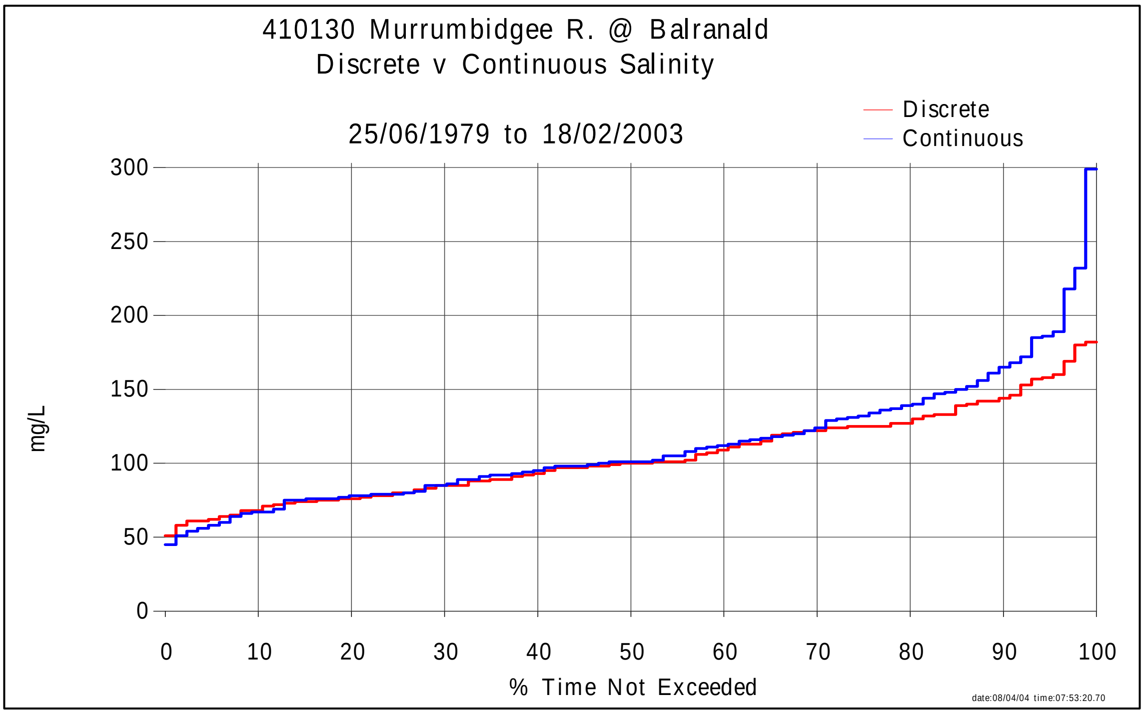


Figure 5.20. Station 410130: Murrumbidgee River @ Balranald: non-exceedance curve for observed discrete versus continuous salinity.

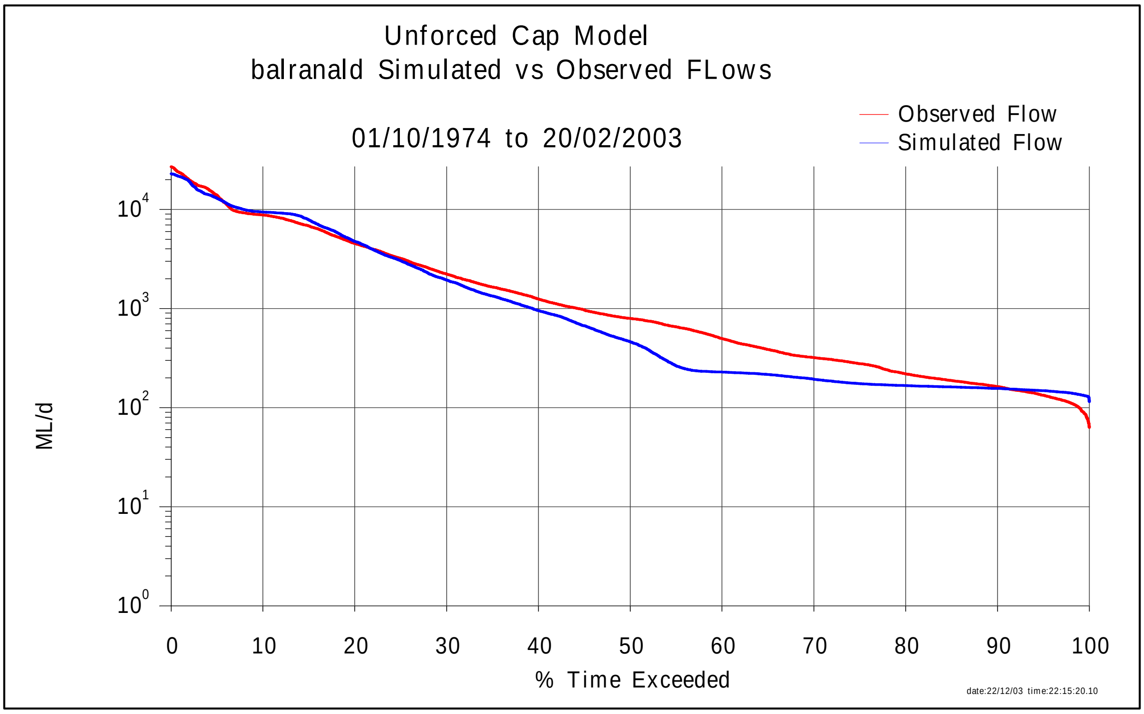


Figure 5.21. Station 410130: Murrumbidgee River @ Balranald: exceedance curve for observed versus unforced Cap model flow.

5.3.8. Station 410016: Billabong Creek @ Jerilderie

Discrete salinity data is available for the whole calibration period at Jerilderie. Sampling frequency varies from once every two months in the earlier years to monthly after 1993 although there are significant gaps from 1978-80, 1980-81, 1991-92 and in 2000. The data is representative of all months (Table 5.19) and all flow ranges, except for the high flow range where sampling missed the higher flows (Table 5.20).

Table 5.21 and Figure 5.22a show a reasonable match of mid-range flows. High flows are underestimated, suggesting that modelled losses between Walbundrie (Upper Billabong) and Jerilderie are too high or there are some unmodelled residual catchment inflows. Low flows are overestimated, probably due to under-representation of irrigation between Walbundrie and Cocketgedong. Salinity is generally underestimated, particularly in the low flow range (Figure 5.22b). The over-estimation of low flows and under-estimation of high flows suggests too much Murrumbidgee River water reaching Jerilderie via Yanco and Colombo Creeks and too little Upper Billabong water. Some trialling of a different loss regime in the Walbundrie to Cocketgedong reach was undertaken, the results of which will be presented in the Darlot section.

Table 5.19. Distribution of flow with discrete EC across flow ranges and months for Station 410016: Billabong Creek @ Jerilderie

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2000	19	2	2	1	0	2	1	3	0	0	1	2	3
Medium		118	12	12	13	11	11	7	8	5	7	7	12	7
High		24	0	0	0	0	1	0	2	7	6	3	2	0
All		161	14	14	14	11	14	8	14	13	13	11	16	10

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 410016: Billabong Creek @ Jerilderie

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	129	37	0	179
	With EC obs	129	39	52	179
Medium	*All*	346	136	180	783
	With EC obs	343	132	183	764
High	*All*	1,992	1,081	784	5,770
	With EC obs	1,768	986	867	5,117
ALL	*All*	622	836	0	5,770
	With EC obs	530	654	52	5,117

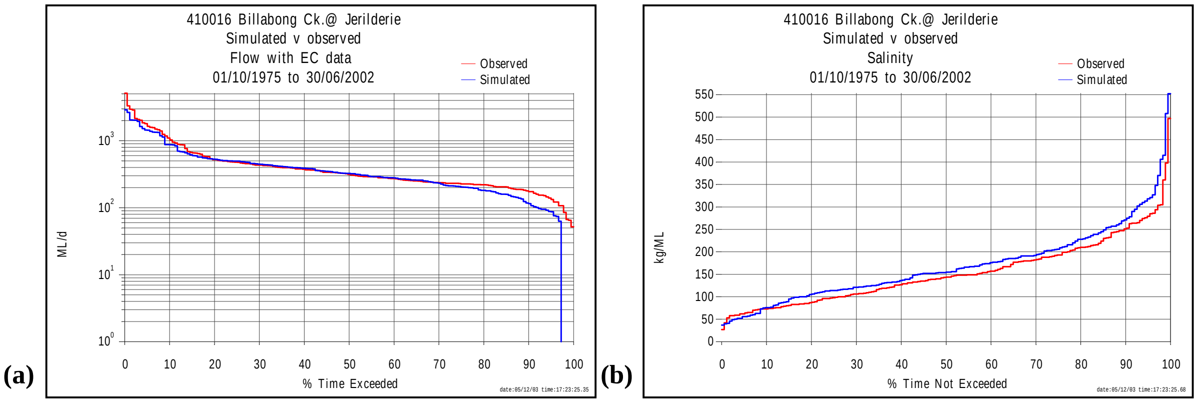


Figure 5.22. Station 410016: Billabong Creek @ Jerilderie; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.

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 Station 410016: Billabong Creek @ Jerilderie

Flow range	**Data set**	**Distributions**								**C_o versus C_s**		**Mean load (t/d)**
		Flow (ML/d)				**Salinity (mg/L)**				*Avg. error (mg/L)*	*R^2*	
		Mean	*S.D*	*Min*	*Max*	*Mean*	*S.D*	*Min*	*Max*			
Low	*Observed*	139	36	52	179	175	68	58	294	76	0.902	24
	Simulated	175	123	63	498	241	149	52	552			33
Medium	*Observed*	343	128	183	764	153	74	42	497	44	0.514	55
	Simulated	341	155	88	870	161	76	37	415			55
High	*Observed*	1,768	986	867	5,117	143	70	27	398	54	0.002	228
	Simulated	1,340	696	209	2,902	168	53	81	370			208
All	*Observed*	522	629	52	5,117	153	73	27	497	48	0.435	76
	Simulated	464	458	63	2,902	169	84	37	552			74

5.3.9. Station 410017: Billabong Creek @ Conargo / Station 41010997: Billabong Creek @ Conargo Bridge

The original station at Conargo (410017) generally has data points every two months from 1975 to 1990 then monthly until 1995. Gaps occur from 1980-82 and in 1992 and there are very few points from 1978-1980. The new station (41010997) started in 1992 and has monthly samples with the exception of a 4-month gap in 1996. The flow data still comes from the original gauge as the new station is only used for water quality sampling. The results for the two stations are reported separately as data was collected at both stations between 1992 and 1995.

The data for 410017 is representative of all months (Table 5.22) and all flow ranges (Table 5.24). The data for 41010997 is representative of all months but the low flow range is significantly under-represented in terms of the number of samples (Table 5.23). Statistically, the data represents all the flow ranges reasonably well (Table 5.25).

From 1975-1995 (ie. when there is salinity data for 410017), flows are significantly underestimated (Figure 5.23a) whilst salinities are overestimated (Figure 5.23b). From 1992-2002 (ie. when there is salinity data for 41010997), the simulated flows and salinities are much closer to observed values (Figure 5.24a, b). The simulated versus observed salinity and salt load statistics given in Table 5.26 and Table 5.27 confirm that the model performs better during the later part of the evaluation period.

This may be explained by the significant changes that have occurred in the way this part of the system is operated and which make it impossible to match the observed behaviour over the entire evaluation period. However, some trials were undertaken to improve losses, the results of which are presented in the results for Darlot (Section 5.3.10).

Table 5.22. Distribution of flow with discrete EC across flow ranges and months for Station 410017: Billabong Creek @ Conargo

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2000	20	3	4	1	2	1	1	4	1	0	1	0	1
Medium		79	9	5	10	6	10	5	5	2	2	5	7	5
High		29	0	1	1	0	1	0	2	6	5	3	3	0
All		128	12	9	11	8	11	6	11	11	7	9	10	6

Table 5.23. Distribution of flow with discrete EC across flow ranges and months for Station 41010997: Billabong Creek @ Conargo Bridge

Flow range	Period	Number Points	Number of months with data											
			Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Low	1975-2000	5	1	0	2	0	1	0	0	0	0	0	0	1
Medium		124	9	11	9	10	9	9	9	6	6	7	8	9
High		35	1	1	2	0	0	0	1	4	4	3	2	2
All		164	9	11	11	10	10	9	9	10	10	10	10	11

Table 5.24. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 410017: Billabong Creek @ Conargo

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	199	53	25	274
	With EC obs	188	72	45	273
Medium	*All*	535	196	275	1,051
	With EC obs	546	199	290	995
High	*All*	2,319	1,040	1,052	6,059
	With EC obs	2,502	1,470	1,100	5,863
ALL	*All*	822	900	25	6,059
	With EC obs	934	1,116	45	5,863

Table 5.25. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 41010997: Billabong Creek @ Conargo Bridge

Flow range	Data set	Flow (ML/d)			
		Mean	*SD*	*Min*	*Max*
Low	*All*	200	53	25	274
	With EC obs	261	11	248	271
Medium	*All*	532	192	275	1,051
	With EC obs	591	194	277	995
High	*All*	2,301	1,036	1,052	6,059
	With EC obs	2,174	905	1,059	4,119
ALL	*All*	801	873	25	6,059
	With EC obs	918	795	248	4,119

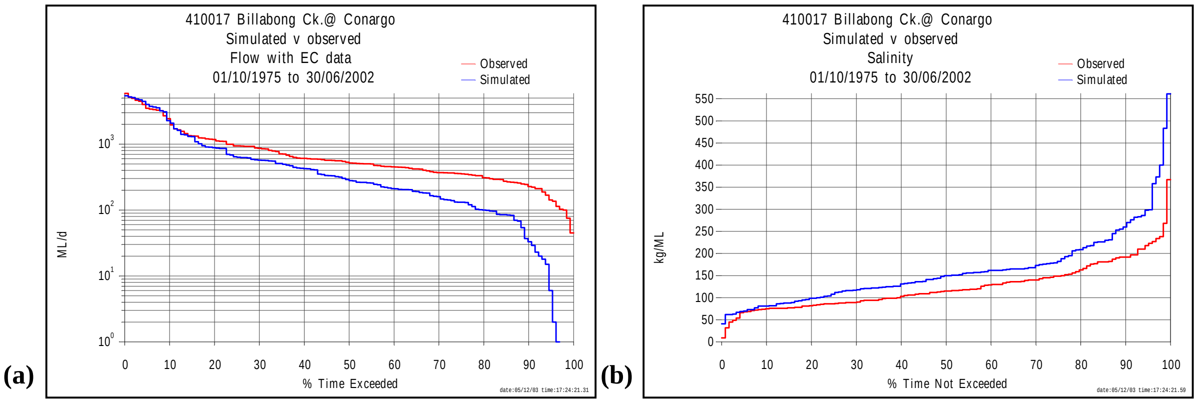


Figure 5.23. Station 410017: Billabong Creek @ Conargo; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.

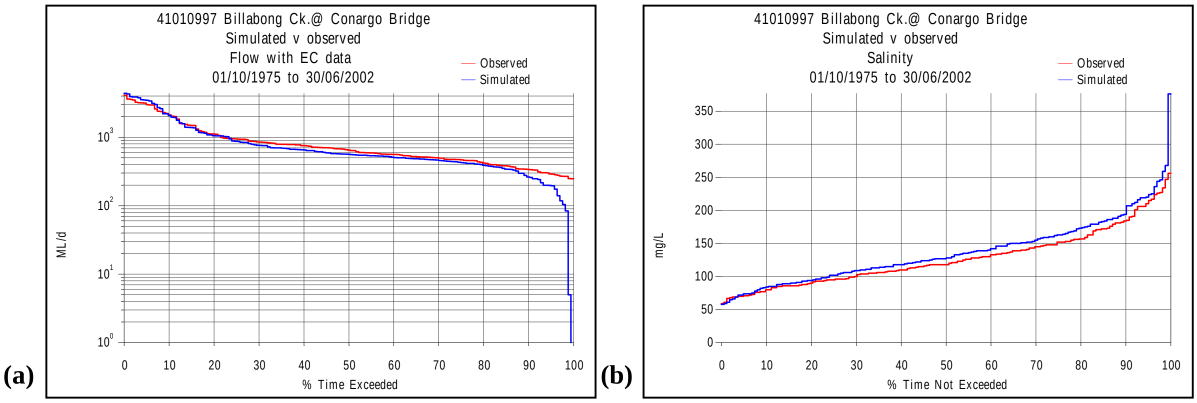


Figure 5.24. Station 41010997: Billabong Creek @ Conargo Bridge; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.

Table 5.26. 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 410017: Billabong Creek @ Conargo

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*	189	73	45	268	99	51	9	238	88	0.099	19
	Simulated	94	57	15	192	176	99	41	400			15
Medium	*Observed*	549	198	290	995	122	53	32	367	67	0.049	71
	Simulated	318	221	1	1,086	160	91	62	561			52
High	*Observed*	2,502	1,470	1,100	5,863	143	44	82	268	33	0.171	333
	Simulated	2,454	1,652	510	5,396	155	35	117	255			362
All	*Observed*	963	1,128	45	5,863	124	52	9	367	62	0.048	126
	Simulated	793	1,234	1	5,396	161	82	41	561			120

Table 5.27. 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 41010997: Billabong Creek @ Conargo Bridge

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*	259	12	248	271	124	47	61	169	79	0.017	32
	Simulated	276	184	140	548	174	68	111	244			42
Medium	*Observed*	592	194	277	995	123	42	59	247	31	0.312	73
	Simulated	548	263	5	2,086	133	52	58	376			74
High	*Observed*	2,174	905	1,059	4,119	142	38	95	256	23	0.348	294
	Simulated	2,208	1,208	504	4,381	145	27	109	236			313
All	*Observed*	926	797	248	4,119	127	42	59	256	31	0.294	120
	Simulated	900	915	5	4,381	137	48	58	376			125

5.3.10. Station 410134: Billabong Creek @ Darlot

The station at Darlot has monthly EC samples in the earlier years, increasing to fortnightly or weekly samples in the later years. There is an 18-month gap from 1992-1993 and 1-year gaps in 1980/81 and 1998/99. The data is representative of all months and flow ranges (Table 5.28 and Table 5.29).

The forced simulation model performs badly for both salinity and flow at Darlot over the entire evaluation period. As expected, the exceedance and time series plots (Figure 5.25 and Figure 5.26) show that performance improved towards the end of the evaluation period. However, the results are still unsatisfactory, especially in terms of salt loads.

Some attempts were made to improve the representation of flows and salinities from the Coleambally system, losses from Walbundrie to Cocketgedong and losses in the Yanco-Colombo-Billabong system. These were put into an unforced baseline conditions model and compared to observed data. An indication of the improvement achieved can be seen in Figure 5.28 and Figure 5.29.

