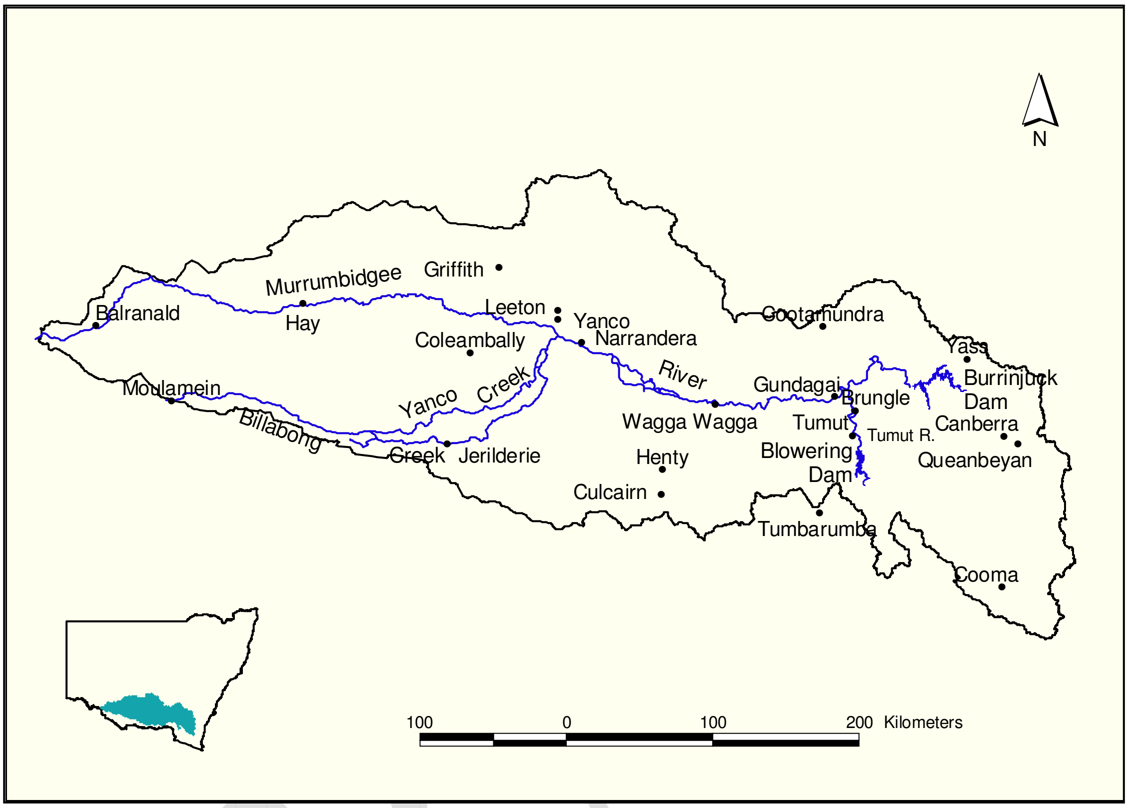
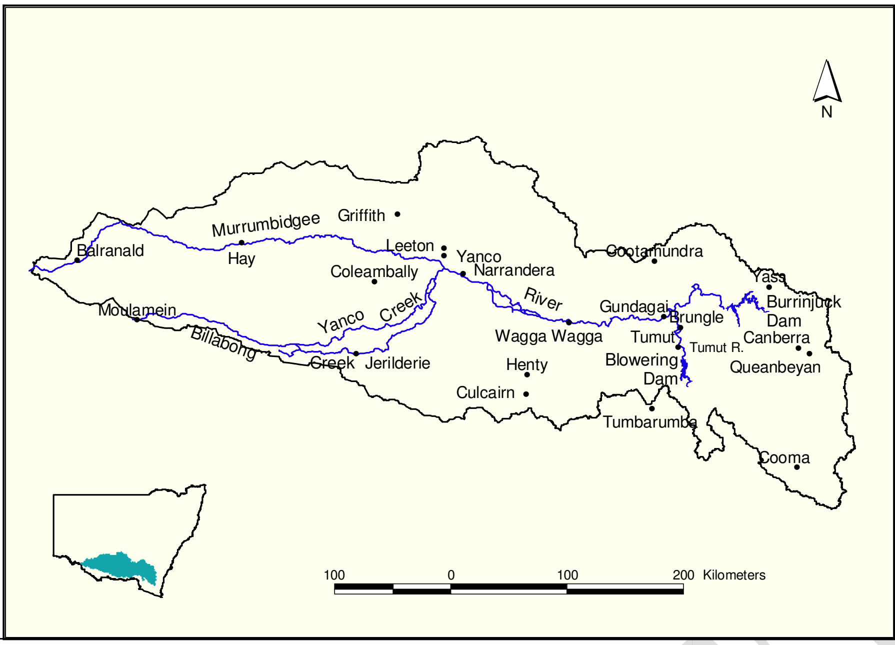


Murrumbidgee River Valley

IQQM Cap Implementation

Summary Report

NSW Department of Water & Energy



Murrumbidgee River valley
IQQM Cap Implementation
Summary Report

Murrumbidgee River Valley

IQQM Cap implementation summary report

Issue: 4

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August, 2007

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Executive Summary

What has initiated the work?	The MDBMC Cap and NSW Water Reform initiatives have required that NSW develop a suitable planning tool to enable review of water use and sharing arrangements in the Murrumbidgee River Valley. The tool accepted as suitable for the purpose is a calibrated water balance model that includes all relevant important features on and in the system. Such a model is called an integrated quantity quality model, or IQQM for short.
Scope of this report summarises the Murrumbidgee–IQQM status	This report summarises and documents the IQQM calibration, validation and model used for Cap runs.
Purpose is to prove model suitability as a Cap estimation tool and present Cap modelling results	The primary purpose of this IQQM summary report is to demonstrate to the reader that the developed model includes all of the important features in the system, and closely replicates records of flow and flow extraction behaviour. The secondary purpose is to demonstrate that the model can be successfully used to define the 1993/94 diversion Cap.
Model construction includes all important features	Chapter 2 describes the main physical and management features included in the model. The availability and extent of time series data is also described in this chapter, as well as decisions on the number, type and arrangement of the nodes and links used to construct the Murrumbidgee Valley IQQM.
Calibration and validation over the 1982-1995 period demonstrates model suitability	Chapter 3 describes the model calibration and validation results. Comparison is made between time series observed data and time series model simulated behaviour. Quality ratings were applied to the model calibration. The model water diversion volumes were generally a close match to the observed water diversions. Model end-of-system flows were of an “adequate” quality for comparison of alternate management options. Model storage behaviour had a “high” quality rating. Overall, the model achieved a “high” quality rating, demonstrating the model’s suitability for the intended purposes.
Statement of model adequacy for comparing management options	The Murrumbidgee River Valley IQQM can now be accepted as calibrated and validated to a satisfactory degree. The model is suitably robust for 100+ year scenario running and for comparison of impacts from alternative management scenarios.
1993/94 Cap scenario run	Chapter 4 describes the 1993/94 development conditions and the use of the Murrumbidgee River IQQM to simulate the 1993/94 Cap scenario. Results are presented for: a) the 114 year period from 1892 to 2006 inclusive, to estimate the average annual long term diversions for the Cap scenario;

	b) the 1997/98 – 2006/07 period, to estimate diversions for auditing under the provisions of Schedule F of the Murray-Darling Basin Agreement.
Improvement suggestions	Chapter 5 lists a series of short and long term model improvement suggestions. These suggestions are not intended to reduce the credibility of the upgraded model, but should be viewed as part of DNR's ongoing quality assurance process, promoting continuous improvement on it's key planning tools and products.

Glossary of Terms

Allocation Level	Allocation level or announced allocation is the percentage of the licensed entitlement volume that general security irrigators can divert in the current water year during on allocation periods. The first allocation level for the forthcoming irrigation season is announced at the beginning of water year and except in extreme circumstances is not reduced from this announcement, noting however that it can be increased. NSW announce increased allocation levels from time to time during the irrigation season. The term was replaced by *Available Water Determination per Unit Share expressed as a Percentage* with the write up of Water Management Act 2000. In this report and, consistent with the terminology used in 1993/94, the term allocation will be used.
Annual Accounting	An annual accounting system is where at the end of a water year unused allocated general security water either gets fully re-socialised or partially by allowing a limited amount of carryover
Calibration Model	An IQQM model configuration used to derive model parameters by a process of calibrating against historical data.
Cap	The Murray Darling Basin Ministerial Council Cap on extractions for consumptive users at the level that would have occurred under 1993/94 development conditions and management rules over a long term period of varying climatic conditions
Cap Scenario Model	An IQQM model that has been configured for the simulation of 1993/94 development conditions and management rules, commencing 1890 for the Murrumbidgee Valley model, to provide an estimate of the long term average diversions that would have occurred over the last 100+ years under these rules
Cap Audit Scenario	An IQQM model that has been configured for the simulation of 1993/94 development conditions and management rules. The model commences simulation in 1 October 1990 for the Murrumbidgee Valley model allowing for model warm up, and then model output is collated from 1 July 1997 to provide estimates of water diversions that would have occurred under Cap (1993/94 development) conditions.
Coefficient of Determination	A statistical term that describes the degree of correlation between two data sets, that is, when plotted one data set against the other, how close the points are to a line. (usually observed and simulated data points). Its value is always expressed as a decimal less than 1.0, such that the closer its value is to 1.0, the better the correlation. The symbol $\mathbf{r}^2$ is often used to represent the coefficient of determination.
Coefficient of Mean Absolute differences	A comparative statistic developed by DNR to assess the match between simulated and observed annual values for model calibration. It value is equal to the mean absolute error divided by mean observed value expressed as a percentage
DNR	NSW Department of Natural Resources. Superseded the NSW Department of Land

	and Water Conservation (DLWC), the NSW Department of Sustainable Natural Resources (DSNR) and the NSW Department of Infrastructure, Planning and natural Resources (DIPNR). Has now been superseded by the Department of Water and Energy . The Departmental history is presented to put references to "DNR" in context.
d/s	Downstream.
ECA	Environmental Contingency Allowance; a volume of water set aside in storage for environmental purposes. Replaced by the term Environmental Water Allowance (EWA) in the write up of NSW Water Sharing Plans.
Entitlement	The total amount of license volume a river extractor owns and remains static over time. In an annual accounting system, the water share is multiplied by the allocation to determine the water available in their account for the current water year. The term was replaced by *number of shares* with the Water Management Act 2000. In this report and, consistent with the terminology used in 1993/94, the term *Entitlement* will be used.
Farmer's Risk	See irrigator behaviour
General Security Licences	Licences that are supplied with water after high security licence needs are fully allocated. These licences cover the great majority of irrigation licences both in terms of number and annual entitlements. Announced allocations are made each year to indicate the percentage of annual licence entitlement volume that can be supplied.
High Security Licences	Licenses that provide the highest reliability of water supply. Generally these licences are for stock & domestic, town water supplies and permanent plantings (orchards, vineyards etc). In announcing allocation entitlements high security licences are fully satisfied prior to any allocation for general security licences.
IQQM	An integrated quantity/quality river basin simulation model developed by DNR since the early 1990's. It is a tool that can be used to investigate water resources management issues in large river basins, typically with complex water regulation, irrigation and environmental requirements. It operates on a daily time-step.
IQQM Model's nodes & links	An IQQM model is designed with "nodes", which represent the processes which affect water flows and water uses in the model and links, which connect the nodes. In general links are used to represent the hydraulic factors (flow routing) which affect the passage of water along rivers and canal channels. A link may in some circumstances simply connect two or more nodes where a process needs more than one node to represent it.
Irrigator Behaviour	This relates to the irrigator's area planting decision and the main factors affecting this decision. For example, given a drought period with dry antecedent climatic conditions and low allocations, an irrigator who plants the same area as in wet years (i.e. years when storages are full) is taking a higher than the risk he takes in those wet years. That is, there is an increased likelihood that the irrigator will run out of water supplies unless additional streamflows or rainfall occurs