Table 5.28. Distribution of flow with discrete EC across flow ranges and months for Station 410134: Billabong Creek @ Darlot

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	115	7	9	8	3	3	3	5	5	2	3	2	4
Medium		385	16	12	12	12	16	11	10	8	7	10	12	13
High		146	2	1	3	1	1	2	4	9	11	9	4	3
All		646	16	17	17	15	18	15	16	17	17	17	16	16

Table 5.29. Comparison of statistics within flow ranges of all observed flows versus observed flows on days with discrete EC data during evaluation period for Station 410134: Billabong Creek @ Darlot

Flow range	**Data set**	**Flow (ML/d)**			
		Mean	*SD*	*Min*	*Max*
Low	*All*	223	78	15	330
	With EC obs	235	77	24	330
Medium	*All*	643	241	331	1,284
	With EC obs	649	236	332	1,282
High	*All*	2,695	1,122	1,285	5,750
	With EC obs	2,578	1,039	1,294	5,750
ALL	*All*	971	1,028	15	5,750
	With EC obs	1,011	1,009	24	5,750

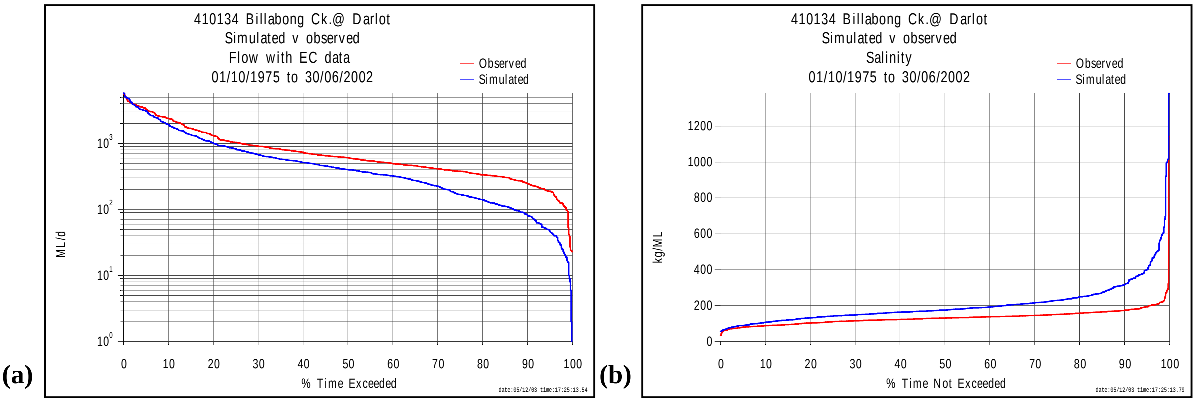


Figure 5.25. Station 410134: Billabong Creek @ Darlot; (a) Exceedance curve for observed versus simulated flow, (b) Non-exceedance curve for observed discrete versus simulated salinity.

Table 5.30. 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 410134: Billabong Creek @ Darlot

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*	229	81	23	330	142	94	68	1,141	135	0.001	33
	Simulated	227	180	2	767	243	209	56	1,382			44
Medium	*Observed*	641	230	332	1,282	133	37	52	291	78	0.070	87
	Simulated	407	287	17	1,674	199	97	59	681			78
High	*Observed*	2,554	1,031	1,294	5,750	129	26	34	209	63	0.000	319
	Simulated	2,219	1,219	310	5,775	189	64	116	509			392
All	*Observed*	956	967	23	5,750	134	51	34	1,141	86	0.008	124
	Simulated	745	962	2	5,775	205	123	56	1,382			136

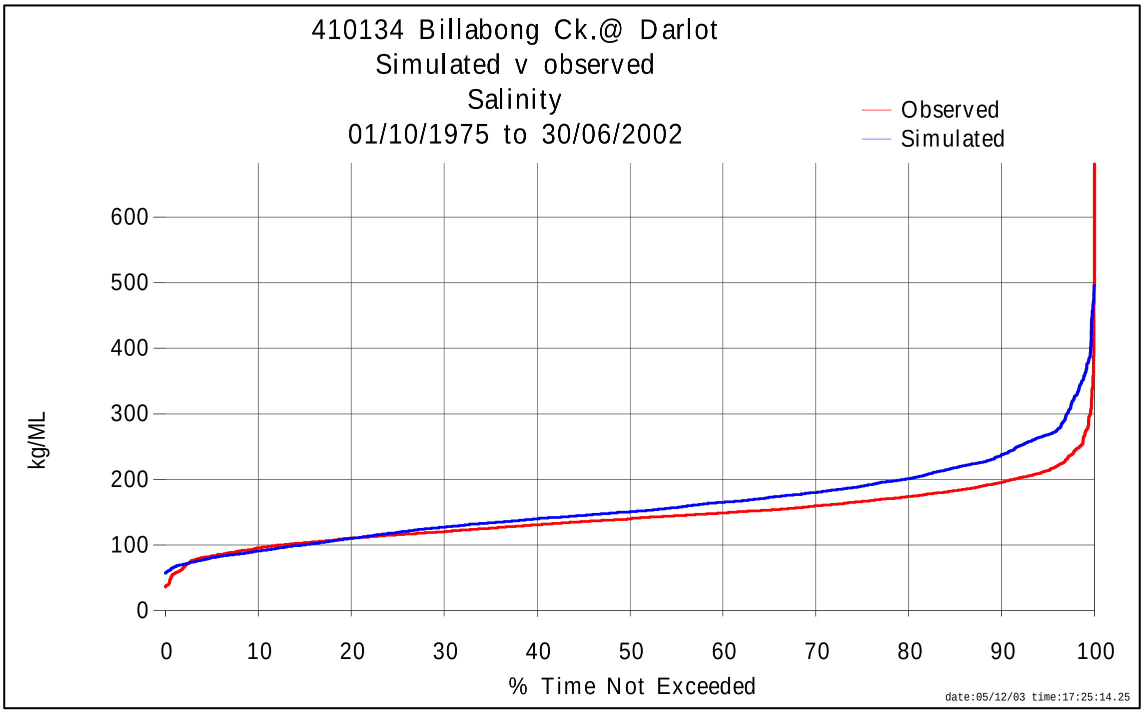


Figure 5.26. Station 410134: Billabong Creek @ Darlot; exceedance curve of observed continuous versus forced Cap model salinity.

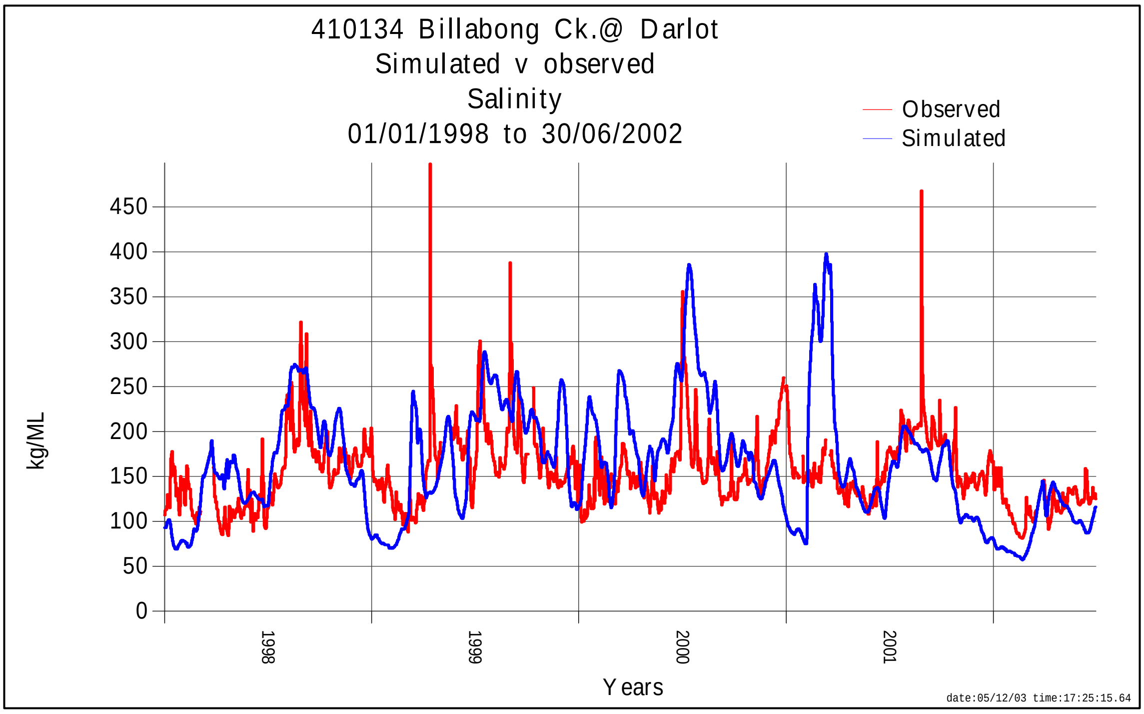


Figure 5.27. Station 410134: Billabong Creek @ Darlot; time series plot of observed continuous versus forced Cap model salinity (for last 5 years of evaluation period).

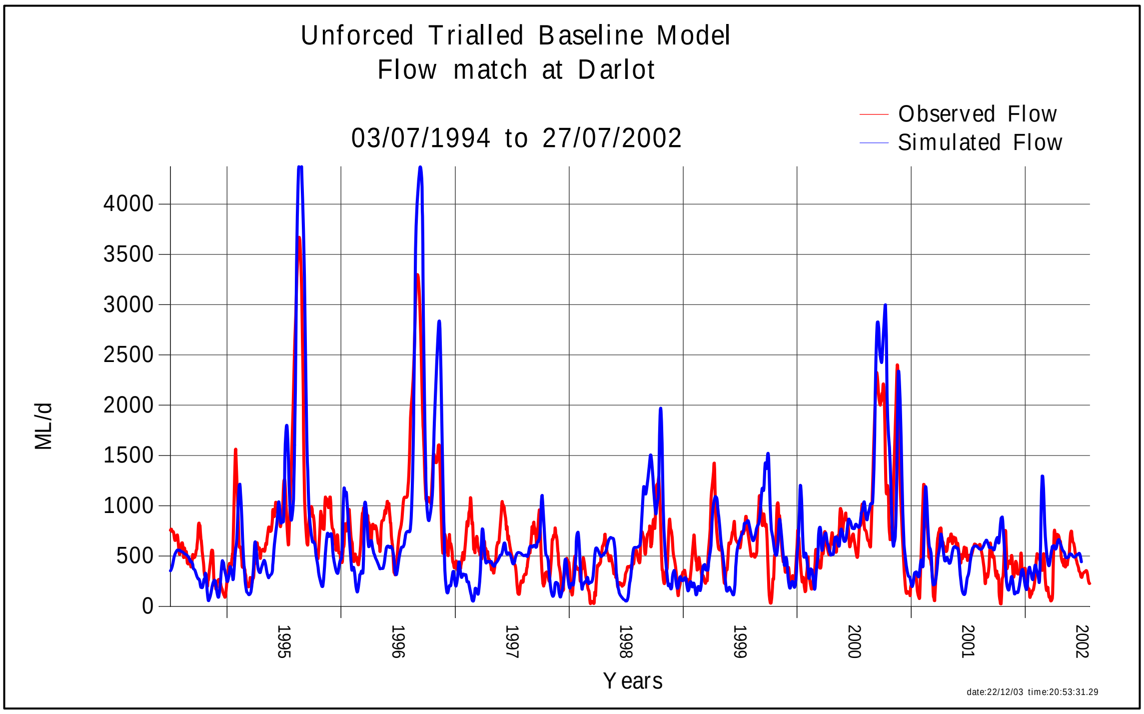


Figure 5.28. Station 410134: Billabong Creek @ Darlot; time series plot of observed continuous versus Baseline Conditions model flow.

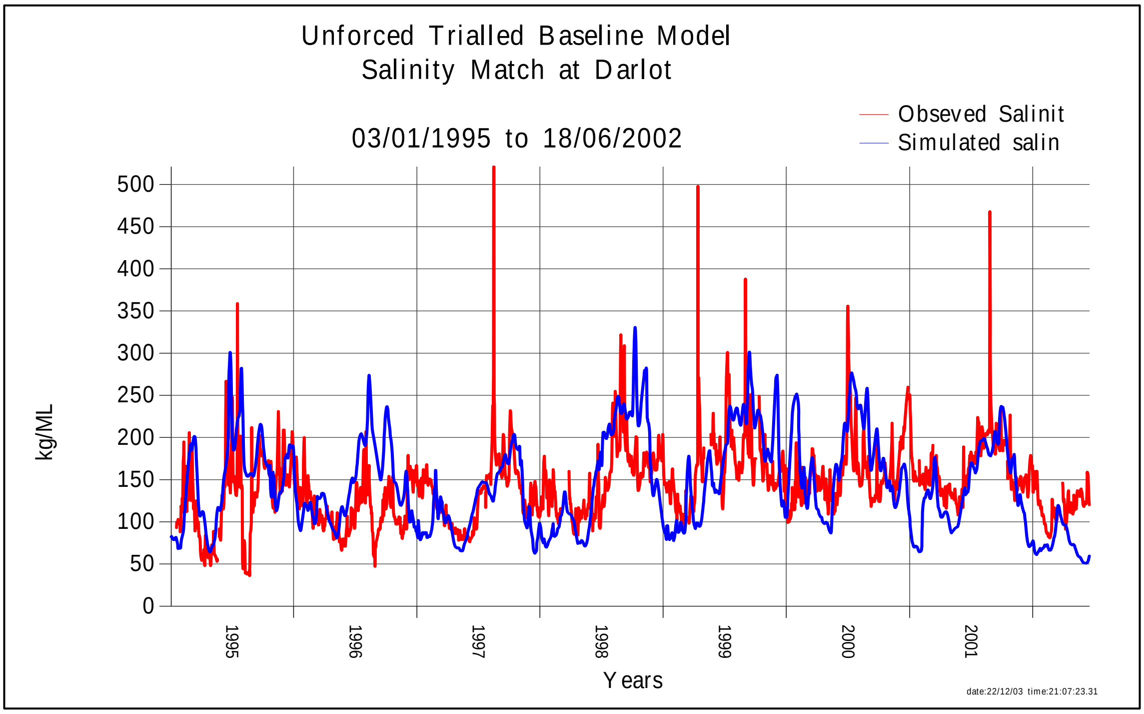


Figure 5.29. Station 410134: Billabong Creek @ Darlot; time series plot of observed continuous versus Baseline Conditions model salinity.

5.3.11. Discussion of results from the forced release Cap model

Table 5.31 provides a summary of the salinity and salt load results given in Sections 5.3.1 to 5.3.10. The modelled salinity and salt load are generally within 10% of the observed values for all stations on the Tumut River and the Murrumbidgge River as far downstream as Wagga Wagga. The results for the lower Murrumbidgee River and Billabong Creek are much poorer, especially in the low flow range where the effects of errors in the mix of water from different sources are more pronounced. The poor results were expected in the lower part of the system because of significant changes that have affected flows into the Billabong Creek system, irrigation diversions, drainage flows and salinity over the Benchmark period. The Cap model with forced dam releases is unable to replicate the effects of these changes.

Therefore, although the model simulates flows and salinities reasonably well at Balranald, there are issues in Billabong Creek that will need to be addressed before the model results at Darlot can be accepted.

The forced release Cap model is an unsatisfactory evaluation tool for two reasons. Firstly, it doesn’t test the ability of the model to match the most important flow time series; the releases from headwater storages. Secondly, the mismatch between Cap and actual diversions results in nonsensical flows at downstream points. For this reason, some results have also been presented for the unforced model as it should allow a more realistic appraisal of the model’s performance.

Table 5.31. Summary of comparisons of simulated versus observed salt loads: forced release model

Target Site		**Concentration Match**				**Salt Load Match**			
Number	Name	*Low*	*Medium*	*High*	*All*	*Low*	*Medium*	*High*	*All*
		Legend: 1 < ±10%; 2 < ±20%; 3= > ±20%							
Headwaters of the Murrumbidgee River									
410073	**Blowering Dam:** Tumut River @ Oddys Bridge	3	1	1	1	3	1	1	1
410039	Tumut River @ Brungle Bridge	1	1	2	1	2	1	1	1
410008	**Burrinjuck Dam:** Murrumbidgee River d/s Burrinjuck Dam	1	1	1	1	1	1	1	1
Murrumbidgee River									
410004	Murrumbidgee River @ Gundagai	2	1	1	1	1	1	1	1
410001	Murrumbidgee River @ Wagga Wagga	2	1	2	1	1	1	2	1
410136	Murrumbidgee River d/s Hay Weir	2	1	2	1	3	3	2	2
410130	Murrumbidgee River @ Balranald	2	1	2	1	3	2	1	2
Billabong Creek									
410016	Billabong Creek @ Jerilderie	3	1	2	1	3	1	1	1
410017	Billabong Creek @ Conargo	3	3	1	3	1	2	2	1

41010997	Billabong Creek @ Conargo Bridge	3	1	1	1	3	1	1	1
410134	Billabong Creek @ Darlot	3	3	3	3	3	1	2	2

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

Table 5.32 shows the mean salt loads for Audit inflow and balance points from (i) the Audit, (ii) the initial IQQM using Audit flow-load relationships and (iii) the IQQM using Audit flow-load relationships with forced dam releases (N.B. the statistics for the latter are for th eperiod 1/5/1976-30/04/2000 as dam outflow data is not available from 1/5/1975).

Taking into account the different periods covered by the Audit and the model runs, the results are reasonably for the majority of inflow points and all of the balance points in the system.

Table 5.32. Comparison of average annual salt loads: Salinity Audit, Audit as modified, Audit as modified with forced dam releases

Audit inflow / balance point		**Mean salt load ('000 T/year)**		
Number	**Name**	*Salinity Audit*	*IQQM using Audit inflows*	*IQQM using Audit inflows and forced releases*
410073	Tumut River @ Oddys Bridge	*35.2*	37.9	36.0
410057	Goobarragandra River @ Lacmalac	*6.6*	8.0	7.8
410059	Gilmore Creek @ Gilmore	*1.8*	3.5	3.5
410071	Brungle Creek @ Red Hill	*0.4*	3.6	3.0
R1	Ungauged Tumut River u/s Brungle Bridge	*2.0*	7.1	7.6
410039	**Tumut River @ Brungle Bridge**	***48.6***	**59.6**	**57.3**
410038	Adjungbilly Creek @ Darbalara	*5.2*	5.2	5.2
410008	Murrumbidgee River d/s Burrinjuck Dam	*147.0*	125.6	122.3
410025	Jugiong Creek @ Jugiong	*53.8*	54.2	54.6
410044	Muttama Creek @ Coolac	*23.5*	25.8	26.2
R2	Ungauged Tumut and Murrumbidgee Rivers u/s Gundagai	*21.6*	61.5	61.8
410004	**Murrumbidgee River @ Gundagai**	***307.9***	**331.1**	**326.3**
410061	Adelong Creek @ Batlow Road	*7.5*	2.3	2.2
410045	Billabung Creek @ Sunnyside	*6.6*	1.8	1.8
410043	Hillas Creek @ Mount Adrah	*18.2*	14.0	13.8
410047	Tarcutta Creek @ Old Borambola	*26.2*	22.9	22.3
410048	Kyeamba Creek @ Ladysmith	*20.4*	8.5	8.5
R3	Ungauged Murrumbidgee River between Gundagai and Wagga Wagga	*6.0*	14.3	14.1
410001	**Murrumbidgee River @ Wagga Wagga**	***401.8***	**394.2**	**383.6**

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 the processes simulated in IQQM. Point (vii) may affect either catchment inflows, or IQQM operation.

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

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

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

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

6.2. RESULTS

The baseline 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 on the Murrumbidgee River part of the model. It can be seen that concentration increase marginally from Gundagai to Waggato Hay. A bigger change occurs between Hay and Balranald presumably related to Lowbidgee returns.

In the Yanco-Colombo-Billabong system we do not see a close correspondence to observed data. This is expected because of the changes in the Yanco offtake, rising water tables in Coleambally and the introduction of rice growing. As expected salinities decrease from Jerilderie to Conargo with the input of the Yanco Creek, which is dominated by Murrumbidgee River water. The increase between Conargo and Darlot is related mainly to the input of the Coleambally outfall drain. Annual results show a similar pattern.

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

Water Balance Component		Value	Units
Average annual inflows *(benchmark climatic period)*			
Burrinjuck Dam Inflow		1,378	GL/year
Blowering Inflow		1,646	GL/year
Head works Dams to Wagga		1,492	GL/year
Storages			
Blowering			
Active storage		1,601	GL
Snowy air space agreement volume		190	GL
Burrinjuck			
Active storage		1,025	GL
BerembedWeir			
Active storage		1	GL
Gogeldrie Weirs			
Active storage		1	GL
Tombullen off-river storage			
Active storage		11	GL
Active storage		13	GL
Active storage		5	GL
Active storage		5	GL
Active storage		40	GL
Minimum-available allocation	< 90%	50	GL
	90-100%	50-150	GL
Provisional-available allocation	< 60%	0	GL
	60-80%	25	GL
	80-100%	25-200	GL
Irrigation *			
General security licences		2,043	GL/year
High security licences		333	GL/year
Conveyance		373	%

Water Balance Component	Value	Units
Maximum allocation	100	%
Maximum irrigable area	290,000	Ha
On-farm storage capacity	0	GL
Crop types (See Table 6.2)		
Supplementary Access HOU Annual Limit	220	GL/year
Snowy Inflows		
Minimum notification	1,026	GL/year
Town water supply		
Jugiong	5.6	GL/year
Gundagai	1.2	GL/year
Wagga	8.0	GL/year
Narrandera	2.2	GL/year
Hay	2.8	GL/year
Balranald	1.3	GL/year
In-stream water supply *(refer to Table 4.1 for details)*		
Balranald (available allocation < 80%)	200	ML/day
Balranald (available allocation >=80%)	300	ML/day
Darlot	50	ML/day
D/s Burrinjuck Dam - minimum.	615	ML/day
D/s Blowering Dam - minimum	560	ML/day
Warriston Weir	100	ML/day

Table 6.2. Crop types, proportions, and irrigation factors

Crop type	% of total	Average crop factor for month											
		J	F	M	A	M	J	J	A	S	O	N	D
Rice	29	0.94	0.94	0.77	0.25	0.00	0.00	0.00	0.00	0.00	0.70	0.80	0.87
Vines	4	0.56	0.49	0.39	0.00	0.00	0.00	0.00	0.32	0.42	0.52	0.52	0.52
Winter pasture	23	0.00	0.25	0.39	0.56	0.59	0.56	0.56	0.56	0.52	0.35	0.25	0.00
Lucerne	2	1.30	1.28	1.23	1.15	0.96	0.74	0.65	0.71	0.91	1.15	1.28	1.30
Summer cereal	3	0.85	0.85	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.50	0.70
Winter cereal	28	0.00	0.00	0.25	0.25	0.32	0.39	0.73	0.84	0.84	0.66	0.28	0.00
Orchard	4	0.52	0.52	0.56	0.56	0.56	0.56	0.56	0.56	0.52	0.49	0.49	0.49
Vegetables	2	0.64	0.56	0.43	0.38	0.49	0.54	0.54	0.51	0.45	0.59	0.64	0.65
Summer oil seed	2	0.75	0.96	0.89	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Winter oil seed	1	0.00	0.00	0.00	0.30	0.43	0.58	0.69	0.74	0.74	0.64	0.42	0.00
Fodder	2	0.63	0.63	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.56	0.63

It is not possible to give a full explanation of these numbers in this report. The reader is referred to regulated system gazetted plan in NSWG (2003) and the Murrumbidgee Valley (Regulated System) Water Allocation Plan 2003/04 in DIPNR(2003) (some rules have changed since year 2000 but the essence is unchanged) to gain an understanding of the issues.

However, the following points should be noted:

- The Murrumbidgee IQQM resource assessment does not explicitly use all of the individual licence entitlement numbers related to high security given above. It uses a total number sourced directly from the official resource assessment because of the (slight) historical mismatch between the resource assessment and Licence Volumes obtained from DIPNR's LAS database system..

- A constant level of inter- and intra-valley trade has been assumed in the Murrumbidgee model which means some deviations occur from the entitlement numbers given above.

- Also, due to the lack of data on the exact location of general and high security entitlement, the model is a hybrid of pre- and post- conversion from general to high security.

- Irrigation water usage in IQQM can be simulated using two methods. One method is to adjust crop factors for inefficiencies in delivering water to crops using efficiency factors. The second way is to explicitly model the processes which cause inefficiencies such as seepage, flood irrigation over watering, canal losses and escape flows. The latter method has been adopted in the Murrumbidgee IQQM, primarily because of the need to model recycling in the MIA system. For this reason, no efficiency factors are given in Table 6.2.

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)**			
Number	**Name**	***Mean***	*Percentile non-exceedance*			***Mean***	*Percentile non-exceedance*		
			20	***50***	***80***		***20***	***50***	***80***
410004	Murrumbidgee River @ Gundagai	83	47	67	120	904	278	578	1117
410001	Murrumbidgee River @ Wagga Wagga	86	51	72	124	1,064	328	675	1285
410136	Murrumbidgee River d/s Hay Weir	91	61	78	126	574	73	156	918
410130	Murrumbidgee River @ Balranald	106	70	92	140	445	28	84	803
410016	Billabong Creek @ Jerilderie	163	95	159	228	74	25	44	116
410017	Billabong Creek @ Conargo	147	80	125	198	116	20	42	192
410134	Billabong Creek @ Darlot	170	100	144	224	134	22	51	222

- In Bewsher (2004) it has been recommended that the Murrumbidgee River model be classified as Class 2. This means that there is acceptable confidence in statistical variability of baseline conditions from this model and the percentiles should be used tentatively. 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*	*Rank*		
			5	*13*	*21*
410004	Murrumbidgee River @ Gundagai	330	208	322	466
410001	Murrumbidgee River @ Wagga	388	221	411	550
410136	Murrumbidgee River@d/s Hay weir	209	66	220	344
410130	Murrumbidgee River @Balranald	163	34	156	298
410016	Billabong Creek @Jerilderie	27	14	31	36
410017	Billabong Creek @ Conargo	42	17	45	65
410134	Billabong Creek @ Darlot	49	19	48	77

- In Bewsher (2004) it has been recommended that the Murrumbidgee River model be classified as Class 3. This means that there is acceptable confidence in statistical variability of baseline conditions from this model and the percentiles should be used tentatively. 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.

Figure 6.1 to Figure 6.18 compare the baseline conditions with observed data for Murrumbidgee River at Balranald.

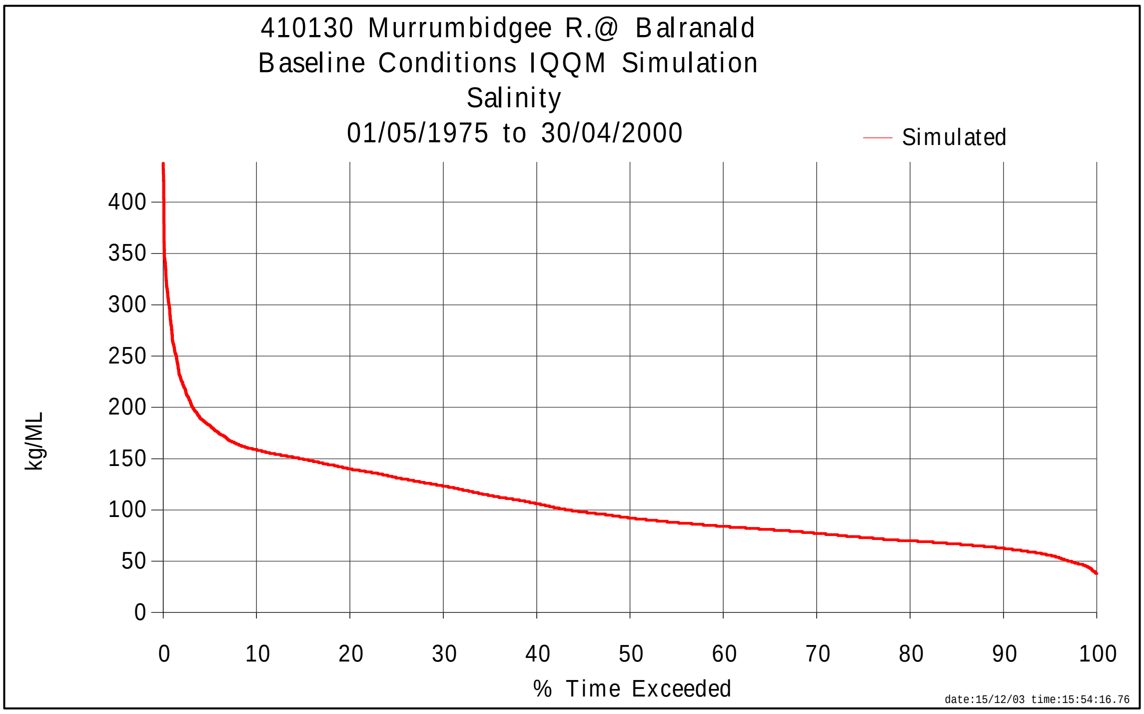


Figure 6.1. Frequency of exceedance of simulated salinity for Baseline Conditions scenario (1/5/1975-30/4/2000) for Murrumbidgee River @ Balranald

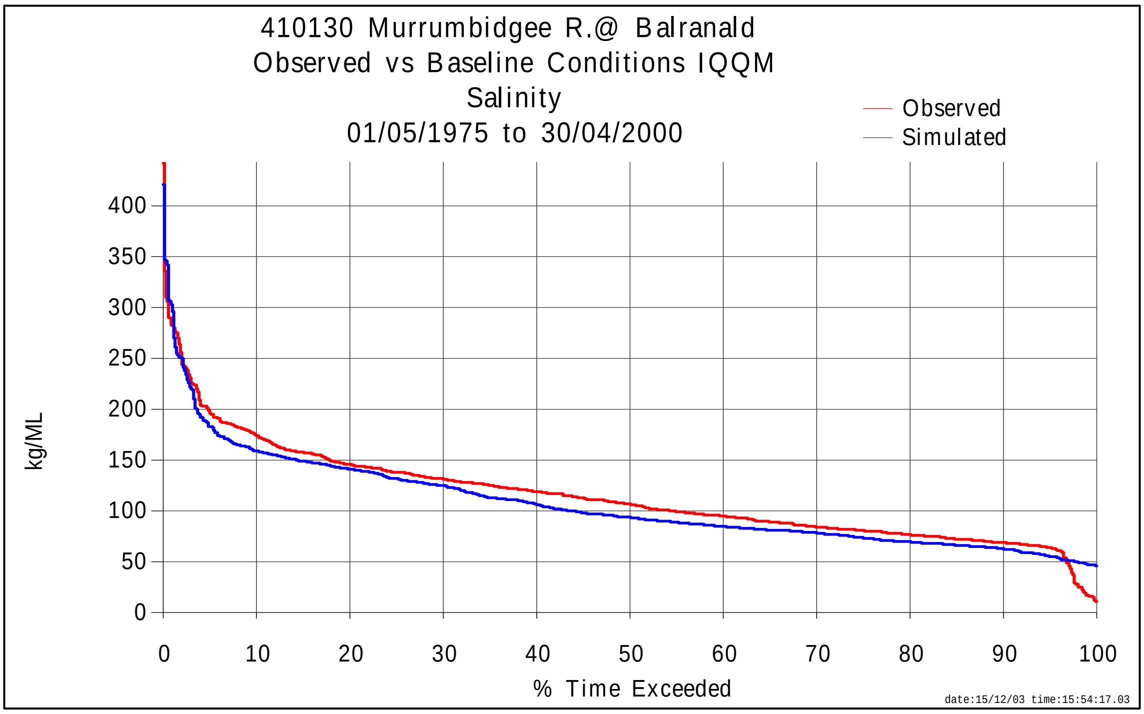


Figure 6.2. Frequency of exceedance of simulated salinity for Baseline Conditions scenario on days with salinity observations (1/5/1975-30/4/2000), compared with salinity observations for Murrumbidgee River @ Balranald

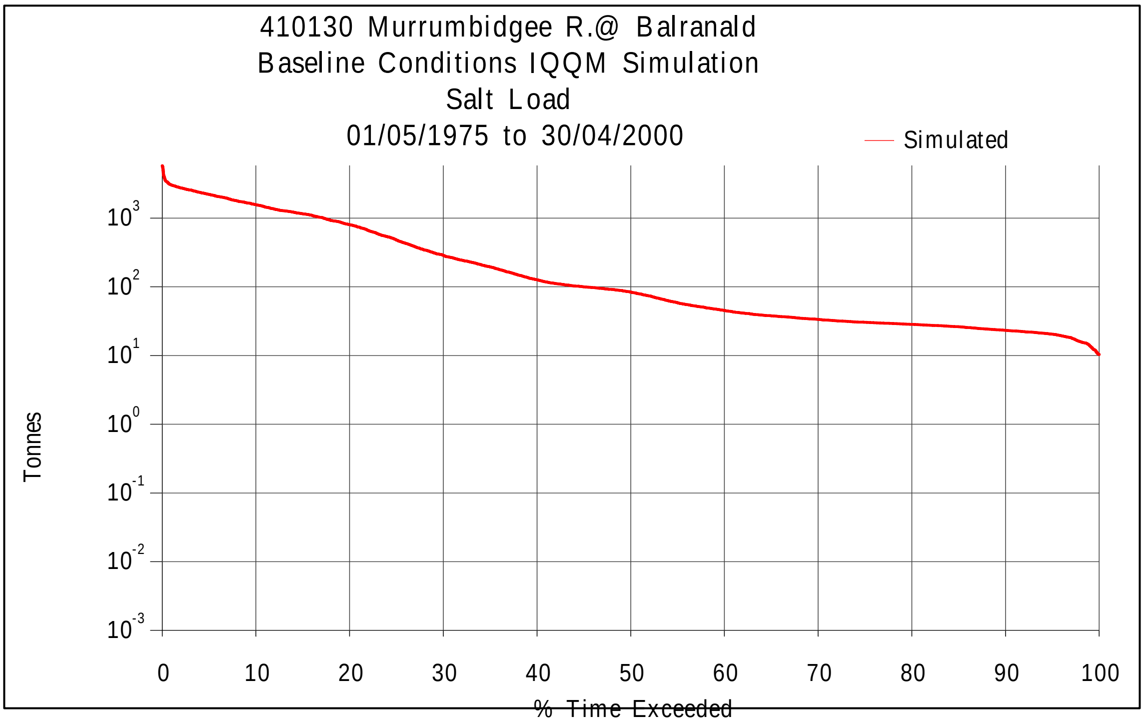


Figure 6.3. Frequency of exceedance of simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Murrumbidgee River @ Balranald

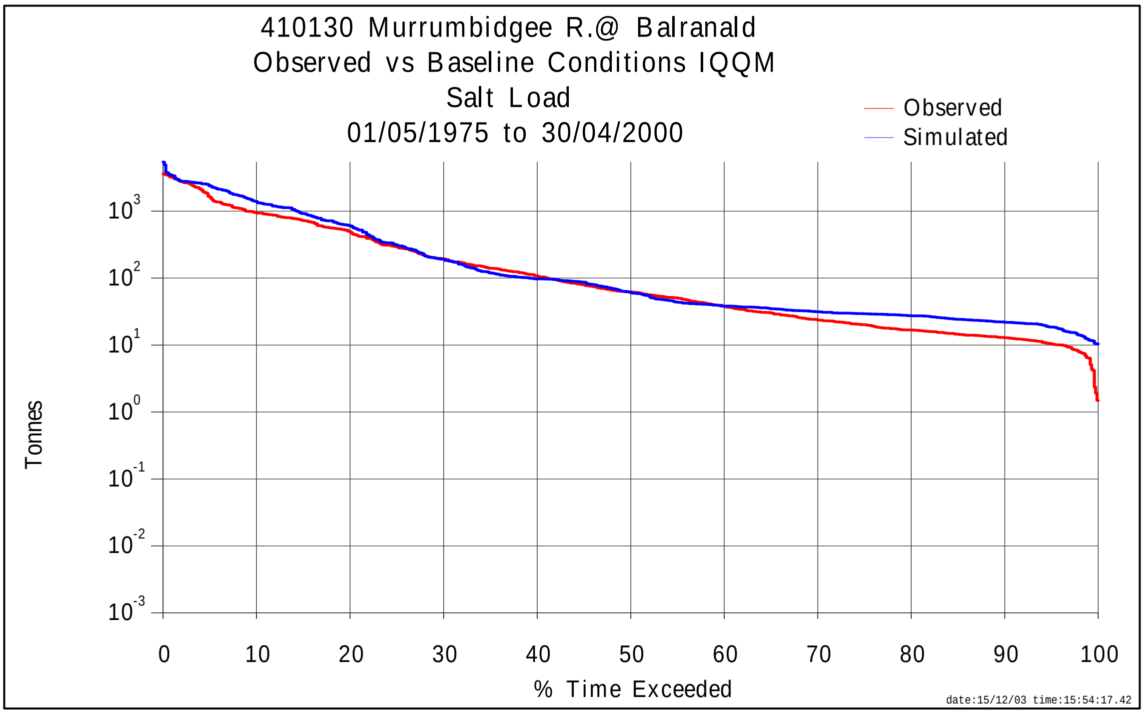


Figure 6.4. Frequency of exceedance of simulated salt load for Baseline Conditions scenario on days with salinity and flow observations (1/5/1975-30/4/2000), compared with salinity observations for Murrumbidgee River @ Balranald.