Licensed Entitlement Volume	The maximum on allocation volume of water that a licence holder on a regulated stream/river/supply channel can divert in a water year when allocations have reached 100%. The amount drawn may be subject to other licence conditions. With the Water Management Act 2000 the equivalent term, "*number of unit shares*", was introduced.
MDBC	Murray Darling Basin Commission, a joint interstate/federal commission with responsibility for managing the Murray River system and coordinating water management issues in the Murray Darling Basin.
MDBMC	Murray Darling Basin Ministerial Council, a body composed of the relevant State and Federal ministers which oversees the management of the Murray Darling Basin Commission
ML/d	Units used to express rate of flow, in terms of megalitres (i.e. millions of litres) per day
OFA	Off Allocation extraction is the volume of water extracted by general security licence holders during an off allocation period.
Off Allocation Period	A period when the river flow is in excess of the anticipated demands of the downstream users and a number of other conditions are met such as equity, ease of access and environmental requirements. The amount of water drawn during off-allocation periods is not debited from the allocated portion of the irrigator's water entitlement for the water year. Off allocation periods can occur when dams are spilling, tributaries downstream of dams are flowing significantly and when there are significant upstream rain rejections. In the Water Management Act 2000 the term off allocation period has been replaced by *supplementary access period*.
On Allocation Period	A period which does not include any off allocation periods. The amount of water drawn during on allocation periods is debited from the allocated portion of the irrigator's water entitlement for the water year. In recent years this has been called a *debit water period*.
OFS	On Farm Storage, usually referring to a large private storage constructed on an irrigator's property to store water.
ONA	On Allocation extraction is the volume of water extracted by an irrigator during an on allocation period
Pump capacity (IQQM)	The maximum extraction rate for an IQQM irrigation node (ML/d). It represents the sum of the maximum extraction rates of all irrigation licences represented by an IQQM irrigation node.
Rainfall-runoff model	See Sacramento model
Reach	A defined length of river with defined start and end locations
Regulated River	The section of river that is downstream from a major flow regulation storage that supplies water to licensed extractors

Residual Catchment	This is an ungauged catchment existing between known upstream and downstream river gauges. It can include ungauged creeks or rivers as well as areas of land adjacent to the main streams between the gauges. The outflow from this catchment is simulated in the model as the difference between the flow of upstream and downstream gauges taking into consideration river losses and diversions.
Tributary	A stream that contributes its flow to a larger stream or water body.
Tributary utilisation	The proportion of the flow from the tributary that is operationally calculated as usable to meet water orders.
Unregulated River	A river with no major storages by which flows could be regulated.
u/s	Upstream
Water Year	A continuous twelve-month period starting from a specified month for water accounting purposes. In the Murrumbidgee Valley the water year commences on the 1st July and concludes on the 30th June
YCB	Yanco Colombo Billabong. The regulated creek system receiving Murrumbidgee flows from the Yanco offtake and unregulated inflows from the upper Billabong catchments
MI, MIA	Murrumbidgee Irrigation, Murrumbidgee Irrigation Area
CICL,CIA	Coleambally Irrigation Co-operative Limited, Coleambally Irrigation

1. Introduction

1.1. BACKGROUND TO IQQM

Monthly time step models were used for planning purposes by DNR until the late 1990's. In the early 1990s it was recognised that the monthly time step was inadequate for modelling processes such as off allocation announcements and usage and environmental flow management. A search commenced for a new a daily time step platform for planning purposes. Building on the concepts in the WARAS model (DWR 1989), DNR proceeded to develop a more generalised and complete modelling tool, in the form of the IQQM software (DLWC (1995).

Up to the year 2000, a monthly time step computer model of the Murrumbidgee Valley had been constructed, calibrated and used to investigate various policy and water sharing initiatives. In 1994 DNR initiated the building of a daily time step IQQM Murrumbidgee model. The model's building was slowed over the next few years due to the need for further software development and also due to other organisational commitments. A more intensive development phase commenced in 1999, which culminated in the first use of the model for *MDB agreement requirement* purposes in 2000. That being for the 1999/2000 MDB Schedule F Cap audit run. In the years 2001 & 2002 the Murrumbidgee IQQM was the primary model used in the Murrumbidgee WSP process. In that process it was mainly used for investigations of alternative environmental flow rules.

In the above mentioned software development additional features were added to the IQQM software to represent specific Murrumbidgee processes and operating rules. The main ones of these are presented below.

- Extra functionality to IQQM decision trees (IDT). IDTs allow model rules in one part of the model to be related to what is happening in other parts of the model.
- Simulation of rice crop irrigation, including pre-watering. Rice cropping is different from other crops represented in IQQM because rice is a ponded crop.
- Bulk licences to represent the licences held by Murrumbidgee Irrigation and Coleambally Irrigation. Also as a means to represent extractor access to multiple licence categories, commonly found in river pumper reaches.
- A range of environmental flow rules relating to storage releases and targeted use of water from environmental water accounts.
- Hydraulic connection between the river and off-river wetlands. This is mainly used in the Murrumbidgee IQQM model to represent processes occurring within the Redbank portion of the Lowbidgee area.

The Murrumbidgee IQQM was further developed during 2003 to include modelling salinity generation and transport. That work also necessitated a more detailed representation of inflows from sub-catchments. During that phase, the opportunity was taken to update model flow data and improve the calibration of river flow routing parameters and transmission losses. As the drought increased in severity and duration further flow recalibrations were carried out to try to the match a more diverse and extreme flow regime.

A full description of IQQM, including details about model structure, algorithms, processes that can be modelled and assumptions are described in the IQQM Reference Manual (DLWC, 1995).

1.2. AIM OF IMPLEMENTING IQQM IN THE MURRUMBIDGEE RIVER SYSTEM

The IQQM has been implemented for the Murrumbidgee Valley from the headwaters of Burrinjuck and Blowering Dams to the confluence of the Murray and Murrumbidgee Rivers, Yanco Creek, Colombo Creek, Forest Creek above Warriston Weir and Billabong Creek from its confluence with Colombo Creek to the Murray River. The aim of this IQQM implementation is to establish and define a tool that is capable of simulating daily hydrologic processes over a 100+ year period including:

- Reproducing river system operational behaviour over the calibration period;
- Reproducing daily flows at key locations for assessment of environmental flow rules;
- Analysing the impacts of alternative irrigation development scenarios over a long term (100+ years) simulation period;
- Developing and analysing the impacts of environmental flow and river operation rules to meet specific river flow objectives;
- Estimating the long-term average annual diversions for the Murrumbidgee Valley under a 1993/94 Development Conditions scenario, i.e. using the Cap model and;
- Assessing current irrigation diversions relative to those that would have occurred under 1993/94 development conditions with the current climatic inputs, i.e. the Cap audit scenario. This scenario is required for the MDBMC Cap auditing process.

1.3. IQQM IMPLEMENTATION

1.3.1. Procedure

The main steps in the implementation of the Murrumbidgee IQQM were as follows:

1) Configure and calibrate the model to reproduce historical data;
2) Model configuration for 1993/94 development conditions and management rules;
3) Validate the cap scenario for a period considered representative of 1993/94 development conditions and management rules;
4) Simulate the long term valley diversions for 100+ years to establish the MDBMC Cap.
5) Simulate the Cap Audit Scenario to compare the Murrumbidgee Valley's performance relative to the MDBMC Cap. The comparison being done from the audit commencement date of 1 July, 1997.

1.4. STATUS OF IQQM IMPLEMENTATION

All stages of this implementation are now complete.

1.5. AIM AND OBJECTIVE OF THIS REPORT

The aim of this summary report is to outline the main findings and conclusions in relation to calibration, validation and 1993/94 Cap determination. This report will be presented to the Murray-Darling Basin Commission as part of the Cap model approval process.

1.6. SCOPE OF THIS REPORT

The scope of work covered in this report includes:

- Describing the river system to be modelled (Chapter 2).
- Calibrating IQQM (Chapter 3).
- Establishing an agreed 1993/94 run (Chapter 4).
- Outlining model improvement plans (Chapter 5).

- Describing quality assessment guidelines (Appendix A).

1.7. QUALITY ASSESSMENT SYSTEM

A set of quality assessment guidelines (Appendix A) has been used in this report to evaluate and report on the model's calibration and validation performance. The definitions are used to assess the model's ability to replicate observed data. There are five categories:

- Very high confidence;
- High confidence;
- Moderate confidence;
- Low confidence; and
- Very low confidence.

Some comments have been made in the report on the suitability and accuracy of the data to represent observed behaviour over the calibration period.

2. The Murrumbidgee River Valley

2.1. CATCHMENT DESCRIPTION

The Murrumbidgee Valley is shown in Figure 2-1. The Murrumbidgee River valley, located in southern NSW westward of the Great Dividing Range, occupies an area of about 84,000 km^2 or about 10% of NSW. 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. The river rises on the Monaro Plateau, an area of elevated plains averaging 1,200 m with occasional peaks of up to 1,800 m Most of the flow enters the river system upstream of Wagga Wagga, the largest tributary being the Tumut River, with its catchment contributing almost one-third of the total runoff of the Murrumbidgee Valley. An important feature is the Yanco-Colombo-Billabong (YCB) Creek system, which is the most significant effluent stream system in the valley, and includes tributary inflows from the undulating eastern part of the catchment. About two-thirds of the Murrumbidgee Valley is flat, having slopes less than 3 degrees. Average annual rainfall varies from well over 1,200 mm east of Blowering Dam to less than 350 mm in the west. Average Class A pan evaporation varies from less than 1,100 mm/year in the south-east, to around 2,000 mm/year in the west.