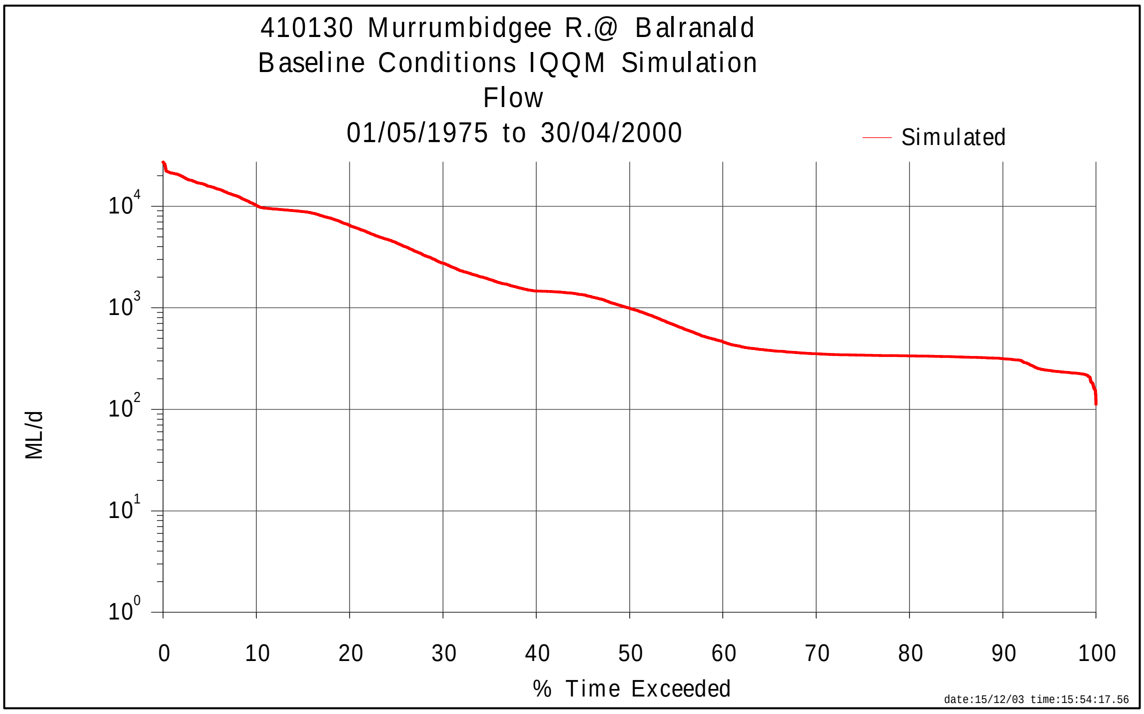


Figure 6.5. Frequency of exceedance of simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Murrumbidgee River @ Balranald

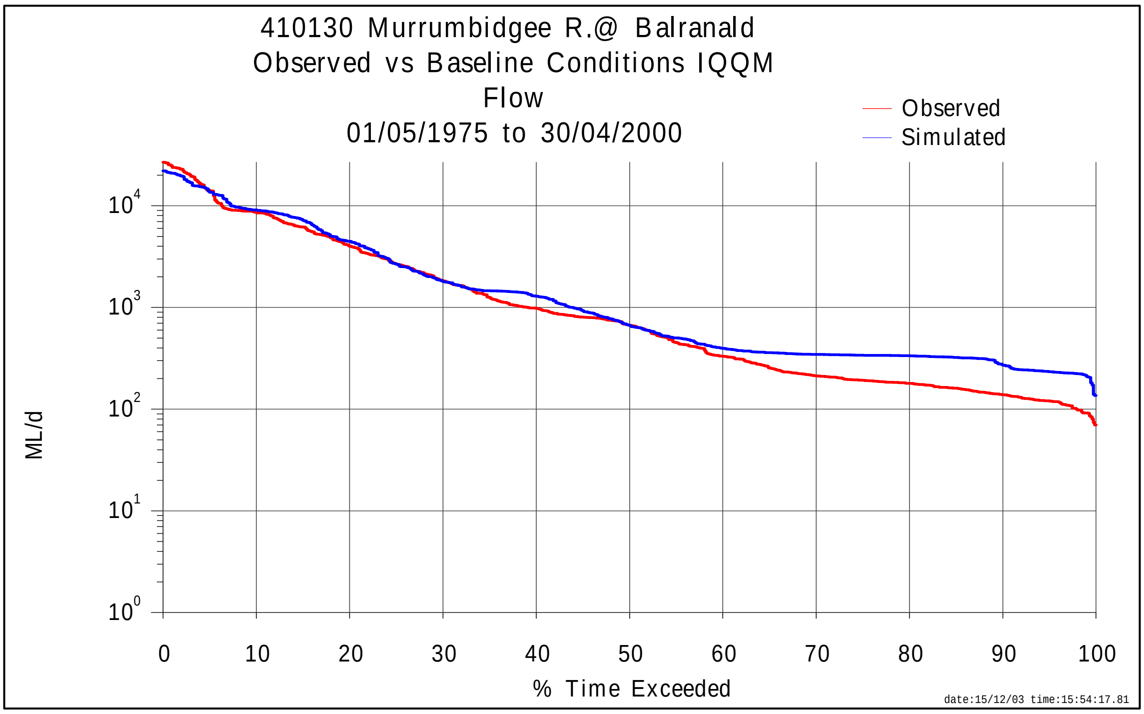


Figure 6.6. Frequency of exceedance of simulated flow for Baseline Conditions scenario on days with flow observations (1/5/1975-30/4/2000), compared with observed flow for Murrumbidgee River @ Balranald

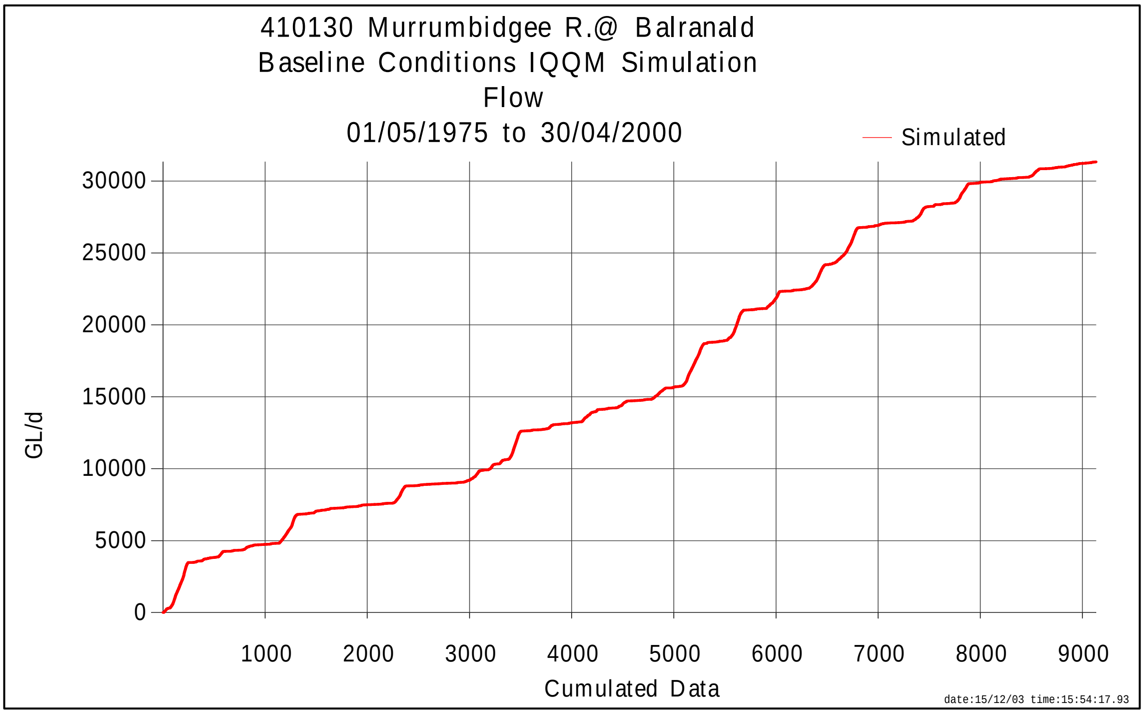


Figure 6.7. Cumulative simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Murrumbidgee River @ Balranald

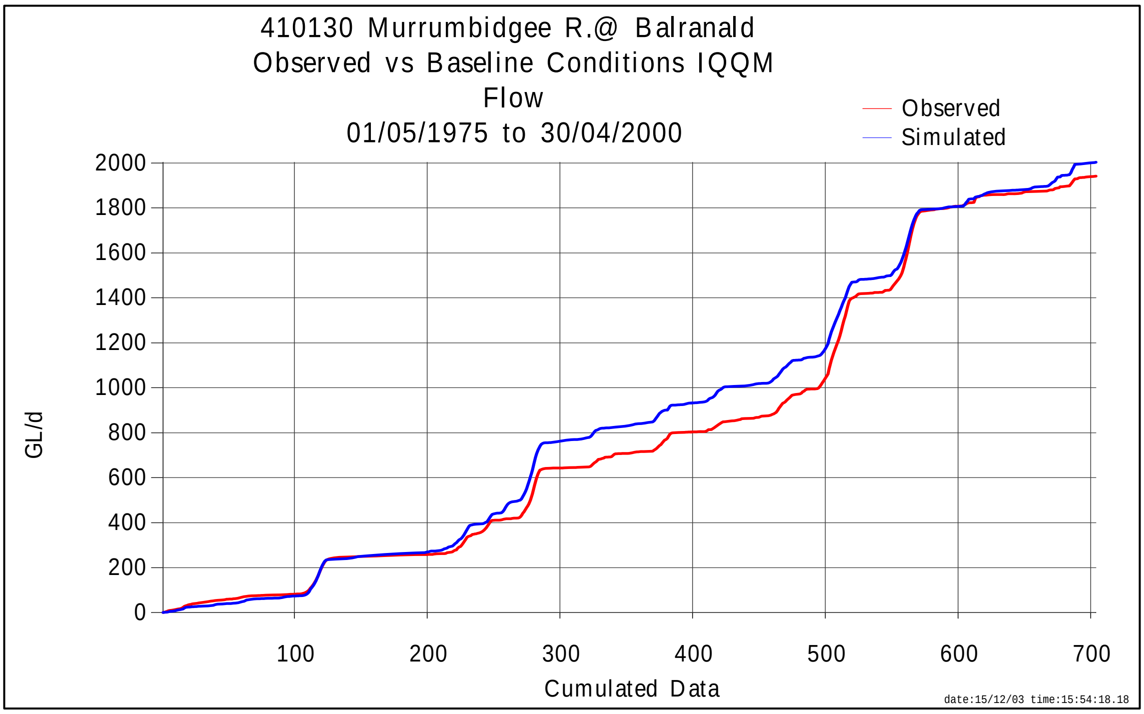


Figure 6.8. Cumulative simulated flow for Baseline Conditions scenario for days with observed flow, and observed flow (1/5/1975-30/4/2000) for Murrumbidgee River @ Balranald.

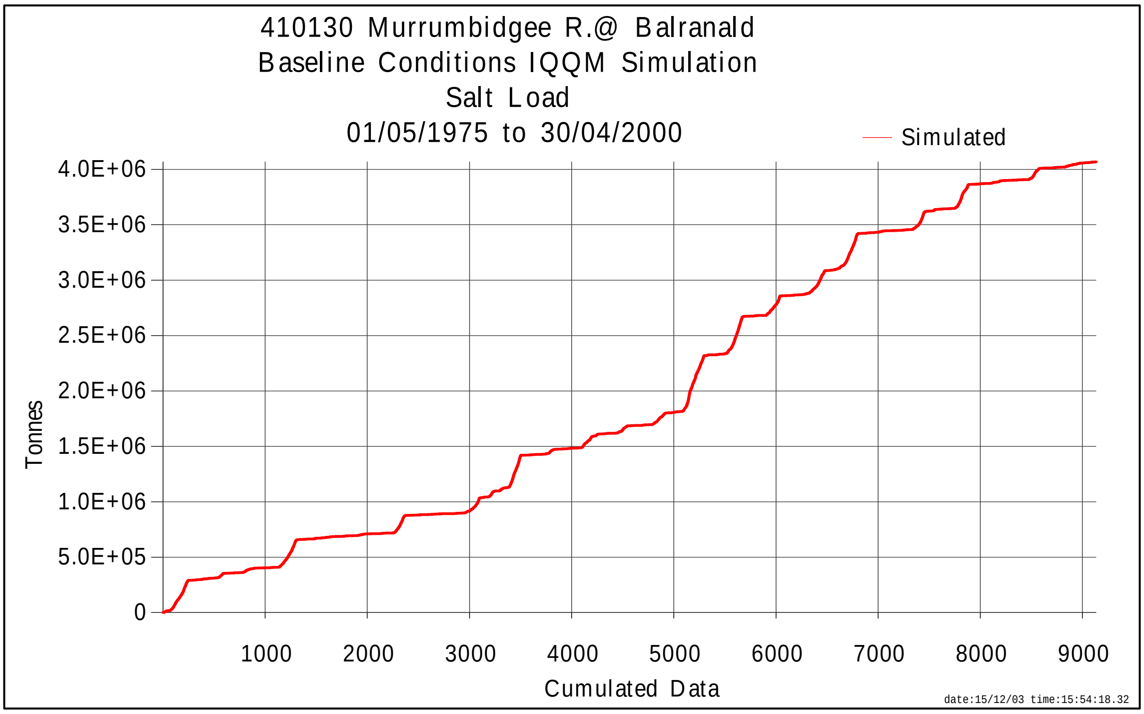


Figure 6.9. Cumulative simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Murrumbidgee River @ Balranald.

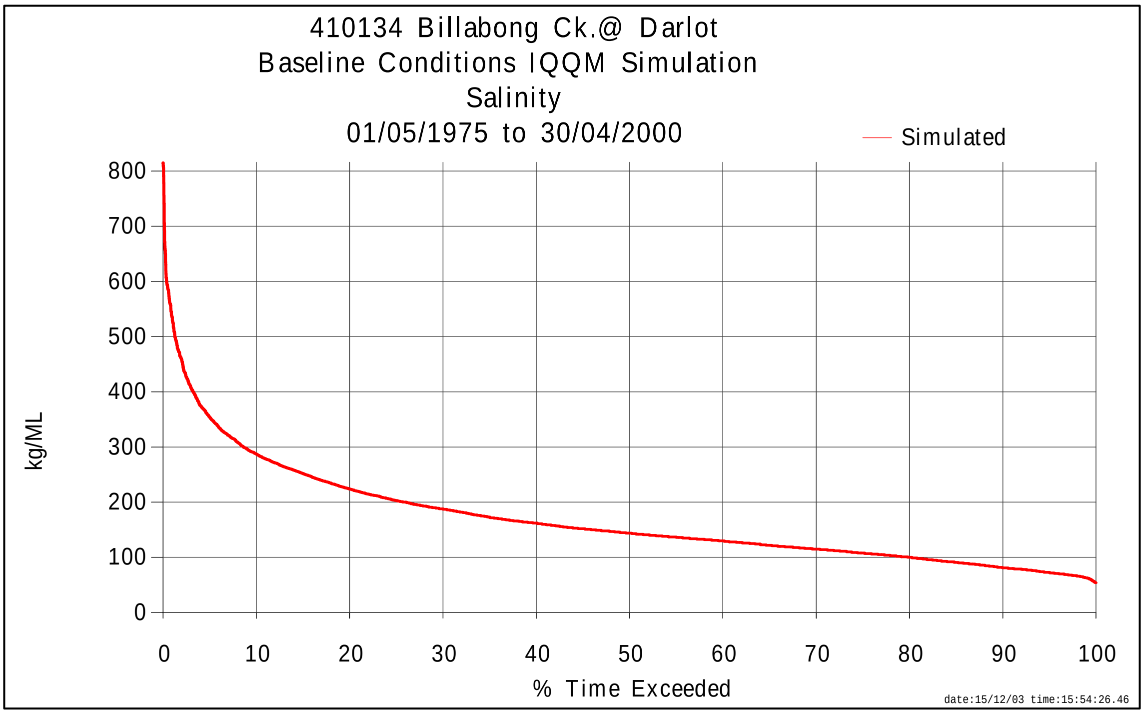


Figure 6.10. Frequency of exceedance of simulated salinity for Baseline Conditions scenario (1/5/1975-30/4/2000) for Billabong Creek @ Darlot.

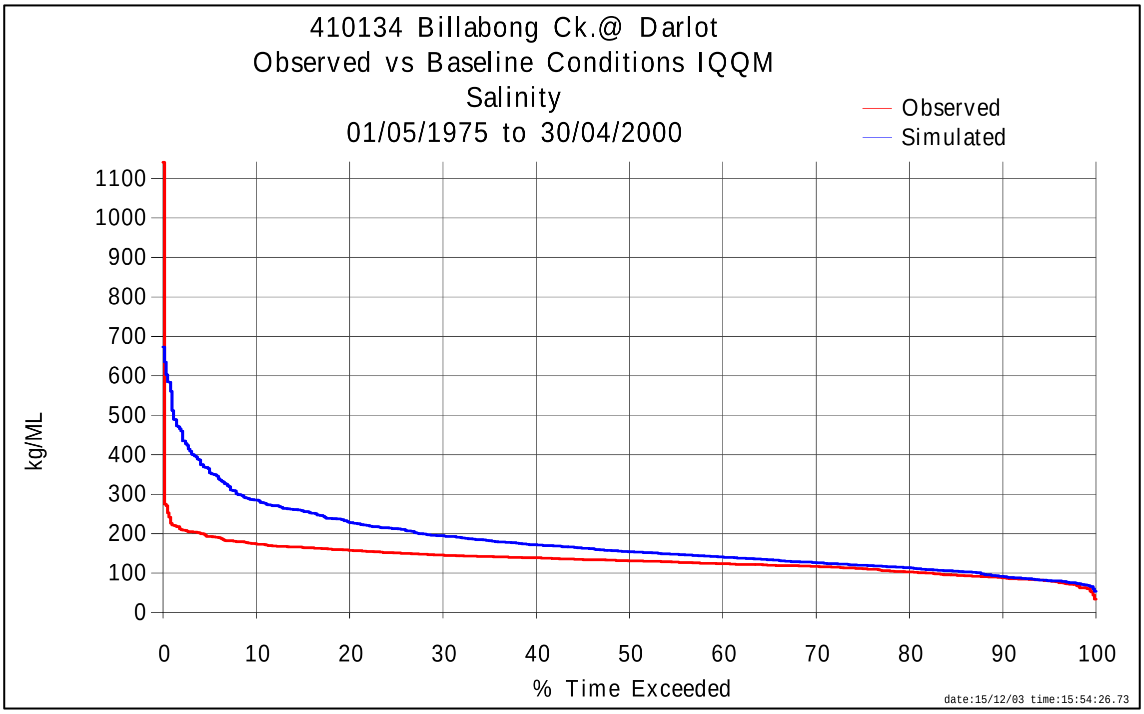


Figure 6.11. Frequency of exceedance of simulated salinity for Baseline Conditions scenario on days with salinity observations (1/5/1975-30/4/2000), compared with salinity observations for Billabong Creek @ Darlot.

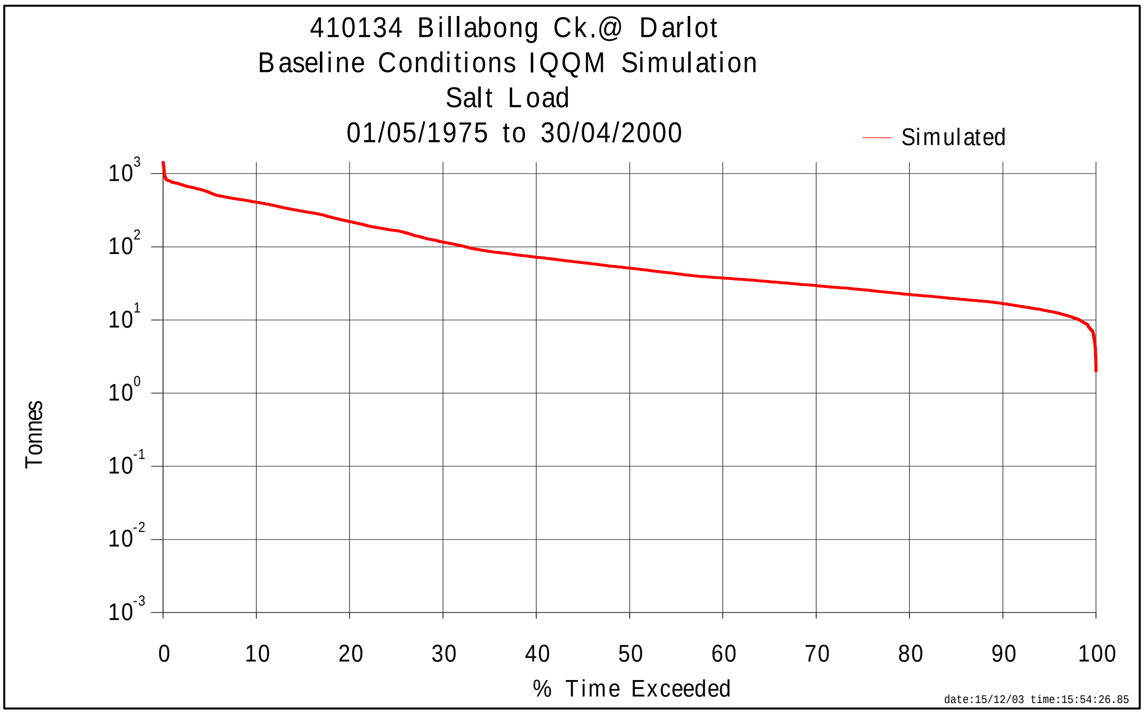


Figure 6.12. Frequency of exceedance of simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Billabong Creek @ Darlot.

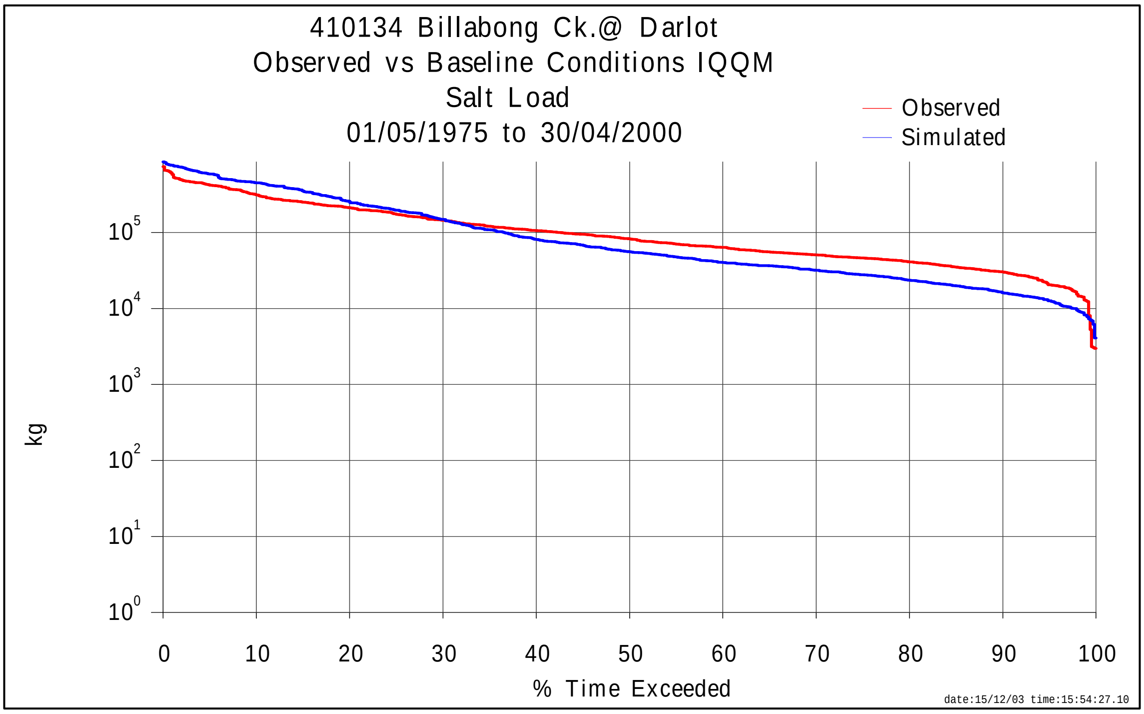


Figure 6.13. Frequency of exceedance of simulated salt load for Baseline Conditions scenario on days with salinity and flow observations (1/5/1975-30/4/2000), compared with salinity observations for Billabong Creek @ Darlot.

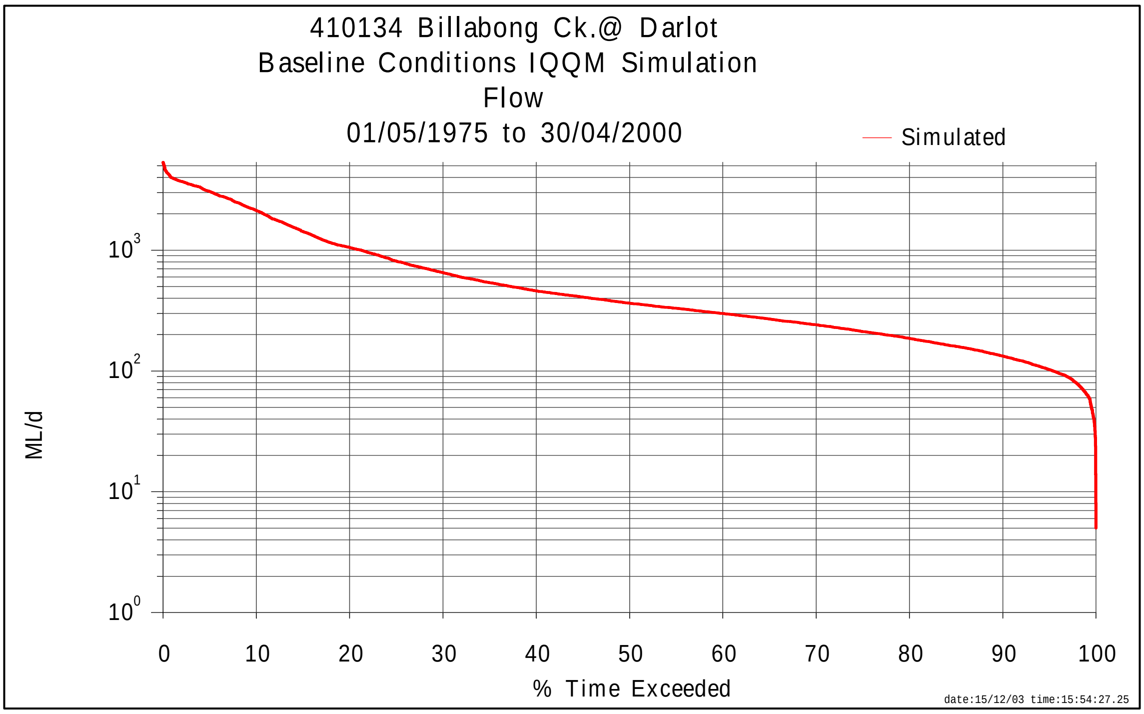


Figure 6.14. Frequency of exceedance of simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Billabong Creek @ Darlot

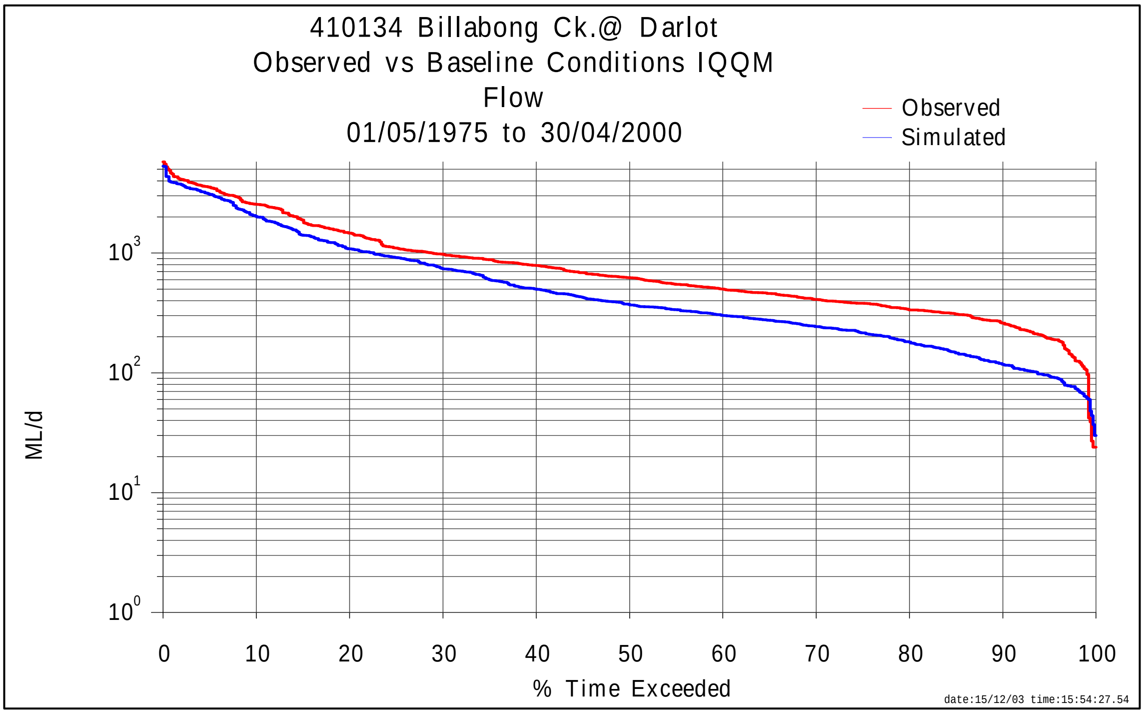


Figure 6.15. Frequency of exceedance of simulated flow for Baseline Conditions scenario on days with flow observations (1/5/1975-30/4/2000), compared with observed flow for Billabong Creek @ Darlot..

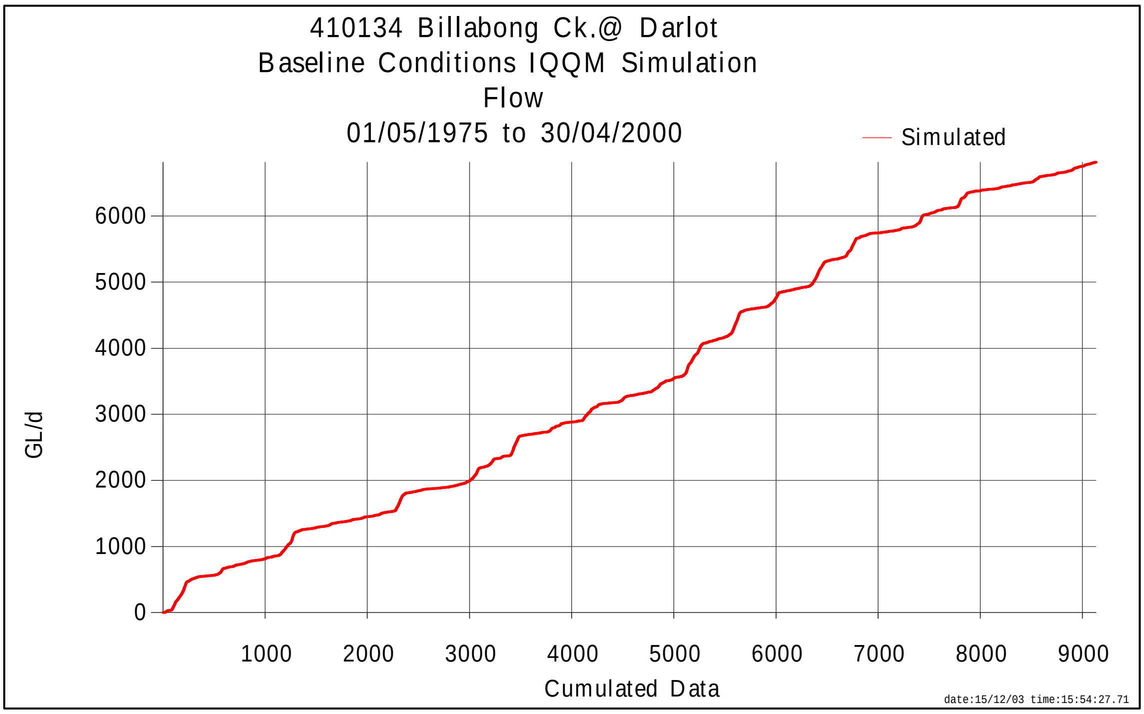


Figure 6.16. Cumulative simulated flow for Baseline Conditions scenario (1/5/1975-30/4/2000) for Billabong Creek @ Darlot.

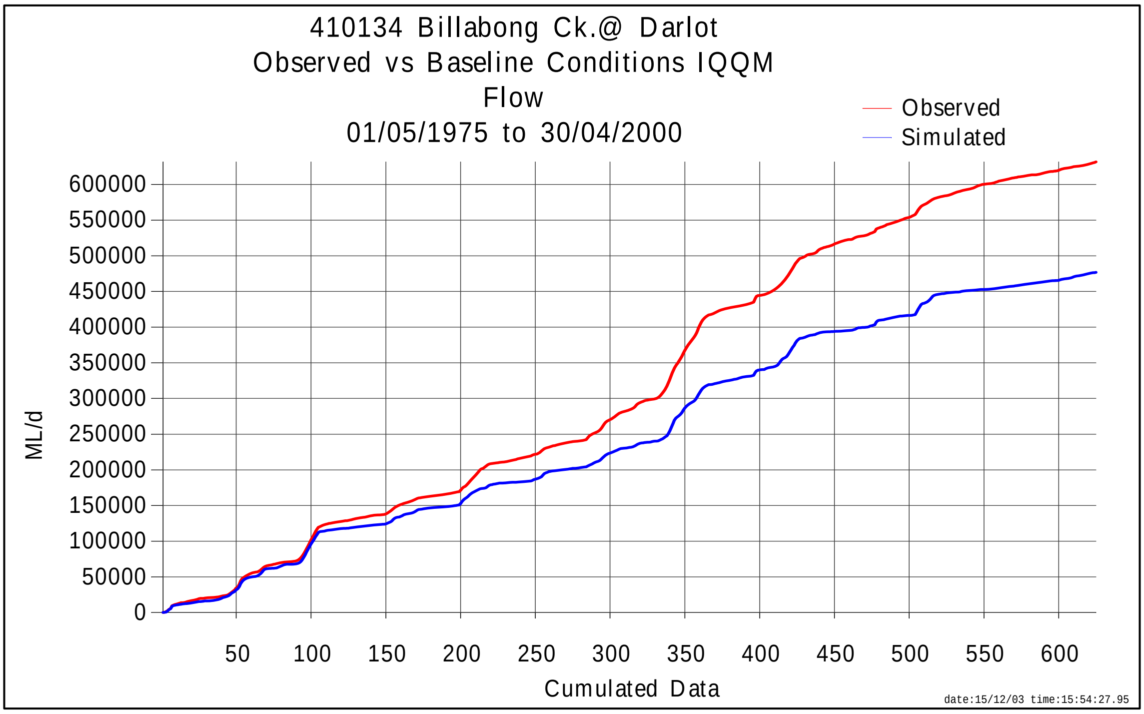


Figure 6.17. Cumulative simulated flow for Baseline Conditions scenario for days with observed flow, and observed flow (1/5/1975-30/4/2000) for Billabong Creek @ Darlot.

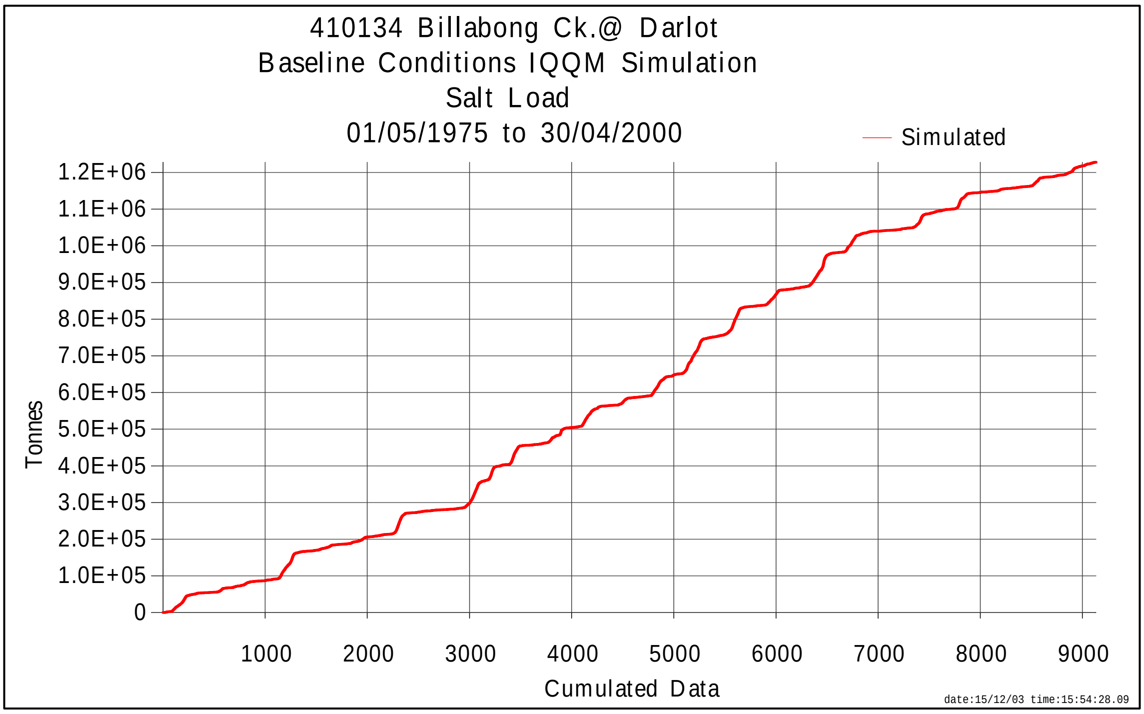


Figure 6.18. Cumulative simulated salt load for Baseline Conditions scenario (1/5/1975-30/4/2000) for Billabong Creek @ Darlot.