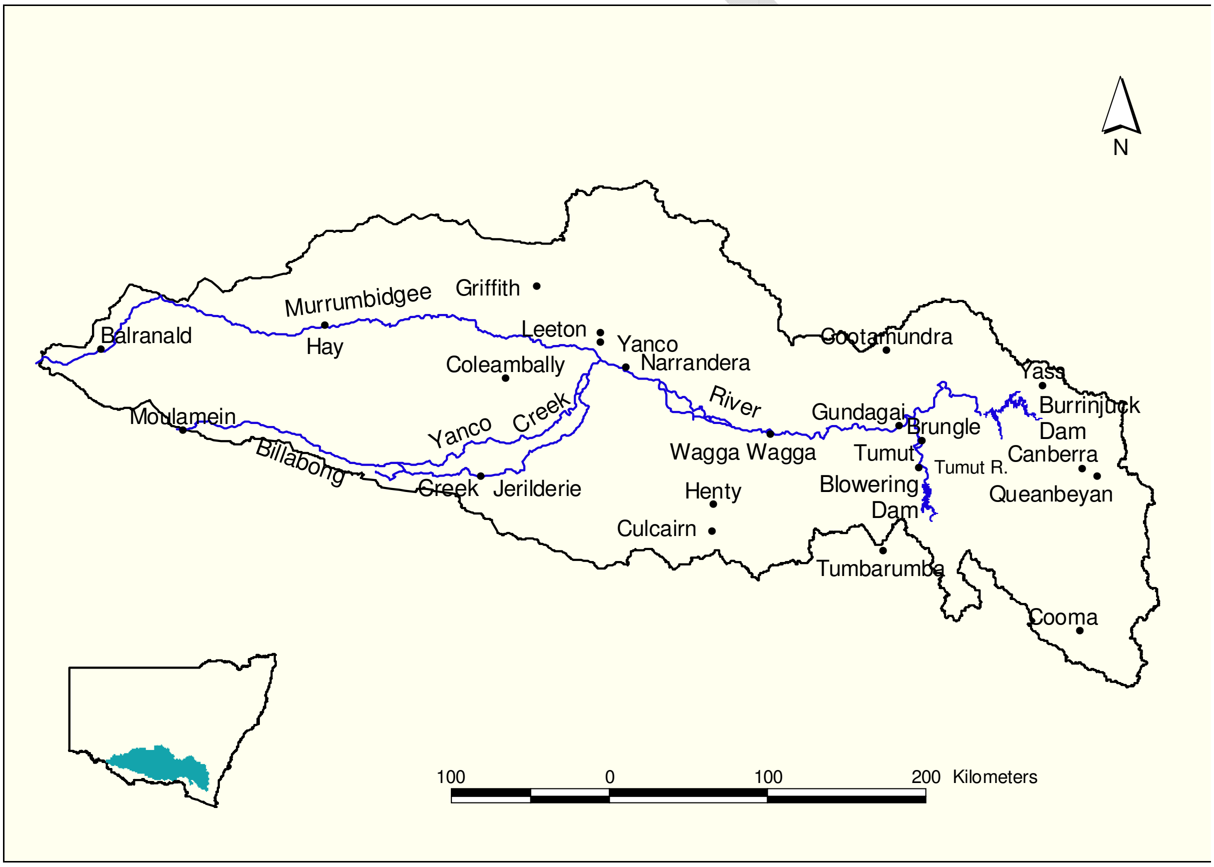


Figure 2-1 The Murrumbidgee valley

For most of the length of the Murrumbidgee River, flows are regulated for consumptive use through two major storages and a series of smaller structures. The extent of regulation downstream of the headworks dams is shown in Figure 2-2 (the headworks dams are shown in Figure 2-1) .The Murrumbidgee River is a complex regulated river system having numerous effluents, anabranches, billabongs and wetlands, two major headwater storages and a number of re-regulating storages, major irrigation developments, and various environmental needs. The two headwater storages in the Murrumbidgee Valley are Burrinjuck Dam on the Murrumbidgee River and Blowering Dam on the Tumut River. Burrinjuck Dam has a total catchment area of 13,000 km^2, and is directly fed by the Murrumbidgee, Goodradigbee and Yass Rivers. Blowering Dam 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 Mountains Hydro-Electric Scheme. The Tumut River joins the Murrumbidgee River a short distance upstream of Gundagai. Under normal flow conditions water released from storages takes about three weeks to pass through Balranald and into the Murray River.

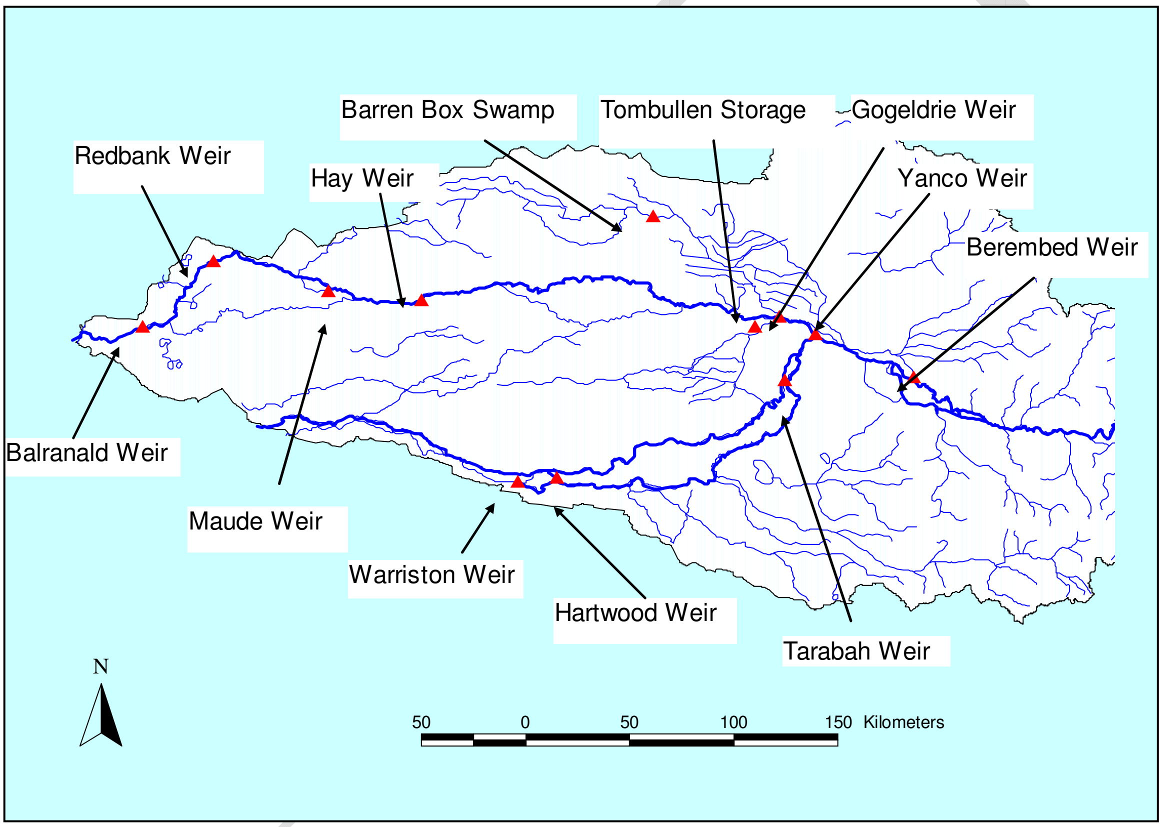


Figure 2-2 Extent of Regulation in the Murrumbidgee Valley

Several important diversion weirs are located downstream of Burrinjuck and Blowering Dams. These weirs have limited storage and primarily provide head (simply raised water level so that the desired water course is downwards) for diverting water to major irrigation channel systems, effluent creeks, forested and wetland areas. The diversion weirs are Berembed Weir, Yanco Weir and Gogeldrie Weir on the Murrumbidgee River, Tarabah Weir on Yanco Creek and Hartwood Weir on Billabong Creek.

There are three storages on the lower reaches of the Murrumbidgee River. These are Hay Weir, Maude Weir and Redbank Weir. They act as a buffer against fluctuations in irrigation demand that cannot be met by the headworks dams due to the long travel times.

Other major storages in the Murrumbidgee Valley are Barren Box Swamp located within the Murrumbidgee Irrigation Area and servicing the Wah Wah area and Tombullen Storage, an off river storage, that re-regulates surplus flows emanating from upstream of Gogelderie Weir.

Table 2-1 Murrumbidgee Valley Storages

Storage	Dead Storage (ML)	Total Capacity (ML)
Burrinjuck Dam	3,250	1,028,000
Blowering Dam	23,990	1,628,000
Berembed Weir	120	3,380
Gogeldrie Weir	200	7,400
Hay Weir	1,000	13,500
Maude Weir	300	5,000
Redbank Weir	400	5,550
Balranald Weir		4,700
Barren Box Swamp		100,000
Tombullen Storage (off river storage)	372	11,320

A large proportion of all Murrumbidgee Valley agriculture depends on irrigation. The major crops irrigated in the valley are rice, pasture and cereals, with rice irrigation accounting for around two thirds of the total diversions in the Murrumbidgee Valley. Most of the valley's irrigation occurs in two large state-constructed irrigation channel systems, the Murrumbidgee Irrigation Areas on the north side of the Murrumbidgee River, and the Coleambally Irrigation Area on the south side. There are also approximately 1,000 licensed private pumpers along the Murrumbidgee River and its effluents, who account for about one quarter of the valley's water use.

The Murrumbidgee Valley has a long history of irrigation, commencing with the construction of Burrinjuck Dam prior to World War I. Following the completion of the Snowy Scheme and the relaxation in the regulation of rice irrigation in the major state-run irrigation areas, large increases in irrigation development occurred during the early to mid 1970s. Some further increases in irrigation development occurred when large-scale irrigation was permitted in the Yanco Creek system in the 1980s, and again when regulation of rice irrigation was relaxed for river pumpers outside the major irrigation areas in the early 1990s. Some 300,000 Ha is currently used for irrigation of crops in the areas of the valley supplied by the regulated Murrumbidgee River system (DLWC 1998).

The Snowy Mountains hydro-electric scheme is made up of a large series of storages, transfer tunnels and power stations. The Scheme transfers flows from the upper Snowy River catchment, through the Snowy Mountains to the Murray and Murrumbidgee Rivers. This provides hydro-electric power and water to the inland valleys for irrigation. The general principle of the Snowy Mountains Scheme is that waters from high elevations in the Snowy River Catchment, which would naturally flow towards the coast, are impounded and diverted inland through long tunnels driven westwards through the Snowy Mountains to the Murray and Murrumbidgee Rivers. In passing through the trans-mountain tunnels and shafts the collected waters fall 750 metres, generating large quantities of hydro-electric power. The water can then be used for irrigation purposes in the Murray and Murrumbidgee catchments.

The scheme can be described as having two geographical sections See Figure 2-3 for a representation of those two groupings. They are described below.

The Snowy-Tumut Section: this provides for the diversion through a trans-mountain tunnel from Lake Eucumbene on the Eucumbene River, which is a tributary of the Snowy River, to the Tumut River. It also provides for the diversion via another tunnel of the Upper Murrumbidgee River from Tantangara Reservoir to Lake Eucumbene, which can then in turn be diverted to the Tumut River. A diversion tunnel is also used to bring water from the Tooma River in the Murray Catchment to the Tumut River.

The Snowy-Murray Section: this provides for the diversion through a second trans-mountain tunnel system from either Lake Eucumbene or Lake Jindabyne on the Snowy River, to the Murray River. This tunnel system also collects flow from the Geehi River in the Murray River Catchment.

Water in Lake Eucumbene is a store for both sections of the Scheme with water being able to be diverted to either of the two development sections.

From a hydrologic point of view, these diversions result in higher flows in the Tumut River at Blowering Dam than what would pass through this point under natural conditions. At the same time, the diversion from the Upper Murrumbidgee River reduces the flows in the Murrumbidgee River at Burrinjuck Dam compared to what would pass through this point under natural conditions.

From a hydrologic point of view, these diversions result in higher flows in the Tumut River at Blowering Dam than what would pass through this point under natural conditions. At the same time, the diversion from the Upper Murrumbidgee River reduces the flows in the Murrumbidgee River at Burrinjuck Dam compared to what would pass through this point under natural conditions.