7. Recommendations

7.1. ACCEPTANCE FOR BSMS USAGE

The Murrumbidgee IQQM model provides an unsatisfactory end of system representation at Darlot both in terms of flow and salinities. It is recommended that an intense re-calibration exercise be undertaken for the Yanco-Colombo-Billabong system along the lines of the recommendations in Section 7.3.2. If significant improvements are achieved, the model could then be accepted for use in the BSMS. It should be noted that current MSM-BIGMOD practice of using historical salinities is also unsatisfactory because of changes to the Yanco offtake and within the Yanco-Colombo-Billabong system.

7.2. RECOMMENDATIONS ON FUTURE DATA MONITORING AND PROCESSING

The Murrumbidgee catchment has a good quantity of flow and salinity data as well as competent, knowledgeable and helpful hydrographic staff. However, there are still some areas where improvements could facilitate better modelling and these are described below.

7.2.1. Editing of continuous salinity data

Editing of continuous salinity data is necessary because salinity probes are prone to go off track. Editing involves bringing the salinity probe readings back into alignment with reference points derived from laboratory or field measurements. There is a DIPNR committee due to report soon on how to uniformly apply editing procedures.

It is recommended that after that committee reports that as soon as possible all existing Murrumbidgee salinity data sets be edited. At present, the data sets provide a means of checking model performance in terms of general salinity behaviour but cannot be used to check for bias. This severely limits their use in the BSMS context.

7.2.2. Monitoring

The inflows between Gundagai and Wagga are poorly measured. A recently created station on Hillas Creek will improve the situation but it is recommended that all major tributaries be gauged. However, because of backwater effects, there will always be significant residual areas that will not be measurable. It is recommended that a monthly time step run of the river sampling program be undertaken to gain an understanding of residual salinity contributions. It is also recommend that this program be extended downstream of the tributary inflow areas to gain an understanding of any changes in river groundwater interaction due to changes in river irrigation practices and cropping.

7.3. RECOMMENDATIONS ON MODEL IMPROVEMENTS

The model evaluation undertaken for this report has brought out a number of issues that are outlined in the following sections.

7.3.1. Model Evaluation Techniques

The evaluation techniques used are mainly based on using a Cap model with forced historical dam releases. In the Murrumbidgee Valley, the Cap model is only representative of irrigation demand for a few years around 1993/94. Outside this period, modelled diversions will differ significantly in terms of timing and magnitude from the observed diversions. This will lead to a mismatch of flows in the effluent systems and the lower parts of the main river and hence problems in matching salinities. It is recommended that the existing time series of crop areas be extended to cover the last five years of the baseline period. That will allow evaluation to be carried out without gross flow mismatches. It is further recommended that a program of annually updating these data sets be undertaken to allow for continuous model checking and, where necessary, model updating.

7.3.2. Recommendations on model improvements

Review of the available salinity data and development of the Murrumbidgee IQQM 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 the priority of modelling work within the Department. Although the Department is committed to developing the salinity models, the timetable for model improvements will be part of future work planning. The following points summarise the areas where model improvements could be made.

- Loss representation in the Yanco-Colombo-Billabong system needs to be examined. A related issue is the possible need to represent the runnoff generated from those parts of the system outside the Coleambally Irrigation Area.
- The drainage canal flow generation process needs to be re-examined. Canal flows can arise through rainfall-runoff processes, flood irrigation processes and the use of drainage canals as supply channels. A re-examination would involve obtaining all available Coleambally Irrigation information on on-farm recycling and use of canals as supply channels.
- Supplementary flows into Yanco Creek vary significantly in relation to Narrandera flows. Attempts to model Yanco Creek supplementary flows have been unsatisfactory, leading to significant flow mismatches at Jerilderie, Conargo and Darlot. State Water may be able to advise on a systematic way of dealing with Yanco supplementary flows.

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

Beale, G.T.H., R. Beecham, K. Harris, D. O’Neill, H. Schroo, N.K. Tuteja and R.M. Williams (1999). *Salinity predictions for NSW rivers within the Murray-Darling Basin* CNR 99.048. NSW DLWC (Parramatta).

Bewsher D (2004), *Assessment of NSW Tributary IQQM Models*, Bewsher Consulting Pty Ltd, January 2004. Report prepared for Baseline Conditions Technical Subcommittee, Murray Darling Basin Commission.

Braaten, R. and G. Gates (2002). *Groundwater - surface water interaction in NSW: a discussion paper*. NSW DLWC (Sydney).

Department of Environment and Climate Change (2006). NSW Sate of the environment 2006. (Sydney)

Department of Environment and Climate Change (2007). *Salinity Audit: Upland catchments of NSW* (*draft*). (Sydney).

Department of Infrastructure Planning and Natural Resources (2003), *Murrumbidgee Valley (Regulated System) Water Allocation Plan 2003/04*.

HydroTechnology (1995) Synthesis of Daily Flow Sequences Murrumbidgee River System

I.Jolly, R. Morton, G. Walker, G. Robinson, H. Jones, N. Nandakumar, R. Nathan, R. Clark and V. McNeill (1997). *Salinity Trends in Catchments of the Murray-Darling Basin*, CSIRO Technical Report 14/97

Murray Darling Basin Ministerial Council (1999). *The Salinity Audit of the Murray Darling Basin. A 100 year perspective 1999*. MDBC (Canberra).

Murray Darling Basin Ministerial Council (2001). *Basin Salinity Management Strategy 2001-2015*. MDBC (Canberra).

Natural Resources Commission (2005) Standard for Quality Natural Resources Management (Sydney).

New South Wales Government (2000a). *NSW Salinity Strategy: Taking the challenge*. NSW DLWC (Sydney).

New South Wales Govenment (2000b). *NSW Salinity Strategy: Salinity Targets Supplementary Paper*. NSW DLWC (Sydney).

New South Wales Government (2003), *Water Sharing Plan for the Murrumbidgee Regulated River Water Source*, John Aquilina, Minister for Land & Water Conservation

Murrumbidgee Catchment Management Board (2003), *Murrumbidgee Catchment Blueprint*, Murrumbidgee Catchment Management Board

Summerell, G.K., Miller, M., Beale, G., Emery, K. & Lucas, S. (2005), *Current and predicted minimum and maximum extents of land salinisation in the upland portion of the Murray–Darling*

Basin. **in** A. Zerger & R.M. Argent (editors) MODSIM 2005 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand, December 2005

Appendix A. Availability of salinity data

Table A1. EC data in the Murrumbidgee Valley

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
410001	Murrumbidgee River @ Wagga Wagga	35.102	147.366	Continuous	1993-2001	3,121
410001	Murrumbidgee River @ Wagga Wagga	35.102	147.366	Discrete	1976-2001	177
410002	Murrumbidgee River @ Hay	34.517	144.842	Discrete	1957-1983	165
410003	Murrumbidgee River @ Balranald	34.648	143.562	Discrete	1966-1986	530
410004	Murrumbidgee River @ Gundagai	35.076	148.106	Continuous	1993-2002	3,043
410004	Murrumbidgee River @ Gundagai	35.076	148.106	Discrete	1976-2001	191
410005	Murrumbidgee River @ Narrandera	34.757	146.548	Discrete	1976-1991	179
410006	Tumut River @ Tumut	35.304	148.233	Discrete	1970-1987	133
410007	Yanco Creek @ Offtake	34.707	146.408	Discrete	1970-1987	142
410008	Murrumbidgee River d/s Burrinjuck Dam	35.003	148.574	Continuous	2001-2002	377
410008	Murrumbidgee River d/s Burrinjuck Dam	35.003	148.574	Discrete	1976-2001	154
410012	Billabong Creek @ Cocketgedong	35.317	146.035	Discrete	1970-1986	90
410013	Main Canal @ Berembed	34.879	146.834	Discrete	1976-1985	23
410014	Colombo Creek @ Morundah	34.938	146.294	Discrete	1968-2000	131
410015	Yanco Creek @ Morundah	34.947	146.254	Discrete	1970-1987	132
410016	Billabong Creek @ Jerilderie	35.355	145.735	Discrete	1970-2002	222
410017	Billabong Creek @ Conargo	35.286	145.208	Discrete	1923-1995	164
410019	Little Gilmore Creek @ Batlow	35.536	148.154	Discrete	1984-1984	1
410021	Murrumbidgee River @ Darlington Point	34.568	146.002	Discrete	1966-2000	461
410022	Murrumbidgee River @ Jugiong	34.828	148.321	Discrete	1985-1991	28
410023	Murrumbidgee River d/s Berembed Weir	34.881	146.834	Continuous	1999-2001	750
410023	Murrumbidgee River @ Berembed Weir	34.881	146.834	Discrete	1976-2001	82
410024	Goodradigbee River @ Wee Jasper (Kashmir)	35.167	148.686	Continuous	1999-2002	1,027
410024	Goodradigbee River @ Wee Jasper (Kashmir)	35.167	148.686	Discrete	1970-1987	116
410025	Jugiong Creek @ Jugiong	34.790	148.378	Continuous	2001-2002	216

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
410025	Jugiong Creek @ Jugiong	34.790	148.378	Discrete	1970-2000	230
410026	Yass River @ Yass	35.844	148.907	Discrete	1970-1991	135
410027	Murrumbidgee River @ Yeumburra	35.067	148.917	Discrete	1990-1990	1
410029	Buddong Creek @ Buddong Falls (Buddong Weir)	35.650	148.217	Discrete	1967-1977	50
410030	Billabong Creek @ Windouran	35.056	144.209	Discrete	1982-1983	58
410033	Murrumbidgee River @ Mittagang Crossing	36.175	149.093	Discrete	1976-1991	91
410035	Murrumbidgee River @ Cotter Crossing	35.325	148.949	Discrete	1976-1977	7
410036	Murrumbidgee River d/s Yanco Weir	34.697	146.399	Discrete	1976-1987	91
410038	Adjungbilly Creek @ Darbalara	35.019	148.246	Discrete	1968-1987	144
410039	Tumut River @ Brungle Bridge	35.123	148.204	Discrete	1970-1987	117
410040	Murrumbidgee River @ Maude Weir	34.479	144.300	Discrete	1976-1991	97
410041	Murrumbidgee River @ Redbank (Weir No.5)	34.381	143.780	Discrete	1976-1991	76
410042	Adelong Creek @ Adelong No.1	35.300	148.067	Discrete	1978-1979	7
410043	Hillas Creek @ Mount Adrah	35.180	147.873	Discrete	1984-1992	4
410044	Muttama Creek @ Coolac	34.932	148.162	Continuous	2001-2002	208
410044	Muttama Creek @ Coolac	34.932	148.162	Discrete	1976-2001	197
410045	Billabung Creek @ Sunnyside	34.982	147.836	Discrete	1976-1992	13
410047	Tarcutta Creek @ Old Borambola	35.164	147.656	Continuous	2002-2002	158
410047	Tarcutta Creek @ Old Borambola	35.164	147.656	Discrete	1967-2000	285
410048	Kyeamba Creek @ Ladysmith	35.198	147.509	Continuous	2000-2002	348
410048	Kyeamba Creek @ Ladysmith	35.198	147.509	Discrete	1970-2000	83
410050	Murrumbidgee River @ Billilingra	35.985	149.126	Discrete	1976-1995	119
410053	Billabong Creek @ Bundy	35.050	144.450	Discrete	1970-1982	58
410054	Billabong Creek @ Boonoke	35.292	145.100	Discrete	1970-1977	41
410055	Main Drain J d/s Warburn Escape	34.264	145.948	Discrete	1957-1994	3,336
410056	Colombo Creek @ Whitbys	35.250	145.967	Discrete	1985-1985	1
410057	Goobagandra River @ Lacmalac	35.331	148.348	Continuous	1999-2001	990
410057	Goobarragandra River @ Lacmalac	35.331	148.348	Discrete	1969-1987	120
410058	Tarcutta Creek @ Westbrook	35.540	147.900	Discrete	1967-1985	104
410059	Gilmore Creek @ Gilmore	35.336	148.167	Discrete	1970-1984	74
410061	Adelong Creek @ Batlow Road	35.333	148.067	Discrete	1967-1987	129

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
410061	Adelong Creek @ Batlow Road	35.333	148.067	Discrete	1967-1987	129
410062	Numeralla River @ Numeralla School	36.179	149.349	Discrete	1976-1987	69
410063	Rock Flat Creek near Bunyan (Rosebrook)	36.150	149.206	Discrete	1976-1985	51
410066	Nacki Nacki Creek @ Truro	35.285	147.984	Discrete	1961-1985	63
410067	Big Badja River @ Numeralla (Goodwins)	36.178	149.397	Discrete	1969-1985	92
410068	Murrumbidgee River @ Glendale	34.917	148.550	Continuous	1999-2002	1,004
410068	Murrumbidgee River @ Glendale	34.917	148.550	Discrete	1980-1986	12
410069	Jugiong Creek @ Cumbumurra	34.700	148.533	Discrete	1977-1985	7
410070	Bombowlee Creek @ Bombowlee	35.272	148.268	Discrete	1967-1984	108
410071	Brungle Creek @ Red Hill	35.136	148.249	Discrete	1967-1984	91
410073	Tumut River @ Oddys Bridge	35.390	148.246	Continuous	1993-2001	3,226
410073	Tumut River @ Oddys Bridge	35.390	148.246	Discrete	1970-2001	208
410075	Kybeyan River @ Kybeyan	36.350	149.419	Discrete	1970-1984	81
410076	Strike-A-Light Creek @ Jerangle Road	35.922	149.236	Discrete	1976-1988	70
410077	Bredbo River @ Laguna	35.985	149.400	Discrete	1967-1984	96
410078	Murrumbidgee River @ Carrathool	34.451	145.416	Discrete	1976-1990	20
410079	Murrumbidgee River @ Burrabogie	34.506	145.193	Discrete	1976-1985	13
410081	Cooma Creek @ Cooma No.2 (The Grange)	36.264	149.133	Discrete	1967-1987	121
410082	Murrumbidgee River @ Gogeldrie Weir	34.617	146.255	Discrete	1967-2000	159
410083	Yanco Main Southern Drain @ Outfall	34.603	146.305	Discrete	1967-1994	1,252
410084	Drainage Channel Railway No.2 @ Outfall to Stoney Point	34.467	146.350	Discrete	1976-1977	4
410085	Little Mirrool Creek Drain d/s Gogeldrie Main Drain	34.406	146.152	Continuous	1992-1996	1,267
410085	Little Mirrool Creek Drain @ d/s Gogeldrie Main Drain	34.406	146.152	Discrete	1970-1994	164
410086	Gogeldrie Main Southern Drain d/s Railway Line	34.538	146.233	Discrete	1958-1994	1,062
410087	Bullenbung Creek above Old Man Creek	35.058	146.954	Discrete	1968-1984	28
410088	Goodradigbee River @ Brindabella (No.2 & No.3 Cabbans)	35.421	148.732	Discrete	1970-1987	105

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
410089	Billabong Creek @ Garryowen	35.664	147.376	Discrete	1969-1987	111
410090	Yass River @ Gundaroo	35.067	149.263	Discrete	1970-1985	90
410091	Billabong Creek @ Walbundrie	35.695	146.723	Continuous	1999-2000	104
410091	Billabong Creek @ Walbundrie	35.695	146.723	Discrete	1970-2002	133
410092	Cunninghams Creek near Harden	34.618	148.369	Discrete	1967-1987	120
410093	Old Man Creek @ Kywong (Topreeds)	34.929	146.783	Continuous	2001-2001	351
410093	Old Man Creek @ Kywong (Topreeds)	34.929	146.783	Discrete	1970-1987	106
410094	Jounama Creek above Jounama Pondage	35.568	148.332	Discrete	1970-1975	33
410095	Umbango Creek @ Humula	35.483	147.758	Discrete	1970-1982	73
410096	Mountain Creek @ Thomond North	35.785	147.155	Discrete	1970-1987	98
410097	Billabong Creek @ Aberfeldy	35.646	147.443	Continuous	2000-2000	104
410097	Billabong Creek @ Aberfeldy	35.646	147.443	Discrete	1970-2002	151
410098	Ten Mile Creek @ Holbrook No.2	35.751	147.335	Discrete	1968-1981	61
410099	Yarra Yarra Creek @ Yarra Yarra	35.722	147.445	Discrete	1970-1977	42
410100	Numeralla River @ Montagu	36.269	149.303	Discrete	1976-1980	20
410101	Murrumbidgee River @ Pine Island	35.431	149.058	Discrete	1976-1985	53
410103	Houlaghans Creek @ Downside	35.006	147.354	Continuous	2001-2002	16
410103	Houlaghans Creek @ Downside	35.006	147.354	Discrete	1974-1989	16
410105	Numeralla River @ Numeralla Dam Site	36.325	149.293	Discrete	1976-1982	32
410106	Gilmore Creek @ Wybalena	35.486	148.189	Discrete	1972-1984	90
410107	Mountain Creek @ Mountain Creek	35.028	148.831	Discrete	1976-1987	61
410108	Drainage Canal 800 @ Outfall	35.105	145.782	Continuous	1992-2001	2,881
410108	Drainage Canal 800 @ Outfall	35.105	145.782	Discrete	1969-1994	304
410109	Drainage Canal 600 above DC500 (Fernbank Road)	34.924	145.665	Discrete	1969-1994	92
410110	Drainage Canal 500 @ Outfall	34.880	145.573	Continuous	1993-2001	2,654
410110	Drainage Canal 500 @ Outfall	34.880	145.573	Discrete	1972-1994	240
410111	Yaven Yaven Creek @ Spyglass	35.401	147.928	Discrete	1973-1987	98
410112	Jindalee Creek @ Jindalee	34.576	148.088	Discrete	1975-1991	71
410114	Killimicat Creek @ Wyangle	35.236	148.306	Discrete	1975-1991	115
410115	Drainage Canal 500 @ Bulls Road	34.850	145.750	Discrete	1969-1994	105

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
410118	Colombo Creek @ Cocketgedong Dam	35.250	145.967	Discrete	1984-1984	1
410121	Murrumbidgee River @ Yass (Taemas Bridge)	35.000	148.833	Discrete	1990-1996	48
410126	Demondrille Creek @ Wongabara	34.540	148.300	Discrete	1975-1987	54
410127	Main Canal @ Narrandera Regulator	34.757	146.562	Discrete	1971-1983	64
410128	Coleambally Canal @ Offtake	34.632	146.279	Discrete	1968-1987	80
410129	Sturt Canal @ Offtake	34.607	146.255	Discrete	1976-1994	89
410130	Murrumbidgee River d/s Balranald Weir	34.667	143.491	Continuous	1992-2001	3,258
410130	Murrumbidgee River d/s Balranald Weir	34.667	143.491	Discrete	1979-2001	740
410132	Adelong Creek @ Adelong No.2	35.333	148.067	Discrete	1981-1981	1
410133	Coleambally Outfall Drain near Bundy	35.035	144.454	Continuous	1993-2001	2,652
410133	Coleambally Outfall Drain near Bundy	35.035	144.454	Discrete	1977-2002	423
410134	Billabong Creek @ Darlot	35.046	144.443	Continuous	1993-2002	3,183
410134	Billabong Creek @ Darlot	35.046	144.443	Discrete	1978-2002	765
410135	Coleambally Catchment Drain @ Farm 544	34.918	146.068	Continuous	1992-2001	2,481
410135	Coleambally Catchment Drain @ Farm 544	34.918	146.068	Discrete	1972-1996	79
410136	Murrumbidgee River d/s Hay Weir	34.522	144.710	Discrete	1980-2001	126
410137	Beavers Creek @ Mundowey	35.062	147.120	Discrete	1996-1996	1
410141	Michelago Creek @ Michelago	35.706	149.149	Discrete	1982-1987	28
410142	Murrumbidgee River @ Tharwa	35.507	149.069	Discrete	1977-1978	3
410145	Tumut River @ Jones Bridge	35.368	148.256	Discrete	1978-1978	1
410146	Mirrool Creek 5 km south of Barellan	34.338	146.562	Discrete	1978-1979	4
410148	Forest Creek @ Warriston Weir	35.343	145.119	Continuous	1999-2001	1,087
410148	Forest Creek @ Warriston Weir	35.343	145.119	Discrete	1982-1987	27
410149	Nottingham Creek @ Nottingham Road Bridge	35.215	148.674	Discrete	1977-1987	38
410150	Main Drain J @ Yoogali	34.304	146.082	Discrete	1977-1987	109
410151	Drainage Channel "S" @ Watkins Avenue	34.308	146.053	Discrete	1978-1994	67
410152	Stony Creek @ Edwardstown	35.138	148.110	Discrete	1984-1987	16
410156	Kyeamba Creek @ Book Book	35.353	147.551	Discrete	1985-1987	10
410157	Coleambally Outfall Drain @ Booroorban	34.931	144.763	Discrete	1992-1994	41

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
410163	D.C. Cudmore u/s Barrenbox Outfall	34.193	145.776	Continuous	1993-1996	1,305
410164	No. 13 Escape u/s Barrenbox Outfall	34.188	145.733	Continuous	1993-1996	1,099
410164	No. 13 Escape u/s Barrenbox Outfall	34.188	145.733	Discrete	1993-1994	9
410165	Mirrol Creek Escape @ Benerembah Pump Station	34.288	145.881	Continuous	1993-1994	299
410166	Willow Dam (Mirrool Creek) @ McNamara Road	34.255	145.874	Continuous	1993-1996	1,234
410167	Barren Box Outfall Channel d/s Benerambah Outfall Drain	34.185	145.713	Continuous	1993-1996	1,132
410168	Billabong Creek d/s Hartwood Weir	35.311	145.287	Continuous	1995-2001	2,091
410169	Yanco Creek @ Bridge 321	35.150	145.771	Continuous	1995-2001	2,353
410169	Yanco Creek @ Bridge 321	35.150	145.771	Discrete	1973-1994	59
410170	Billabong Creek u/s Innes Bridge Road	35.324	145.974	Continuous	1995-2001	2,208
410171	Benerambah No.2 Channel @ Goldbergs Gate	34.275	145.866	Continuous	1995-1996	448
410172	D.C. Central	34.288	145.881	Continuous	1996-1996	183
410176	Yass River @ Riverview	34.865	148.791	Continuous	1999-2002	1,071
410204	Murrumbidgee River @ Halls Crossing	35.133	148.943	Discrete	1992-2001	57
410213	Murrumbidgee River @ Anglers Crossing	35.583	149.108	Discrete	1992-2001	55
410535	Murrumbidgee River above Tantangara Reservoir	35.770	148.569	Discrete	1998-1998	1
410704	Cotter Reservoir @ Dam	35.317	148.933	Discrete	1978-1979	5
410777	Murrumbidgee River @ Halls Crossing	35.133	148.943	Discrete	2001-2001	1
410850	Yass River @ Macs Reef Road	35.182	149.271	Discrete	1970-1988	32
410851	Yass River above Macs Reef Road	35.189	149.283	Discrete	1976-1989	54
410852	Black Joes Creek near Macs Reef Road	35.188	149.282	Discrete	1978-1987	33
41010001	Blowering Dam @ Offtake Weir	35.403	148.243	Discrete	1978-2000	4
41010002	Blowering Dam @ Site 2	35.475	148.257	Discrete	1983-1990	3
41010003	Blowering Dam @ Station 3 Power Cables	35.536	148.286	Discrete	1988-1990	2
41010004	Cudgel Supply @ Farm 1588	34.663	146.438	Discrete	1994-1994	3
41010005	Cudgel Creek & Roaches Escape @ Forest Road	34.650	146.400	Discrete	1984-1994	8
41010006	Cudgel Supply below Main Channel	34.655	146.473	Discrete	1994-1994	3

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41010007	Cudgel Supply @ Site 2	34.681	146.443	Discrete	1994-1994	3
41010008	Cudgel Escape @ Cudgel Escape	34.684	146.430	Discrete	1994-1994	3
41010020	DC840b @ McLarty Road S/C 11	35.032	145.974	Discrete	1994-1994	1
41010021	Burrinjuck Dam @ Station 1	34.990	148.629	Discrete	1979-1991	118
41010022	Burrinjuck Dam @ Station 2	34.962	148.704	Discrete	1980-1991	114
41010023	Burrinjuck Dam @ Station 3	34.943	148.761	Discrete	1980-1996	167
41010024	Burrinjuck Dam @ Station 4	34.916	148.787	Discrete	1980-1996	148
41010025	Burrinjuck Dam @ Station 5	34.916	148.787	Discrete	1980-1996	145
41010026	Burrinjuck Dam @ Station 6	34.987	148.818	Discrete	1981-1996	98
41010027	Yass Inflow @ Burrinjuck Dam	34.876	148.788	Discrete	1981-1991	30
41010028	Burrinjuck Dam @ Yass River Inflow	34.902	148.746	Discrete	1990-1990	1
41010029	Burrinjuck Dam @ Station 8	35.062	148.672	Discrete	1990-1990	1
41010035	Burrinjuck Dam @ Devils Pass	34.884	148.773	Discrete	1993-1994	4
41010036	Burrinjuck Dam opposite Skillens Flat	34.955	148.712	Discrete	1990-1996	55
41010038	Pollen Dam	34.499	144.094	Discrete	1996-1996	1
41010039	Nap Nap Swamp	34.447	144.117	Discrete	1996-1996	1
41010040	Gogeldrie Main Drain @ TRr80	34.416	146.202	Discrete	1972-1977	7
41010042	DC600 @ Main Road 321	34.891	145.849	Discrete	1971-1972	6
41010043	Cooma Creek @ Monaro Highway	36.178	149.153	Discrete	1994-1995	14
41010044	Numeralla River @ Monaro Highway	36.088	149.149	Discrete	1994-1995	28
41010045	Rock Flat Creek @ Rose Brook	36.150	149.206	Discrete	1994-1995	13
41010046	Raw Sewage Inflow	36.221	149.121	Discrete	1994-1994	1
41010047	Sewage Treatment Ponds	36.218	149.119	Discrete	1994-1995	6
41010048	Murrumbidgee River @ Mittagong Crossing	36.170	149.092	Discrete	1994-2001	29
41010049	Wah Wah Main @ Bringagee Road	34.137	145.774	Discrete	1994-1994	1
41010052	Bredbo River @ Monaro Highway	35.964	149.148	Discrete	1995-1995	22
41010053	Cooma Creek @ Mittagong Road	36.194	149.116	Discrete	1994-1995	12
41010054	Cooma Creek @ Mulach Street	36.227	149.121	Discrete	1994-1995	13
41010062	Bullenbong Creek @ Gnadno Station	35.079	146.975	Discrete	1995-2000	5
41010063	Urangeline Creek u/s Urana	35.349	146.281	Discrete	1995-2000	57
41010064	Redbank Creek @ Grong Grong Road	34.773	146.774	Discrete	1995-1996	4

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41010065	Yanga Creek d/s Devils Creek Junction	34.668	143.602	Discrete	1995-2000	4
41010066	Uara Creek @ Waugorah Road	34.688	143.652	Discrete	1995-2000	6
41010067	Bourpie Regulator Discharge	34.639	143.606	Discrete	1995-2000	5
41010068	Colombo Creek @ Urana Road	35.281	145.959	Discrete	1995-2002	88
41010069	Killimicat Creek @ Coolac Road Crossing	35.189	148.227	Discrete	1994-1994	1
41010070	Bombowlee Creek @ Bombowlee Road Crossing	35.279	148.240	Discrete	1994-1994	1
41010073	Murrumbidgee River @ Bolaro	35.982	148.839	Discrete	1995-1995	4
41010076	Tala Lake @ Pumping Station	34.579	143.729	Discrete	1995-2000	6
41010077	Yanga Lake @ Site B Eastern Side	34.728	143.626	Discrete	1995-2000	6
41010078	Urana Lake @ East Bank	35.291	146.216	Discrete	1995-2000	15
41010079	Yanga Creek @ New Bridge	34.701	143.590	Discrete	1996-2000	2
41010080	Tala Creek d/s Tala Lake	34.553	143.703	Discrete	1996-2000	3
41010088	Yass River @ Elizabeth Fields	34.928	149.101	Discrete	1988-1996	147
41010089	Yass River @ Yass Weir	34.833	148.922	Discrete	1996-1999	2
41010090	Queanbeyan River @ Railway Bridge	35.344	149.232	Discrete	1998-1998	1
41010091	Molonglo River @ Weir	35.337	149.240	Discrete	1998-1998	1
41010095	Yass River @ Morton Avenue Bridge, Yass	34.849	148.943	Discrete	1988-1996	147
41010098	Yass River @ Flat Rock, Yass	34.841	148.908	Discrete	1988-1996	143
41010100	Yass River @ Booths Crossing	34.986	149.233	Discrete	1988-1996	147
41010101	Murrumbidgee River @ Wantabadgery	35.072	147.740	Discrete	1991-1991	20
41010102	Eunony Bridge	35.115	147.371	Discrete	1985-2001	188
41010103	Murrumbidgee River @ Moorong	35.103	147.308	Discrete	1985-1991	107
41010104	Murrumbidgee River @ Island Bend	34.969	146.910	Discrete	1991-1991	18
41010106	Bundure Canal @ Bridge Road	34.974	145.892	Discrete	1972-1991	33
41010107	Bundure No.5 @ Leonard Road	35.002	139.976	Discrete	1972-1991	33
41010108	Bundure Canal @ Farm 575	35.004	139.971	Discrete	1972-1991	33
41010109	Burrinjuck Dam opposite Woolgarlo	34.913	142.740	Discrete	1993-1994	6
41010114	Yass River @ Bridge East of Milford	34.923	149.172	Discrete	1988-1996	145
41010118	Dicks Creek @ Culvert East of Pinedale	34.955	149.145	Discrete	1988-1996	147
41010119	Dicks Creek @ Dicks Creek	35.000	149.177	Discrete	1988-1996	147
41010120	Williams Creek @ North Williams Vale	34.991	149.197	Discrete	1988-1996	141

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41010121	Williams Creek @ South Milford	34.926	149.171	Discrete	1988-1996	146
41010127	Sawpit Creek @ Bridge South Booths Crossing	34.993	149.233	Discrete	1988-1996	84
41010130	Sawpit Creek @ Gunya	35.019	149.196	Discrete	1988-1996	84
41010152	Murrumbidgee River @ Long Plain	35.701	148.549	Discrete	2001-2001	1
41010196	Lower Numeralla River below Big Badja	36.158	149.321	Discrete	2001-2001	1
41010308	Eight Mile Creek @ Cobb Highway	35.244	144.822	Discrete	1999-2001	34
41010309	Forest Creek @ Offtake	35.326	145.288	Discrete	1999-2001	33
41010329	Billabong Creek @ Cocketgedong Bridge	35.317	146.037	Discrete	1981-1981	1
41010334	Gilmore Creek @ Rail Bridge	35.336	148.171	Discrete	1981-2000	8
41010335	Billabong Creek @ Walbundrie Bridge	35.699	146.726	Discrete	1980-2000	15
41010336	Murrumbidgee River @ Yaouk Bridge	35.826	148.800	Discrete	1994-2001	9
41010700	Mirrool Floodway @ North Groongal Lane	34.179	145.571	Discrete	1994-1994	1
41010701	Wah Wah Channel 2 @ Mid Western H/Way	34.177	139.205	Discrete	1993-1993	1
41010702	Wah Wah Channel 3 @ Carathool Road	34.084	139.520	Discrete	1993-1993	1
41010703	Wah Wah Channel 8 @ Wongalea Road	34.069	139.087	Discrete	1993-1993	1
41010704	Wah Wah Main Canal Extension @ Tabbita Lane	34.081	145.644	Discrete	1993-1993	1
41010705	Billabung Creek @ Nangus Road	35.032	147.845	Discrete	1992-2000	129
41010706	Wah Wah Channel @ Booligal Road	33.965	139.151	Discrete	1993-1993	1
41010707	Yamma Canal No.2 @ Main Road 321	34.915	139.846	Discrete	1972-1991	33
41010708	Griffith Sewage Works	34.274	145.998	Discrete	1976-1994	139
41010709	Coleambally Outfall Drain @ Four Corners Road	34.859	145.628	Discrete	1992-1993	2
41010711	Barren Box Swamp	34.155	145.828	Discrete	1973-1990	5
41010715	Horticulture Drain @ Hanwood Ave.	34.341	146.054	Discrete	1993-1993	1
41010722	Tarcutta Creek @ Musk Vale	35.715	147.989	Discrete	1994-1995	3
41010723	Tarcutta Creek near Bungarimble	35.666	147.949	Discrete	1994-1995	3
41010724	Tarcutta Creek @ Cottams Road	35.591	147.937	Discrete	1994-1995	3

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41010725	Lower Bago Creek @ Road	35.570	147.964	Discrete	1994-1995	3
41010726	Three Mile Creek @ Road	35.624	147.951	Discrete	1995-1995	2
41010800	Billabong Creek @ "Ellisvale"	35.676	146.902	Discrete	1982-1984	4
41010802	Billabong Creek @ Meryla Homestead	35.666	147.104	Discrete	1982-1982	1
41010803	Billabong Creek @ Morgans Lookout	35.725	146.868	Discrete	1981-1981	1
41010804	Billabong Creek d/s Morven Junction	35.664	147.116	Discrete	1981-2000	22
41010805	Billabong Creek @ Oaklands Road Bridge	35.463	146.189	Discrete	1981-1988	8
41010806	Billabong Creek @ Rand	35.596	146.576	Discrete	1981-1982	4
41010807	Billabong Creek @ Round Hill Crossing	35.670	147.064	Discrete	1982-1982	1
41010808	Billabong Creek @ Round Hill Hotel	35.659	147.091	Discrete	1982-1982	1
41010809	Hillas Creek @ Mundarlo Road Bridge	35.148	147.799	Discrete	1990-2000	102
41010810	Billabong Creek @ Wanganella	35.214	144.814	Discrete	1992-1994	42
41010811	Billabong Creek @ Walla Park Bridge	35.705	146.877	Discrete	1982-1982	1
41010812	Billabong Creek @ Wagga/Holbrook Road	35.641	147.321	Discrete	1982-1982	1
41010813	Bob's Creek @ Carabost Creek Junction	35.549	147.738	Discrete	1988-1988	1
41010814	Budgee Creek @ Bridge Near Maude	34.466	144.332	Discrete	1984-1984	1
41010815	Murrumbidgee River @ "Campdells" Reserve	34.465	145.384	Discrete	1984-1984	4
41010816	Murrumbidgee River @ "Canally" Station	34.726	143.354	Discrete	1984-1984	1
41010817	Carabost Creek @ Humula	35.490	147.757	Discrete	1988-1988	1
41010818	Redbank Weir @ Juanbung Regulator	34.356	143.842	Discrete	1991-1991	1
41010819	Carabost Creek u/s Shockeroo Creek Junction	35.503	147.734	Discrete	1988-1988	1
41010820	Carabost Creek Bridge @ Coorong Station	35.551	147.734	Discrete	1988-1988	1
41010821	Carabost Creek Bridge near Mamaregh Station	35.569	147.726	Discrete	1988-1988	1
41010822	Carabost Creek @ Carabost Road Bridge	35.600	147.726	Discrete	1988-1988	1
41010823	Carabost Creek @ Woodara Station	35.649	147.689	Discrete	1988-1988	3

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41010824	Coleambally Argoon Canal @ Main Road 321	34.877	145.852	Discrete	1972-1991	33
41010825	Bundure Supply No.3 @ Glen Road	34.960	146.033	Discrete	1972-1991	34
41010826	Cocketgedong Creek near Jerilderie	35.278	146.001	Discrete	1982-1982	1
41010827	Cootamundra Creek @ "The Gap"	34.650	147.991	Discrete	1984-1984	1
41010828	Cootamundra Creek @ Cootamundra	34.654	148.014	Discrete	1984-1987	3
41010829	Murrumbidgee River @ Jugiong Bridge	34.826	148.333	Discrete	1985-1993	32
41010830	Cunningham Creek @ Wallendbeen	34.533	148.160	Discrete	1985-1986	3
41010831	Currawong Creek u/s Harden	34.534	148.357	Discrete	1985-1985	1
41010832	Deep Creek @ Hume Highway Road Bridge	34.814	148.449	Discrete	1985-1985	1
41010833	Downfall Creek @ Canaarvan	35.579	147.836	Discrete	1988-1988	1
41010834	Murrumbidgee River @ Hay Water Supply	34.509	144.858	Discrete	1987-1987	1
41010835	Ironbong Creek @ Mahers Bridge, Cootamundra	34.654	147.830	Discrete	1984-1984	1
41010836	Jacobs Creek @ Carabost Road Bridge	35.564	147.726	Discrete	1988-1988	1
41010837	Little Mirrol Creek d/s North Kooba Pump	34.416	146.178	Discrete	1985-1985	1
41010838	Little Mirrool Creek u/s North Kooba Pump	34.417	146.180	Discrete	1985-1985	1
41010839	Lake Wyangan No.1	34.205	146.031	Discrete	1981-1989	52
41010840	Lake Wyangan No.2	34.207	146.037	Discrete	1981-1990	58
41010841	Lake Wyangan No.3	34.208	146.021	Discrete	1981-1995	77
41010842	Lake Wyangan No.4	34.209	146.020	Discrete	1960-1990	134
41010843	Lake Wyangan No.5	34.231	146.020	Discrete	1966-1990	94
41010846	Main Canal @ Jondaryan Bridge, Griffith	34.293	146.050	Discrete	1957-1977	140
41010847	Mirrool Creek @ Widgelli	34.331	146.130	Discrete	1978-1978	1
41010848	Mooneymooney Creek between Coolac & Cootamundra	34.902	148.160	Discrete	1984-1984	1
41010849	Murraguldrie Creek @ Murraguldrie	35.446	147.744	Discrete	1988-1988	1
41010850	Muttama Creek @ Forsyth Lane	34.578	148.036	Discrete	1988-1988	1
41010851	Coleambally Drain 500 @ Main Road 321	34.862	145.855	Discrete	1971-1991	40
41010852	Nowranie Creek u/s Junction Billabong	35.339	146.029	Discrete	1990-1990	1