Until recent years when Snowy Savings measures meant a reduction, the Scheme provided a minimum guaranteed annual release (*now known as the Required Annual Release*) from the Tumut development to Blowering of 1,026 GL, and an actual average annual release of approximately 1,200 GL.

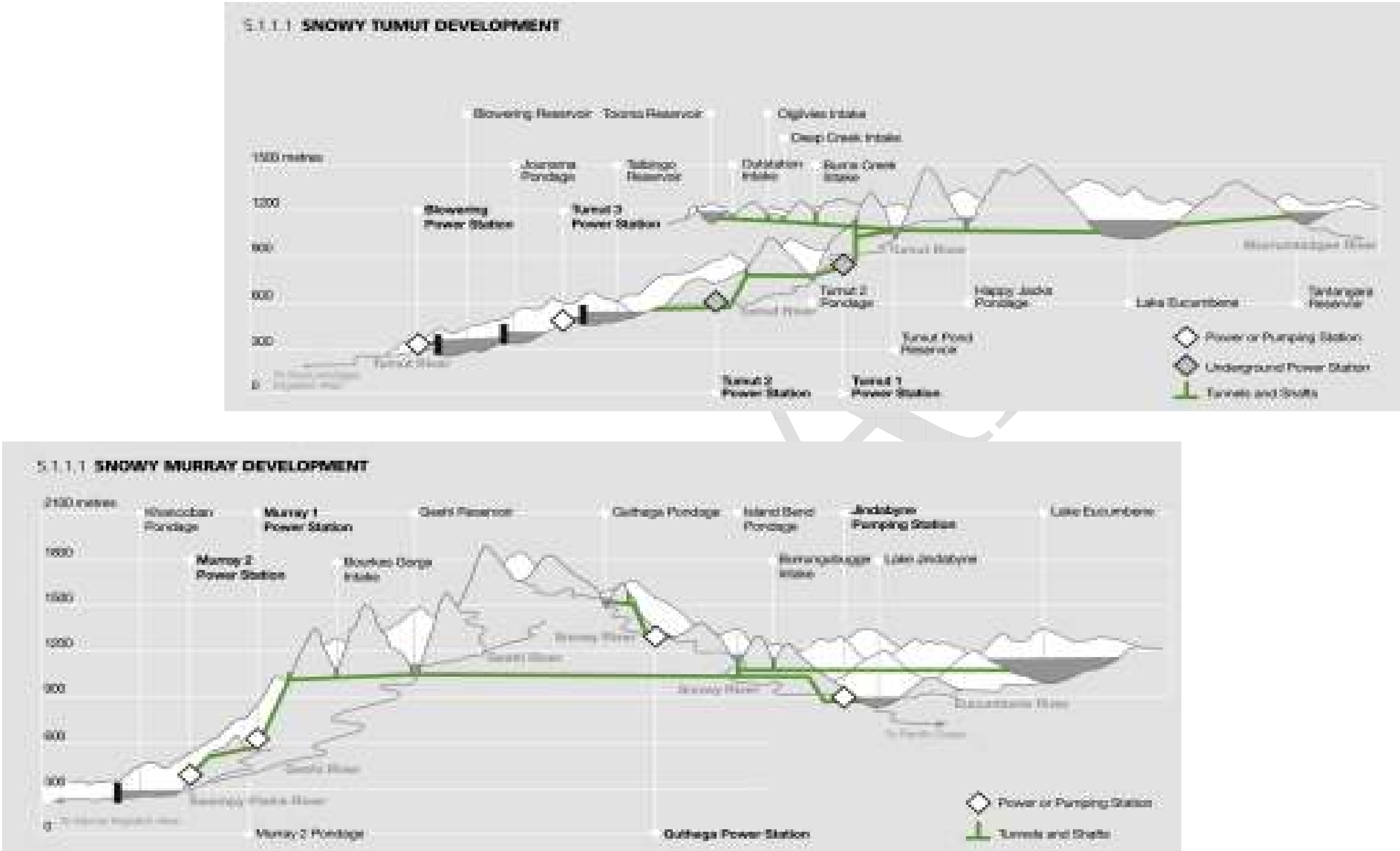


Figure 2-3 The Snowy Scheme

On the 28 June, 2002 the Snowy Mountains Hydro Electric Authority (SMHEA) was, after a long and complex process, corporatised and Snowy Hydro Limited came into being. The Commonwealth (13%), NSW (58%) and Victoria (29%) became the shareholders in the new company. Snowy Hydro operates under a licence which prescribes the Required Annual Release that must be made to each of the Murray and Murrumbidgee valleys.

2.1.1. Areas and Districts

The Murrumbidgee Valley contains two major irrigation areas, which were established by the NSW government, and corporatised in 1997; the created corporations were Murrumbidgee Irrigation Limited (MI) and Coleambally Irrigation Co-operative Limited (CICL). MI's area of operation is called the Murrumbidgee Irrigation Area (MIA) and the CICL area of operation is called the Coleambally Irrigation Area (CIA).

The MIA is the larger of the two, occupying an area of approximately 3,624 km^2 encompassing over 2700 farms. The MIA first received regulated water from Burrinjuck Dam in 1912, and has increased in size several times since the initial districts were set up. Prominent crops grown in the area are rice, corn, wheat, grapes and citrus. The MIA is located on the northern side of the Murrumbidgee River, (See Figure 2-4) and is fed by two canals: the Main Canal and the Sturt Canal. The Main Canal receives water diverted from the Murrumbidgee River at Berembed Weir, and can accommodate flows of up to 6,700 ML/day. The Sturt Canal receives water diverted from the Murrumbidgee River at Gogeldrie Weir, and can accommodate flows of up to 1,700 Ml/day.

Excess flows from much of the channel system escape to Mirrool Creek, to be reused by either MIA pump diverters (canal pumpers as opposed to river pumpers), diverted back into the channel supply system or to be stored in Barren Box Swamp. Virtually all drainage escape flows are directed to Barren Box Swamp except for a few drains and escapes which return to the Murrumbidgee River. Water flowing to Barren Box Swamp is utilised to supply further irrigation, stock and domestic users further to the west in the Wah Wah Irrigation Area (LWMP Task Force 1998, URS 2004).

The CIA was developed by 1971 to use additional water flowing in the Murrumbidgee River from the Snowy Mountains Hydro-Electric Scheme. The CIA is located south of the Murrumbidgee River. Since corporatisation in 1997 CICL has held a bulk license for irrigation of 620 GL and occupies an area of 79,000 Ha. Rice, pasture and winter cereal are the dominant crops irrigated. The CIA is located south of the Murrumbidgee River (see Figure 2-5) and is supplied by one major canal, Coleambally Canal, which receives water diverted at Gogeldrie Weir. The capacity of Coleambally Canal upstream is the Tombullen offtake is 5,000 Ml/d.
The CIA 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 eastwards to join Yanco Creek. The DC800 and the Catchment Drain are also used to supply additional water for river pumpers within the YCB during periods of high demand i.e. additional flows are directed into the Coleambally Canal and then into the DC800 and Catchment Drain before joining Yanco Creek.

Tombullen off-river storage, located off the Coleambally Canal, is used to re-regulate river flows surplus flows emanating from upstream dam spills, tributary events and rain rejections

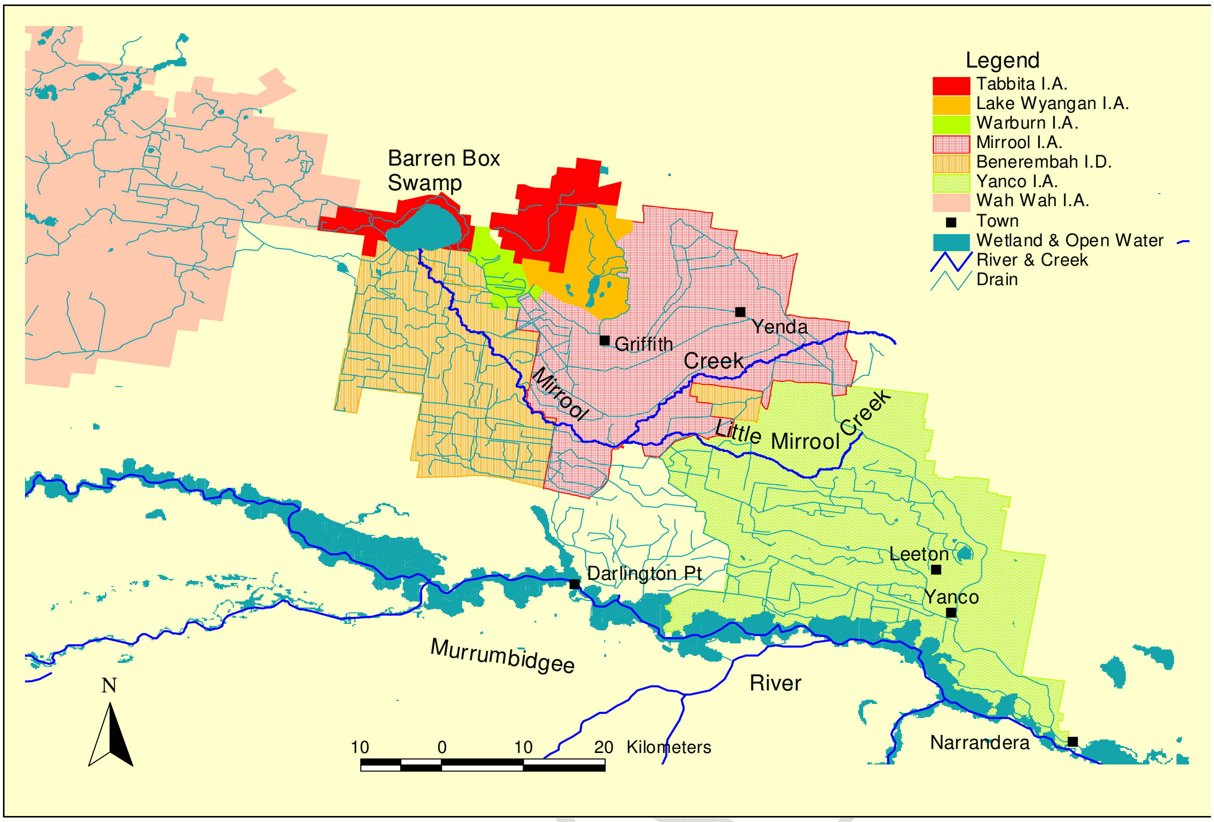


Figure 2-4 Murrumbidgee Irrigation Area (Areas and Districts as at 1993/94)

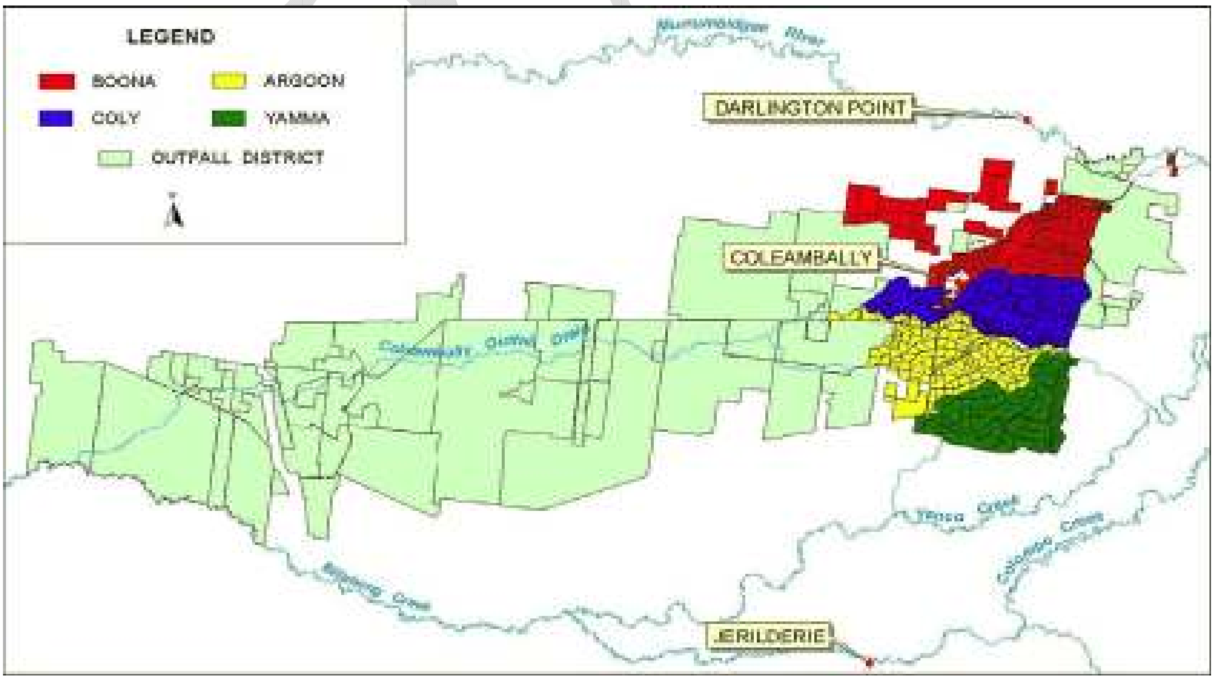


Figure 2-5 Area of Operation of CICL Including Outfall District

2.1.2. Lowbidgee

The Lowbidgee District lies on the lower reaches of the Murrumbidgee River between Hay and Balranald (see Figure 2-6). In this region the Murrumbidgee River's flow carrying capacity reduces significantly, resulting in extensive overbank flows into a floodplain area of over 150,000 Ha. To the south of the main river channel there is an extensive effluent floodway system which supports one of the State's largest areas of lignum, an important wetland habitat, and is one of the largest areas of regularly available habitat for waterbirds in eastern Australia. To the north and closer to the river generally, the frequently inundated floodplain supports large Redgum forests. Both of these ecosystems combine to form an area of national ecological significance. The district also contains fertile alluvial soils that support irrigation and livestock activities following flooding.

Historically, augmentation of flows onto the Lowbidgee floodplain commenced prior to the turn of the century to improve flooding through the Redgum forests. In the 1930s improvements were made to some of the effluents where higher flows broke out onto the southern floodplain areas to offset decreased flooding resulting from the construction of Burrinjuck Dam and developments along the Murrumbidgee River upstream of the Lowbidgee District. At this time levees were also constructed to keep flows from returning to the river downstream of the offtake and to facilitate flows further into the floodplain. Diversions were further augmented by the construction of Maude and Redbank Weirs during the 1940s. During the 1960s the effluents to the southern floodplain were further improved with cuttings and regulators. The last significant change to the Lowbidgee diversion infrastructure was the construction of another regulator on southern effluents in 1980, allowing an increase in the Maude Weir pool operating level to its current level.

Initially, the southern effluents discharged water onto the floodplain in an uncontrolled fashion, generally along what has now become the protected floodways. This was modified in places by the construction of low-level spreader banks by landholders, which increased the areas of inundation before flows continued on down the flood plain. The flooded land produced improved pasture for grazing enterprises which dominated the Lowbidgee District.

During the mid 1970s, wheat crops were planted in the southern floodplain areas to utilise the subsoil moisture remaining after the recession of flooding. With the subsequent development of irrigation, flows to the area have changed from wild flooding to a controlled flooding and there has been a substantial move from grazing to grain production. Organic safflower and wheat are currently the main crops in the Lowbidgee District.

There is no significant licensed entitlement to water for the district and it cannot order regulated supplies from the major storages. The Lowbidgee District receives the majority of its supply from high river flows within the Murrumbidgee River system, generally during the winter and spring period.

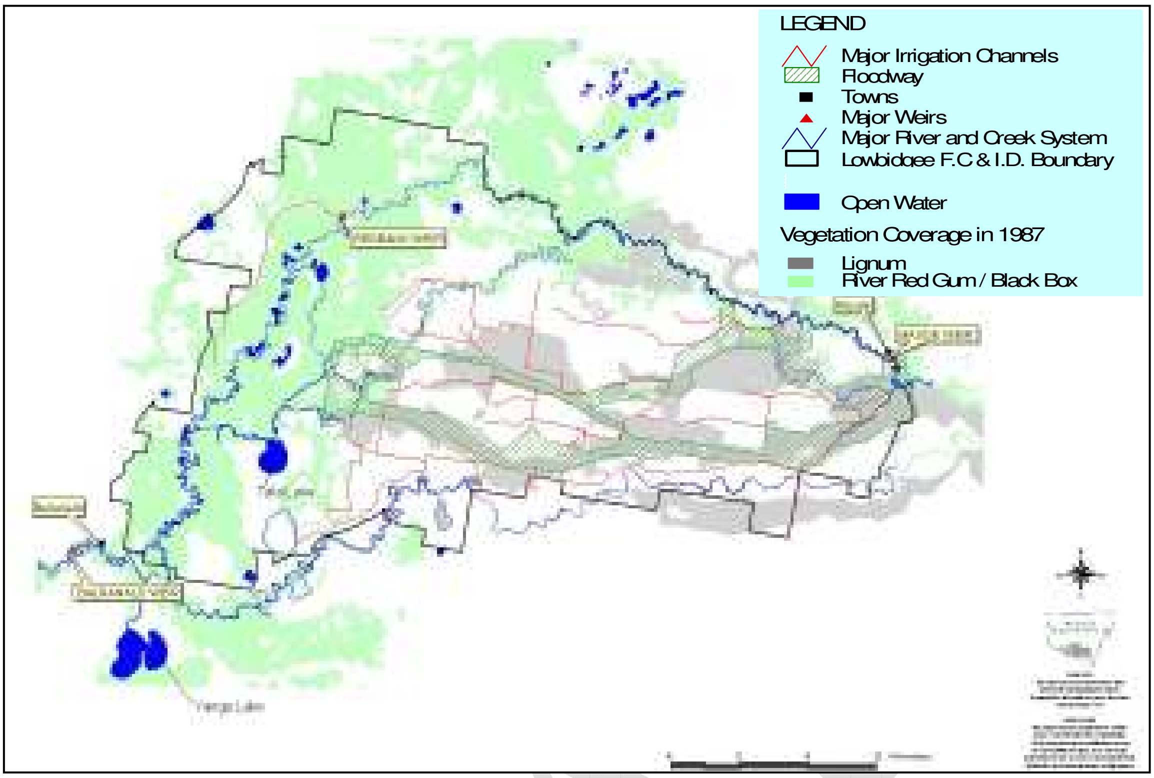


Figure 2-6 Lowbidgee District

2.1.3. Yanco-Colombo-Billabong System

The most significant effluent of the Murrumbidgee River is the Yanco Creek, which flows south from the Murrumbidgee River near Narrandera to the Billabong Creek below Jerilderie. Colombo Creek, in turn, is a major effluent of Yanco Creek near Morundah, and also flows south to a confluence with the Billabong Creek above Jerilderie. The Billabong Creek rises in undulating country around Holbrook and flows westward to the Murray River at Moulamein, joining with the Colombo and then Yanco Creeks along the way.

Forest Creek is a high level effluent of Billabong Creek which starts at Hartwood Weir, just above the Yanco Creek confluence. This is the start of a long anabranch system whose channel capacity has deteriorated with changes to the flow regime and land use, and much of the lower system now forms swamp areas. Flows generally only pass through to the bottom end of the system during sustained high flow periods, with water also returning from the anabranch to the Billabong creek at a number of locations. Figure 2-7 and Figure 2-8 show the main features of the YCB.