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41010853	Petries Creek near Gum Swamp	35.741	146.898	Discrete	1984-1984	1
41010854	Pinchgut Creek @ 'Retreat' Cootamundra	34.650	147.704	Discrete	1984-1984	1
41010855	Poison Water Hole Creek @ Sturt Highway	34.813	146.580	Discrete	1984-1984	1
41010856	Possums Plains Creek @ Humula Road	35.456	147.772	Discrete	1988-1988	1
41010857	Murrumbidgee River "Redgate" Station	34.707	143.417	Discrete	1984-1984	1
41010858	Reedy Creek @ Hume Highway Road Bridge	34.816	148.471	Discrete	1985-1985	1
41010859	Scruby Creek @ Flat Black Bridge	35.541	147.779	Discrete	1988-1988	1
41010860	Shockeroo Creek @ Carabost Road Bridge	35.503	147.733	Discrete	1988-1988	1
41010861	Stoney Creek u/s Carabost	35.629	147.719	Discrete	1988-1988	1
41010862	Tarcutta Creek @ Sturt Highway Bridge	35.191	147.746	Discrete	1979-1992	5
41010863	Ten Mile Creek d/s Holbrook	35.723	147.293	Discrete	1984-1984	1
41010864	Umbango Creek u/s Junction Tarcutta Creek	35.342	147.771	Discrete	1988-1988	1
41010865	Umbango Creek Bridge @ Humula Road	35.382	147.772	Discrete	1988-1988	1
41010866	Umbango Creek on road to Tintenbah Station	35.450	147.766	Discrete	1988-1988	1
41010867	Umbango Creek @ Humula Station	35.475	147.765	Discrete	1988-1988	1
41010868	Umbango Creek Bridge @ Humula	35.490	147.761	Discrete	1988-1988	1
41010869	Umbango Creek @ Black Flat Bridge	35.539	147.779	Discrete	1988-1988	1
41010870	Umbango Creek @ Canaarvan Station	35.578	147.828	Discrete	1988-1988	1
41010871	Lake Urana @ Southern End	35.322	146.153	Discrete	1981-1995	3
41010872	Murrumbidgee River d/s Wagga Sewage Works	35.096	147.353	Discrete	1987-1989	4
41010873	Murrumbidgee River @ "Weimby" Station	34.713	143.233	Discrete	1984-1984	1
41010874	Yanga Lake @ Yanga Station	34.715	143.610	Discrete	1979-1982	6
41010875	Yarra Yarra Creek @ Hume Highway	35.664	147.429	Discrete	1982-1982	1
41010876	Yaven Yaven Creek @ Tumut/Wagga Road Bridge	35.209	147.894	Discrete	1981-1990	4
41010877	Yenda Sewage Works	34.226	146.114	Discrete	1983-1986	18

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41010878	Murrumbidgee River @ Uriarra Crossing	35.246	148.950	Discrete	1990-1990	1
41010879	Murrumbidgee River @ Cusacks Crossing	35.204	148.942	Discrete	1990-1990	1
41010880	Molonglo River @ Coppins Crossing	35.287	149.039	Discrete	1990-1990	1
41010881	Billabong Creek d/s Wanganella Weir	35.217	144.802	Discrete	1982-1982	1
41010882	Drainage Canal 400 @ Main Road 321	34.792	145.869	Discrete	1972-1991	34
41010883	Tarcutta Creek @ Hume Highway	35.281	147.732	Discrete	1979-1979	1
41010884	Tarrcutta Creek @ Glenburn	35.207	147.754	Discrete	1984-1984	1
41010885	Billabong Creek u/s Nowranie Junction	35.313	145.975	Discrete	1990-1990	1
41010886	Coleambally Yamma Canal @ Main Road 321	34.940	145.841	Discrete	1972-1991	33
41010887	Lake Yanga Outlet	34.704	143.588	Discrete	1985-1985	1
41010889	Burrinjuck Dam Wall Station	35.004	148.588	Discrete	1990-1993	2
41010890	Adelong Creek @ Bareena	35.114	148.026	Discrete	1992-2000	76
41010891	Tumut River @ Murrumbidgee Junction	35.028	148.187	Discrete	1992-2000	100
41010892	Muttama Creek @ Hume Highway, Coolac	34.984	148.147	Discrete	1991-1993	4
41010893	Kyeamba Creek @ Sturt Highway	35.163	147.509	Discrete	1992-1992	27
41010895	Little Mirrool Creek below Gauge 410085	34.391	146.135	Discrete	1978-1994	401
41010896	Lake Wyangan Causeway	34.231	146.021	Discrete	1957-1993	243
41010897	Lake Wyangan Outfall	34.258	146.001	Discrete	1969-1994	309
41010899	Boona Canal @ Main Road 321	34.839	145.858	Discrete	1972-1991	31
41010900	Yamma Canal @ McDonalds Road	34.958	145.838	Discrete	1972-1991	33
41010901	Balranald Weir	34.645	143.534	Discrete	1972-2001	655
41010902	Barren Box Effluent	34.190	145.764	Discrete	1975-1996	1,461
41010903	Barren Box Outfall	34.171	145.798	Discrete	1958-1994	821
41010904	Berembed Weir Pool	34.879	146.836	Discrete	1956-2001	351
41010905	Benerembah Outfall Drain	34.192	145.761	Discrete	1981-1993	462
41010906	Murrumbidgee @ Brinagee Station	34.479	145.696	Discrete	1984-1984	4
41010907	Murrumbidgee River @ Bundarbo Station	34.904	148.387	Discrete	1985-1986	6
41010908	Brays Dam	34.400	146.019	Discrete	1975-1994	42

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41010909	Coleambally Last Bundure Escape	35.015	145.862	Discrete	1991-1993	24
41010910	Coleambally 2nd Last Bundure Escape	35.019	145.868	Discrete	1991-1994	23
41010911	Coleambally Canal u/s Sturt Highway Bridge	34.660	146.168	Discrete	1972-1994	64
41010912	Coleambally Supply Escape 160-2 Bullrd	34.845	145.753	Discrete	1991-1994	26
41010914	Coleambally Supply B9 u/s Col Bore	34.842	146.013	Discrete	1991-1994	19
41010915	Cunningham Creek @ McMahons Reef	34.689	148.430	Discrete	1985-1987	9
41010916	Balranald Pump	34.648	143.566	Discrete	1966-1991	458
41010917	Euroly Bridge Yanco	34.640	146.373	Discrete	1977-1995	9
41010918	Murrumbidgee d/s Euyarderry Lagoon	34.623	146.157	Discrete	1984-1984	1
41010919	Murrumbidgee u/s Euyarderry Lagoon	34.615	146.219	Discrete	1984-1984	1
41010921	Gogeldrie Main Southern @ River Road	34.595	146.209	Discrete	1991-1994	29
41010922	Gogeldrie Weir	34.618	146.257	Discrete	1967-1990	210
41010923	Murrumbidgee @ Kroongal Station	34.551	145.788	Discrete	1984-1984	1
41010924	Goodagandra River Crossing Little River Road	35.333	148.340	Discrete	1994-2000	6
41010925	Yanco Offtake	34.612	146.423	Discrete	1958-1994	1,289
41010926	Hay Pump Station	34.497	144.874	Discrete	1984-1991	483
41010928	Hay Weir	34.527	144.710	Discrete	1977-2000	316
41010929	Murrumbidgee @ Homestead Station	34.534	145.754	Discrete	1984-1984	4
41010930	Houlaghans Creek @ "Nyella Park"	35.015	147.321	Discrete	1987-1987	1
41010931	Houlaghans Creek @ Prices Road	35.025	147.314	Discrete	1987-1987	1
41010932	Houlaghans Creek @ Agri College Farm	35.066	147.295	Discrete	1987-2000	9
41010933	Adelong Creek @ Adelong	35.309	148.064	Discrete	1982-1982	1
41010934	Jugiong Creek @ Berremonga Bridge	34.706	148.441	Discrete	1985-1986	8
41010935	Jugiong Creek @ Hume Highway	34.818	148.379	Discrete	1984-1990	28
41010936	Jugiong Creek below Cunningham Creek Junction	34.724	148.441	Discrete	1985-1985	1
41010937	Kooba Outfall Drain	34.403	145.974	Discrete	1980-1991	344

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41010938	Kooba Outfall Drain @ Gauge Board	34.408	145.975	Discrete	1984-1991	154
41010939	Kooba Outfall u/s Mirrool Creek	34.388	145.977	Discrete	1983-1985	22
41010940	Gogeldrie Main Drain @ Lagoon	34.580	146.110	Discrete	1967-1994	140
41010941	Maude Weir	34.478	144.303	Discrete	1984-1991	57
41010942	Maude Stop Sign	34.478	144.306	Discrete	1991-2000	2
41010943	Mirrool Creek @ Brogden Road	34.291	145.904	Discrete	1979-1993	86
41010944	Mirrool Creek @ East Mirrol Regulator	34.290	146.255	Discrete	1991-1993	21
41010945	Mirrool Creek @ Main Road 321	34.406	146.041	Discrete	1974-1984	11
41010947	Mirrool Creek @ Ardlethan	34.356	146.913	Discrete	1978-1989	6
41010948	Mirrool Creek South of Barellan	34.336	146.577	Discrete	1978-1978	4
41010949	Mirrool Creek @ Beckom	34.324	146.959	Discrete	1978-1980	4
41010950	Mirrool Creek Floodway @ Belaley Road	34.061	145.165	Discrete	1989-1989	4
41010951	Mirrool Creek Floodway @ Berangerine Road	34.089	145.231	Discrete	1990-1990	18
41010952	Mirrool Creek @ Carrathool Road	34.175	145.503	Discrete	1988-1994	72
41010953	Mirrool Creek Floodway @ Cobb Highway	34.043	144.824	Discrete	1988-1990	48
41010954	Mirrool Creek @ Gum Creek Road	34.381	145.979	Discrete	1982-1991	63
41010955	Mirrool Creek @ McNamara Road	34.255	145.875	Discrete	1979-1994	74
41010956	Mirrool Creek @ Mirrool	34.308	147.090	Discrete	1980-1980	1
41010957	Mirrool Creek Floodway	34.106	145.301	Discrete	1988-1993	70
41010958	Mirrool Creek @ Pucawan	34.424	147.358	Discrete	1987-1987	1
41010959	Mirrool Creek @ The Willows	34.423	146.720	Discrete	1978-1989	133
41010960	Mirrool Creek Floodway @ Wondgalea Road	34.044	145.095	Discrete	1988-1990	48
41010961	Algudgerie Creek @ Berrigan Escape	35.374	145.623	Discrete	1982-1982	1
41010962	Muttama Creek u/s Cootamundra	34.615	148.025	Discrete	1984-1988	13
41010963	Muttama Creek d/s Cootamundra	34.679	148.043	Discrete	1985-1985	32
41010964	Murrumbidgee @ Nap Nap Station	34.446	144.172	Discrete	1984-1986	4
41010965	Redbank Swamp Inflow	34.376	143.768	Discrete	1986-1986	1
41010966	Redbank Weir	34.379	143.781	Discrete	1984-2000	53
41010967	Stanbridge Swamp Escape	34.508	146.222	Discrete	1978-1991	113
41010968	Redbank Weir opposite Yanga Regulator	34.358	143.811	Discrete	1991-1991	1

Station number	Station name	Lat (S)	Lon (E)	Data type	Period collected	Number of data days
41010969	Tombullen Inlet	34.651	146.168	Discrete	1977-1987	38
41010970	Tombullen Outlet	34.647	146.136	Discrete	1981-1987	42
41010971	Tombullen @ Outlet	34.647	146.139	Discrete	1990-2000	17
41010973	Tombullen Swamp @ Pw 12505-6	34.645	146.152	Discrete	1987-1987	1
41010974	Tombullen Swamp @ Pw 12507	34.653	146.145	Discrete	1980-1987	4
41010975	Murrumbidgee @ Toopuntul Station	34.388	144.051	Discrete	1986-1986	1
41010976	Tumut River @ Snowy Highway	35.366	148.265	Discrete	1991-2001	75
41010977	Barren Box Swamp @ K	34.131	145.859	Discrete	1990-1990	6
41010978	Willow Dam	34.189	145.830	Discrete	1957-1994	1,623
41010979	Wah Wah Channel No.1	34.144	145.509	Discrete	1991-1993	13
41010980	Murrumbidgee d/s Wynburn Station	34.509	143.683	Discrete	1986-1986	1
41010981	Yanco Weir	34.704	146.416	Discrete	1981-2000	41
41010982	Yanco Creek u/s DC800	35.145	145.780	Discrete	1973-2002	194
41010983	Murrumbidgee River u/s Yanco Weir	34.704	146.415	Discrete	1985-1986	25
41010984	Pattersons Swamp Discharge	34.374	143.801	Discrete	1991-1991	1
41010985	Coleambally Drain 400 @ Steel Road	34.804	145.774	Discrete	1978-1994	30
41010986	Cunningham Creek u/s Weir	34.590	148.324	Discrete	1985-2000	16
41010987	Coleambally Outfall @ Conargo/Burbogi	34.900	145.149	Discrete	1992-1994	41
41010989	Billabong Creek @ Moulamein	35.094	144.044	Discrete	1991-2002	176
41010990	Barren Box Swamp @ T	34.167	145.873	Discrete	1990-1991	54
41010991	Benerembah Main Supply	34.402	145.957	Discrete	1980-1991	337
41010992	Billabong Creek @ Berrigan Escape	35.348	145.580	Discrete	1982-1982	1
41010993	Billabong Creek @ Bogan Dillon	35.535	146.377	Discrete	1981-1981	1
41010994	Billabong Creek @ Brooklyn Rd Bridge	35.719	146.838	Discrete	1982-1984	4
41010995	Billabong Creek @ Braeside	35.683	146.898	Discrete	1982-1982	1
41010996	Billabong Creek @ Chirritta Bridge	35.689	147.194	Discrete	1981-1984	6
41010997	Billabong Creek @ Conargo Bridge	35.296	145.179	Discrete	1991-2002	208
41010998	Billabong Creek near Coorabin	35.476	146.252	Discrete	1984-1984	1
41010999	Billabong Creek @ Culcairn Bridge	35.673	147.037	Discrete	1981-1984	6
41015431	Tantangara Reservoir @ Dam	35.798	148.661	Discrete	1998-1998	1
41015432	Tantangara Reservoir @ Nungar	35.759	148.662	Discrete	1998-1998	1
41015433	Tantangara Release	35.801	148.674	Discrete	1998-1998	1

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 Murrumbidgee System IQQM, that it can reliably reproduce the peer reviewed and published results from the Salinity Audit, that have been used to develop Salinity Targets (NSWG, 2000a, 2000b).

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

Table A.8.1 shows a reasonable match between the audit and the IQQM model. The following two points are worth noting.

- The audit analysis was based on tributary data for only four stations. Other stations were estimated using "regional relationships".
- Funding, by the MDBC allowed the IQQM model to use all collected data. The IQQM model aslo used power rather than fourier relationships.

Table A.8.1. Salt transport model results compared with Audit results

	Audit inflow / balance point	**Mean flow (GL/year)**			**Mean salt load ('000 T/year)**				
Number	**Name**	*Audit*	*1*	*2*	*Audit*	*1*	*2*	*3*	*4*
410073	Tumut River @ Oddys Bridge	*1,700*	1,673	1,651	*35.2*	42.7	40.3	37.9	37.9
410057	Goobarragandra River @ Lacmalac	*283*	283	273	*6.6*	8.8	8.5	8.0	8.0
410059	Gilmore Creek @ Gilmore	*20*	86	85	*1.8*	3.8	3.8	3.5	3.5
410071	Brungle Creek @ Red Hill	*19*	20	19	*0.4*	3.4	3.3	3.1	3.6
R1	Ungauged Tumut River u/s Brungle Bridge	*73*	137	132	*2.0*	7.8	7.6	7.1	7.1
410039	**Tumut River @ Brungle Bridge**	***2,152***	**2,197**	**2,158**	***48.6***	**66.4**	**63.4**	**59.6**	**59.6**
410038	Adjungbilly Creek @ Darbalara	*85*	86	82	*5.2*	5.8	5.6	5.2	5.2
410008	Murrumbidgee River d/s Burrinjuck Dam	*1,507*	1,476	1,400	*147.0*	139.8	133.9	125.6	125.6
410025	Jugiong Creek @ Jugiong	*98*	99	101	*53.8*	56.6	57.8	54.2	54.2
410044	Muttama Creek @ Coolac	*53*	54	51	*23.5*	28.7	27.5	25.8	25.8
R2	Ungauged Tumut and Murrumbidgee Rivers u/s Gundagai	*224*	242	236	*21.6*	65.9	65.6	61.5	61.5
410004	**Murrumbidgee River @ Gundagai**	***4,072***	**4,139**	**4,014**	***307.9***	**362.2**	**353.0**	**331.1**	**331.1**
410061	Adelong Creek @ Batlow Road	*40*	40	38	*7.5*	2.6	2.5	2.3	2.3
410045	Billabung Creek @ Sunnyside	*14*	15	14	*6.6*	2.0	1.9	1.8	1.8
410043	Hillas Creek @ Mount Adrah	*111*	112	108	*18.2*	15.3	14.9	14.0	14.0
410047	Tarcutta Creek @ Old Borambola	*191*	191	178	*26.2*	25.9	24.4	22.9	22.9
410048	Kyeamba Creek @ Ladysmith	*50*	43	40	*20.4*	9.7	9.1	8.5	8.5
R3	Ungauged Murrumbidgee River between Gundagai and Wagga Wagga	*114*	116	109	*6.0*	16.0	15.3	14.3	14.3
410001	**Murrumbidgee River @ Wagga Wagga**	***4,594***	**4,631**	**4479**	***401.8***	**432.7**	**420.2**	**394.2**	**394.2**

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

421073 = Inflow (310) (Blowering Dam inflow)

R1 = Inflows (213, 214, 215) – Losses (316, 322)

421008 = Inflow (301) (Burrinjuck Dam inflow)

R2 = Inflows (216, 212, 217) – Losses (306, 330)

R3 = Inflows (218, 219, 272, 232, 273) – Loss (337)