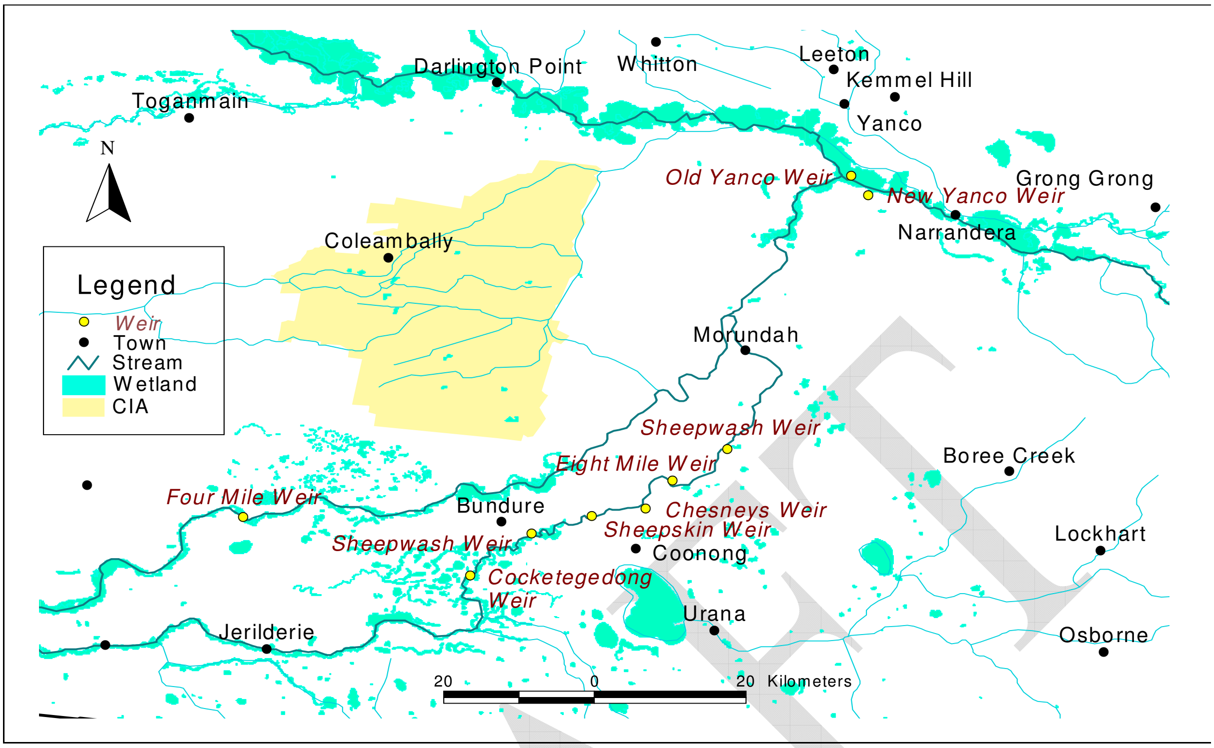


Figure 2-7 Upper Reaches of the YCB

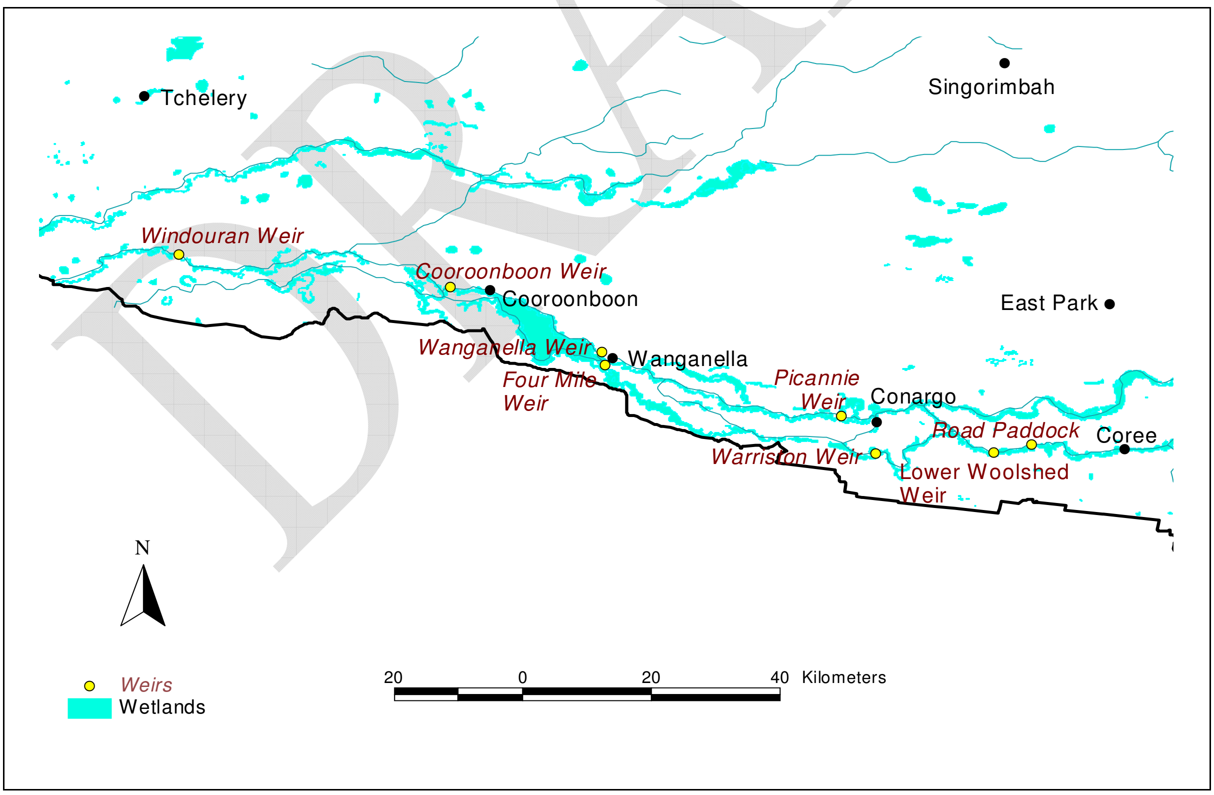


Figure 2-8 Lower Reaches of the YCB

Regulated flows are diverted into Yanco Creek from the Murrumbidgee River, and are supplemented by flows from two outfall drains from the Coleambally Irrigation Area. Regulated supply is provided along the entire Yanco and Colombo Creeks, along the Billabong Creek below the Colombo Creek confluence, and to the top section of the Forest Creek above Warriston Weir. Some additional flows are provided to the Billabong Creek from the Murray Irrigation Districts via several drains and escapes. The travel time for regulated flows to pass through the entire system from the Yanco Creek Murrumbidgee offtake to Moulamein is approximately 4 weeks.

In 1988/89 the growing of rice was de-regulated for the whole of the YCB system. Licensed pumpers were then allowed to irrigate rice, subject to the normal soil type constraints. Consequently, the amount of rice grown in this system increased during the 1990's to around 10,000 ha, allocations permitting. The predominant winter crop for the area is winter pasture.

Low channel capacities at the Yanco Creek offtake (approximately 1,400 ML/day) and along Colombo Creek (approximately 600 ML/day), are a feature of the system. With the significant increase in summer cropping over the last 15 years, supply constraints during periods of peak demand are common. The long-travel times of flow, and the lack of re-regulatory capacity within the system also contribute to supply shortfalls. Additional supply during summer periods has been made available via Coleambally and Murray Irrigation areas, which have drains into the Yanco Creek system. CICL can supply up to 100 ML/day via the Catchment Drain and up to 150 ML/day via the DC800 drain. Murray River flows can be transferred to Billabong Creek via the Murray Irrigation Limited channel system and the Finley Escape at a rate of up to 250ML/d. Water supplied from Finley Escape is effectively an inter-valley transfer and, at the end of each season, that portion of the Finley Escape flows used along the Billabong Creek are assessed and repaid to the Murray valley the following year through Balranald.

2.1.4. Groundwater

The geomorphological pattern for the Murrumbidgee Valley is generally consistent with that for most Murray-Darling Basin rivers, moving from the Dividing Range down to the Barwon or Murray confluence. The tributary streams and the main river sections above the major dams generally drain high relief upland areas, and have high gradients and small or absent alluvial systems. They derive a significant proportion of their flow from discharge from fractured rock aquifers. Because of the lack of alluvial sediments, aquifer transmissibility is low, bore yields are low and there are few irrigation bores in these systems.

The mid-sections of the Murrumbidgee River, generally between the major dams and the river reach around Narrandera, have alluvial systems that are more developed but still narrow and constricted by bedrock. The narrow floodplain produces shallow alluvial water tables and strong hydraulic connection between river and aquifer. See Figure 2-9. The direction of the river-aquifer flux can vary over time. For example, after major recharge events like floods, the aquifer may drain back to the river for several years, followed by a period of the river recharging the aquifer. Changes in flux direction may also be seasonal with the river recharging the aquifer during the irrigation season when river stage is high and the reverse during the off-season when river hydraulic head is low. Because of the proximity of groundwater extraction to the river and the high degree of hydraulic connection, groundwater pumping is expected to impact streamflow to a large degree within a relatively short timeframe

As the constricted mid-sections of the Murrumbidgee River spills out onto the wider semi-arid plains of the lower valley, groundwater levels fall and the hydraulic connection is broken. Extensive alluvium has provided the opportunity for widespread development of bores. In the mid-Murrumbidgee, most bores are clustered within 5 km of the river. In the lower Murrumbidgee, bores are more widely distributed. With the lower Murrumbidgee having low hydraulic connectivity, greater distance between bores and connected reaches of the river and, alternative sources of recharge/discharge it is thought that the proportion of groundwater pumping derived from reduced streamflow will be low and response times long.

In the lower reaches of the lower Murrumbidgee River, factors such as rising bedrock, and reduced aquifer transmittance caused by progressive fining of material, force groundwater levels near the surface re-establishing hydraulic connection to the river. In these reaches, flow direction is again variable, but in the long-term tends to be toward the river. Groundwater in this area is generally of high salinity and groundwater discharge is known to degrade river water quality. Because of the high salinity, there are few irrigation bores and little groundwater extraction.

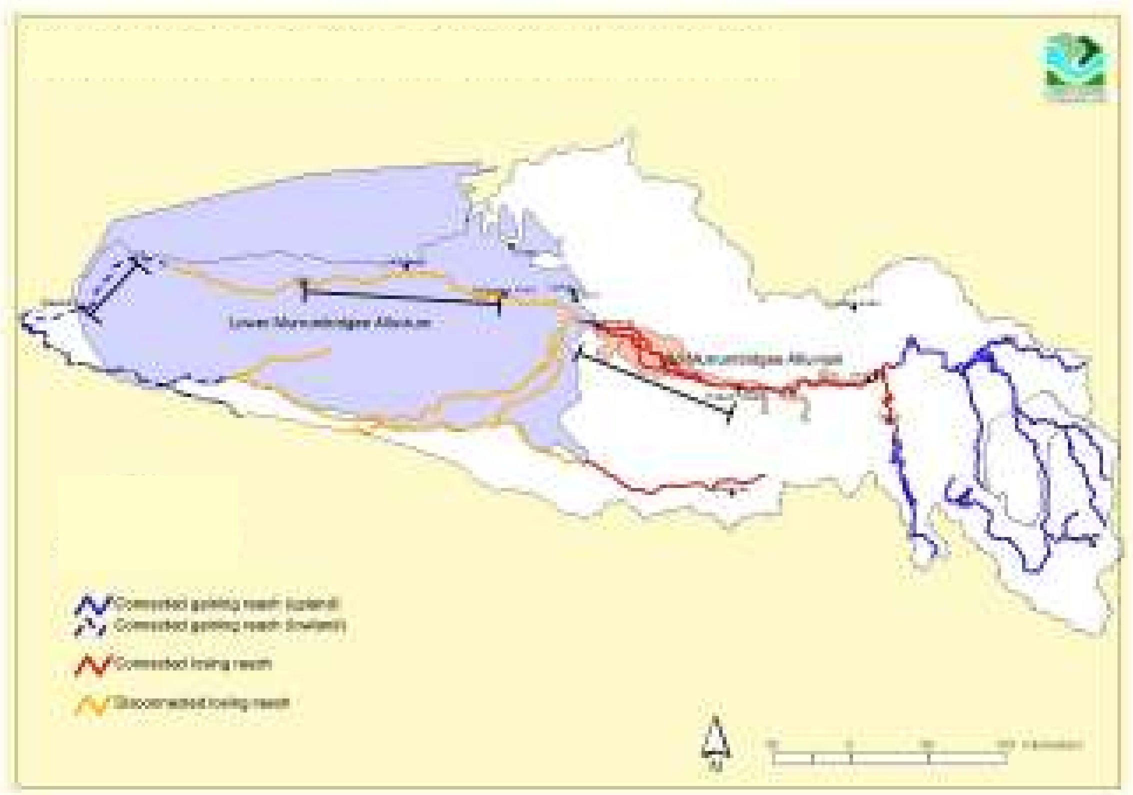


Figure 2-9 River Groundwater Connectivity in the Murrumbidgee Valley

2.2. CLIMATIC DATA

Climatic data is required in the Murrumbidgee IQQM for:

- rainfall-runoff modelling;
- generating crop water requirements;
- modelling the net rainfall/evaporation at storages and river reaches.

The climatic data used for model calibration and simulation was generally obtained from the Bureau of Meteorology. The exception being Griffith potential evapotranspiration (ETo) obtained from CSIRO. Every effort has been made to collate the best available data. The climatic data discussed in this report relate to the IQQM model only. The climatic data used for Sacramento modelling of flows from some of the Murrumbidgee River tributaries have been discussed separately in HydroTechnology (1995).

2.2.1. Rainfall

Rainfall data is required by IQQM to drive the soil moisture accounting, for computing the rainfall onto reservoir storage volumes and rainfall onto river reaches. Rainfall data is also required for generating catchment inflows for some periods using rainfall-runoff modelling.

An extensive network of daily read rainfall gauges covers the Murrumbidgee River Valley and selection of appropriate gauges for each of the above tasks in the Murrumbidgee IQQM is discussed in 3.1.3 with a full listing of the gauges selected provided in Table A.1. The location of the rainfall gauges (and evaporation) used in model calibration and scenario running are shown in Figure 2-10

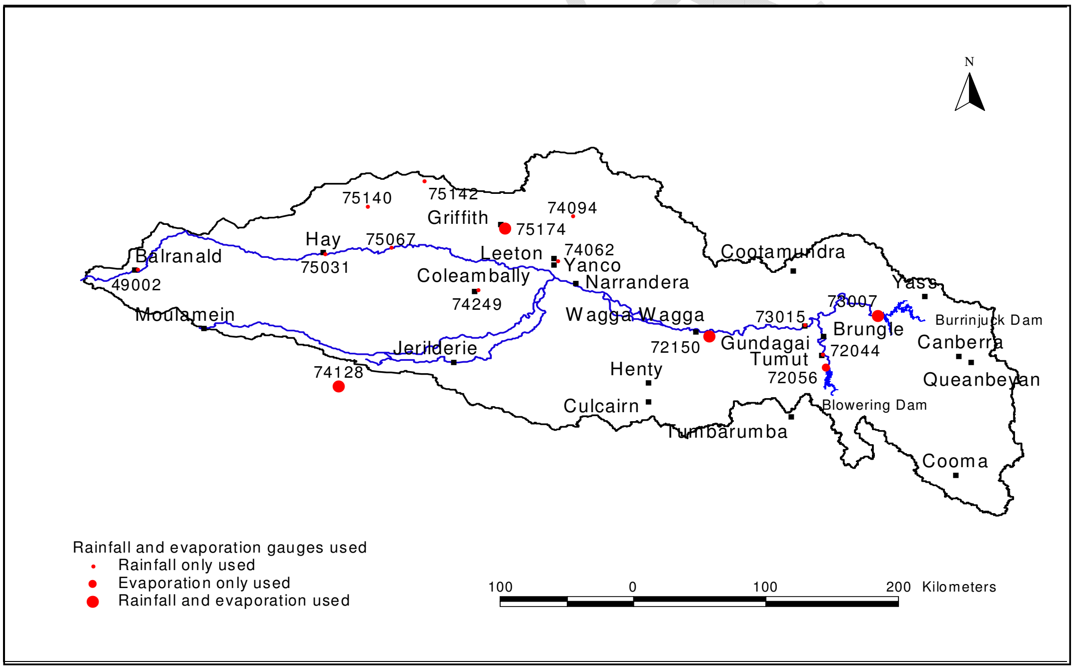


Figure 2-10 Model Used Rainfall and Evaporation Murrumbidgee Valley Gauges

2.2.2. Evaporation and Evapotranspiration

Evaporation data is required by IQQM for computing evaporation losses from reservoirs and from river reaches. Evaporation data is also used for generating catchment inflows for some periods using rainfall-runoff modelling.

There are a number of sites with evaporation records in the Murrumbidgee Valley whose locations are also shown in Figure 2-10.

Evapotranspiration is the combination of evaporation, both from the soil surface and water intercepted by plants, plus transpiration by plants. The same factors governing open water evaporation also govern evapotranspiration, namely energy supply and vapour transport. There is also an additional factor, that being the supply of moisture at the evaporative surface. Hence, when applied to a cropping situation, estimated evapotranspiration is a much more effective variable than pan evaporation with monthly factors applied.

The Penman-Monteith equation estimates reference crop evapotranspiration (ET_o) from climate data. The CSIRO funds & operates a climate recording station at Griffith (075174) that has provided a long-term record of estimated ETo. A large part of the irrigation in the Murrumbidgee Valley occurs in the MIA and CIA, both of which are sufficiently close enough to Griffith for that irrigation's evapotranspiration to be reasonably represented by this station. This also applies to a large proportion of the main river pumpers.

There is also a CSIRO weather station at Hay which provides estimated ETo, but this site was not used in the modelling as there was an insufficient long period of useable record. Griffith ETo was used exclusively for modelling all crop water demand in the model.

The methodology adopted for the selection, processing and extension of evaporation data for IQQM modelling is discussed in section 3.1.4 and 3.1.5.

2.3. STREAMFLOW DATA

Streamflow data is used for model calibration (see Section 3.1.2) and for model scenario simulation (see Section 4.3.1). DNR has an extensive network of flow gauging stations throughout the Murrumbidgee Valley, as shown in Figure 2-11, and time series flow data from these stations is maintained in the DNR's HYDSYS database.

2.3.1. Main stream gauging stations

Some of the flow gauging stations along the Murrumbidgee River have a particularly lengthy period of record, which has helped to provide a long period of climatic (flow) input for model simulation. Selection of appropriate gauges to use in the Murrumbidgee IQQM is discussed in Sections 3.3 and 5.3 with a full listing of the gauges selected provided in Table A-5 and Table A-6. The location of main stream gauging stations has been shown in Figure 2.3.

2.3.2. Tributary inflows

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

The tributaries that contribute to Murrumbidgee River flows are listed in Table A-6and the locations of streamflow gauging stations measuring flows in those tributaries are shown in Figure 2-11 with dashed lines

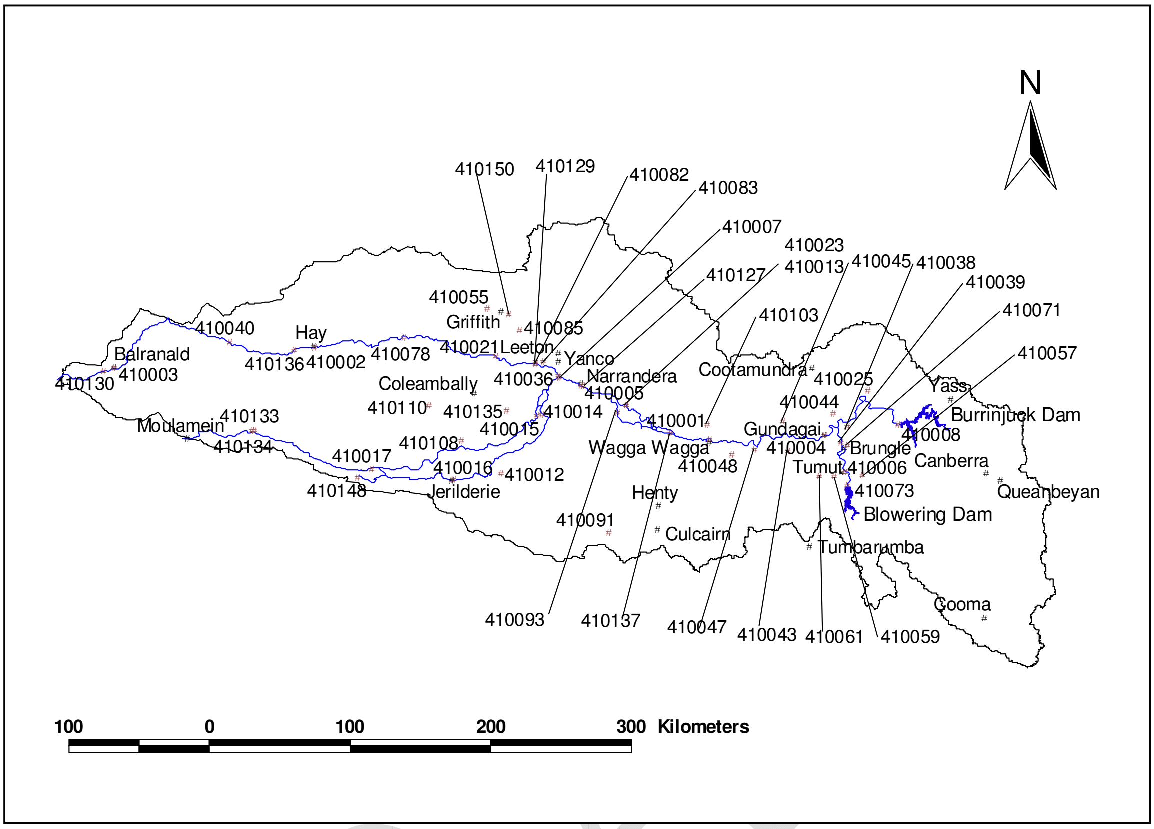


Figure 2-11 Model Used Murrumbidgee Valley Flow Gauges

2.4. IRRIGATION INFORMATION

2.4.1. Irrigation licenses

There are licences for surface water extraction throughout the Murrumbidgee River system, both in the regulated sections below Burrinjuck and Blowering Dams, as well as in the unregulated parts of the catchment above these dams and along the tributaries that enter downstream of these dams. Regulated licences are closely monitored and have an annual licensed entitlement volume. In addition, regulated licences are given permission to divert water without debit to their allocated water from time to time, when river flows are in excess of regulated requirements. As a Cap management measure, this “off-allocation” access was limited in 1996 by way of individual (“quota”) limits, based on an assessment of historical reliance on off-allocation use.

Following the construction of Burrinjuck Dam, its enlargements, and the construction of the Snowy hydro-electric scheme, licences for regulated entitlements to water were progressively issued. For most entitlement categories no new entitlements have been issued since 1977 when DNR announced an administrative embargo on the issue of new licenses. The embargo was placed in recognition that, should the number of licences then issued be fully developed, the water resources available would be fully committed. The licences supplied with water by Burrinjuck and Blowering Dams were converted from area-based licences to volumetric licences at the commencement of the 1982/83 water year. In 1997 the two main government set-up irrigation areas (MIA and CIA), which represent about 70% of licensed entitlements to water within the valley, became privatised entities, with ownership vested in the landholders. That privatisation processes included the issuing of new Bulk licences for MI & CI that covered these corporations rights to divert water from the Murrumbidgee River.

Unregulated river licences have, until recently, been operating on the basis of a maximum authorised irrigable area and a lower flow limit for pumping (usually a visible flow at the nearest flow gauging station). In 2000, most unregulated licences in NSW were converted from area to volume based. Operation of unregulated licences has not been closely monitored to date, and there is generally very little data collected regarding extractions and cropping by these licences.

In the regulated river reaches on the Murrumbidgee River and Yanco-Colombo-Billabong Creek system there are approximately 1,000 licensed pumpers.

Table 2-2 contains the distribution of entitlements between the main user groups in 1993/94 and 2000/01. The main difference is the creation of conveyance entitlements for the irrigation areas and districts when they were privatised. Previously, the State set aside allowances to cover these needs, similar to allowances for transmission losses in the river system, prior to making water available for allocation. Other processes leading to differences in entitlement totals over the last 10 years include: conversion of general security to high security entitlements (with a corresponding reduction factor), formal recognition of water supply under agreements within the Irrigation Corporations, and an ongoing anomalies review process from the original volumetric conversion in 1982.

Licence holders on the regulated sections of the Murrumbidgee River and YCB System are required to order water in advance (up to a maximum of two weeks in advance in general). However, the volume of water actually extracted may vary significantly from the volume ordered because of either over-ordering or if there are significant changes in weather conditions during the time taken for water released from storage to reach licensed users. Water ordered but not diverted due to rainfall can produce significant volumes of excess flows in the river system, generally known as rain rejection flows. It constitutes operational loss from the Murrumbidgee valley and without any re-regulation capacity becomes an unregulated inflow to the Murray either directly (at Balranald) or indirectly via the Edward & Wakool Rivers.

Table 2-2 1993/94 and Current Regulated Murrumbidgee valley Entitlements

		MIA	CIA	River	YCB	TOTAL	(GS+HS)
1993/94	High Security	229,488	8,543	44,187	7,515	289,733	2,406,054
	General Security	1,005,547	475,103	488,499	147,172	2,116,321	
	Conveyance	-	-	-	-	-	
	TOTAL	1,235,035	483,646	532,686	154,687	2,406,054	
2001	High Security	283,411	11,754	54,373	7,639	357,177	2,400,365
	General Security	929,658	479,762	480,360	153,408	2,043,188	
	Conveyance	243,000	130,000	-	-	373,000	
	TOTAL	1,456,069	621,516	534,733	161,047		
WSP	High Security	279,303	11,754	60,896	7,398	359,351	2,388,317
	General Security	930,768	479,762	465,915	152,521	2,028,966	
	Conveyance	243,000	130,000	2,968	0	375,968	
	Supplementary	34,400	26,692	102,496	27,853	191,441	
	TOTAL	1,208,168	636,454	571,379	180,374	2,596,375	

Source: 1993/94 - MDBC Salinity & Drainage Strategy review (1992)
2006/07 – DNR Web site registers.

There were a small number (69) of Special Additional Licences (i.e. additional to an existing general security licence), also known as high flow licences, which could divert water from the Murrumbidgee River when flows exceed a particular flow level. Most of these licences were permitted to extract water when flows exceed 3.84m at the Hay Weir gauge, which equates to approximately 6,600 ML/day. Diversions by these licences were usually recorded as off-allocation diversions against the associated general security licence until 1996, when restrictions to off-allocation access were introduced. In the years around year 2000 significant volumes of water had been diverted by these high flow licences. These licences were converted to supplementary licences as part of the Murrumbidgee WSP.

2.4.2. Irrigator pump capacity and storage infrastructure

Regulated licences in NSW are normally issued with conditions relating to the maximum authorised extraction capacity, generally referred to as the authorised pump capacity. Installed pump capacities were generally available from meter inspectors' records. Based on this data the total system pumping capacity is 156,025 ML/d. Table 2-3 contains the distribution of the pump capacities for the four irrigator groups.

The Murrumbidgee Valley does not generally have significant development of on-farm storages. A survey in 1997 indicated that private pumpers outside the main irrigation corporations had approximately 16 GL of on-farm storage capacity. During 2002/03 a survey of irrigation infrastructure between Darlington Point and Hay indicated that there was an additional 19 GL of on-farm storage in that reach. The reach from Darlington Point to Hay represents around half of the entitlement to private pumpers along the Murrumbidgee River.

This indicates that the total on-farm storage capacity outside of the main irrigation corporations is currently around 35 GL. On-farm storages may be used for a range of activities in addition to harvesting of high river flows, such as re-regulating irrigation runoff, re-regulating rainfall–runoff, and protection against occasional shortfalls in river supplies.

Table 2-3 Pump Capacities in ML/d

	River Pumpers (Main River)	MIA	CIA	Yanco Colombo Billabong
Pump Capacity ML	36,819 (24%)	8,200 (66%)	5,000 (3%)	10,716 (7%)

2.4.3. Irrigation Extraction Data

The majority of diversions, by volume, are made by the two major irrigation corporations (or their pre 1997 privatisation entities) for which daily diversion totals are available. These diversions have been either calculated from head difference and gate openings, using a simple undershot weir discharge formula, or in the case of the MIA main canal using a rating table developed and maintained by DNR hydrographers. In both cases gaugings are carried out by hydrographers from to time to validate observed diversions. In the case of CIA, the observed diversion time series revised as a result of an analysis of gaugings versus "observed" values (DIPNR 2004).

All private river pumpers with an entitlement of 20 ML or more are required to have flow meters installed on pumps. . Since the early 1980s individual meter readings have been recorded in the DNR licensing database, from which final annual diversion totals can be extracted. Meters are read at varying intervals, once per month for larger users, whilst for other users the DNR database is not generally able to provide accurate monthly diversion totals. However, operational monthly use totals that include some estimated use and orders are available from the late 1970s onwards. The operational data is used in conjunction with meter readings to estimate monthly diversions.

On-allocation and off-allocation usage were not recorded separately in the departmental licensing database. Prior to 1994 only records indicating periods when off allocation had been declared were available. Again, operational totals are available on an annual basis. For MI and CI daily totals can be easily inferred with the period of off allocation data (that commenced in the 1989/90 season).

Historical annual diversions (and farm gate deliveries for the irrigation areas) for the main user groups from the DNR database are shown in Table 2-4.

Table 2-4 Regulated Murrumbidgee Valley Diversions and Deliveries

Database Diversions Accounted Against Allocations (GL)							Diversions For Cap Accounting (GL)	
Year	MIA		CIA		Licensed Pumpers	Total Diversion	CIA Cap Diversion	Regulated System Diversion
	Diversion	Delivery	Diversion	Delivery	Pumpers			
1982/83	1,155	961	602	455	311	2,068	508	1,974
1983/84	881	734	629	431	193	1,703	485	1,559
1984/85	1,183	992	715	501	310	2,209	571	2,065
1985/86	1,140	943	603	443	306	2,050	467	1,913
1986/87	1,094	892	582	421	336	2,013	458	1,889
1987/88	1,254	1,043	680	502	405	2,338	539	2,197
1988/89	983	799	567	415	237	1,787	383	1,602
1989/90	1,102	877	569	392	334	2,006	411	1,848
1990/91	1,194	926	531	394	446	2,171	411	2,051
1991/92	1,328	1,051	607	480	519	2,454	456	2,304
1992/93	931	685	469	321	340	1,739	335	1,606
1993/94	1,040	831	527	386	492	2,059	403	1,935
1994/95	1,403	1,072	566	455	608	2,576	510	2,521
1995/96	1,107	870	496	401	556	2,159	417	2,079
1996/97	1,325	1,067	617	505	668	2,611	532	2,526
1997/98	1,227	977	551	448	664	2,442	493	2,384
1998/99	1,033	813	484	380	602	2,119	408	2,043
1999/00	818	644	388	312	507	1,713	315	1,640
2000/01	1,048	857	499	409	651	2,198	406	2,105
2001/02	1,142	917	505	406	607	2,254	429	2,178
2002/03	960	698	411	298	359	1,730	367	1,686
2003/04	861	659	365	243	429	1,655	358	1,648
2004/05	826	578	334	338	228	1443	328	1488
2005/06	1038	761	349	288	516	1903	361	1915

Notes:
1. MIA Diversions as measured at the Narrandera & Sturt regulators.
2. CIA Diversions against allocation are calculated from Coleambally canal diversions net of Tombullen inflows and water ordered and supplied to Yanco Creek system.
3. For Cap purposes, the CIA diversion is net of all returning drain flows - not just those ordered by River Operations.
4. Diversions for MIA and licensed pumpers are the same for accounting against Cap and against allocations.
5. CIA diversions changed following a review of the formula used at offtake.
6. Licensed pumpers are net of Mirrool and Cudgel Ck users, but include high flow licence use.
7. All totals include off-allocation use and high-flow licence use.
8. Canal diversion measurements have been complicated by submerged tailwater conditions at both Coleambally and Sturt Canal offtake structures, and historical diversions were known to be in error. Previously recorded

Coleambally Canal diversions were recalculated in 2001 using discharge coefficients that were more accurate when discharges were made under submerged tailwater conditions, and updated again in 2004 (Ref: Barma 2001, 2004). In 2002, the Coleambally offtake was fitted with an ultrasonic direct flow measurement device. This device accorded well with the revised flow calculation procedures and is now the approved measurement device for Coleambally Irrigation. No recalculation of Sturt Canal diversions has been undertaken as yet.

2.4.4. Crop areas

Estimates of crop type and area irrigated are available for the irrigation areas and districts, from information given when placing orders for water, up to 1988. In 1996 the Coleambally Irrigation Area recommenced collection of crop area and type irrigated via a new central water ordering system, followed by the corporatised Murrumbidgee Irrigation in 2001. A summary of this information is shown in Figure 2-12, Figure 2-13 and Figure 2-15 .

The Coleambally data from 1996 also includes crop area information for a number of small users outside this district, but receiving water from the Coleambally channel system, including the Kerarbury Scheme (which has significant access to groundwater supplies) and the users along the Coleambally outfall drain. These additional users may irrigate up to 12,000 ha per year.

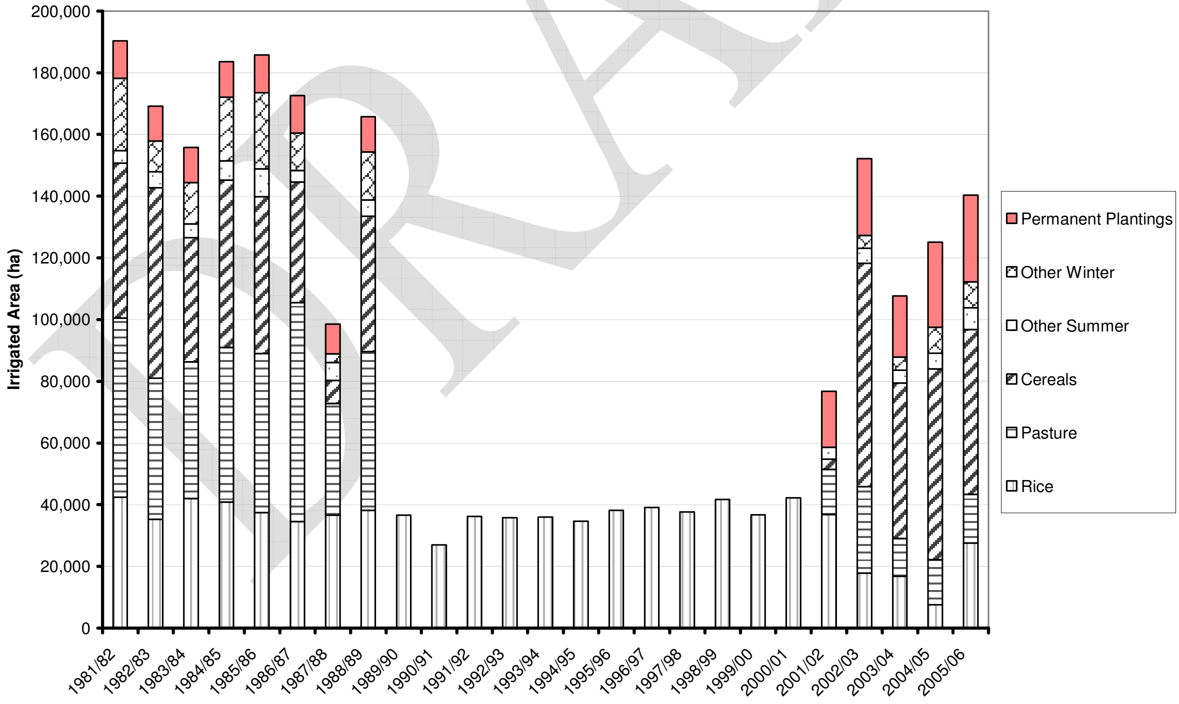


Figure 2-12 Crops Grown in the Murrumbidgee Irrigation Area

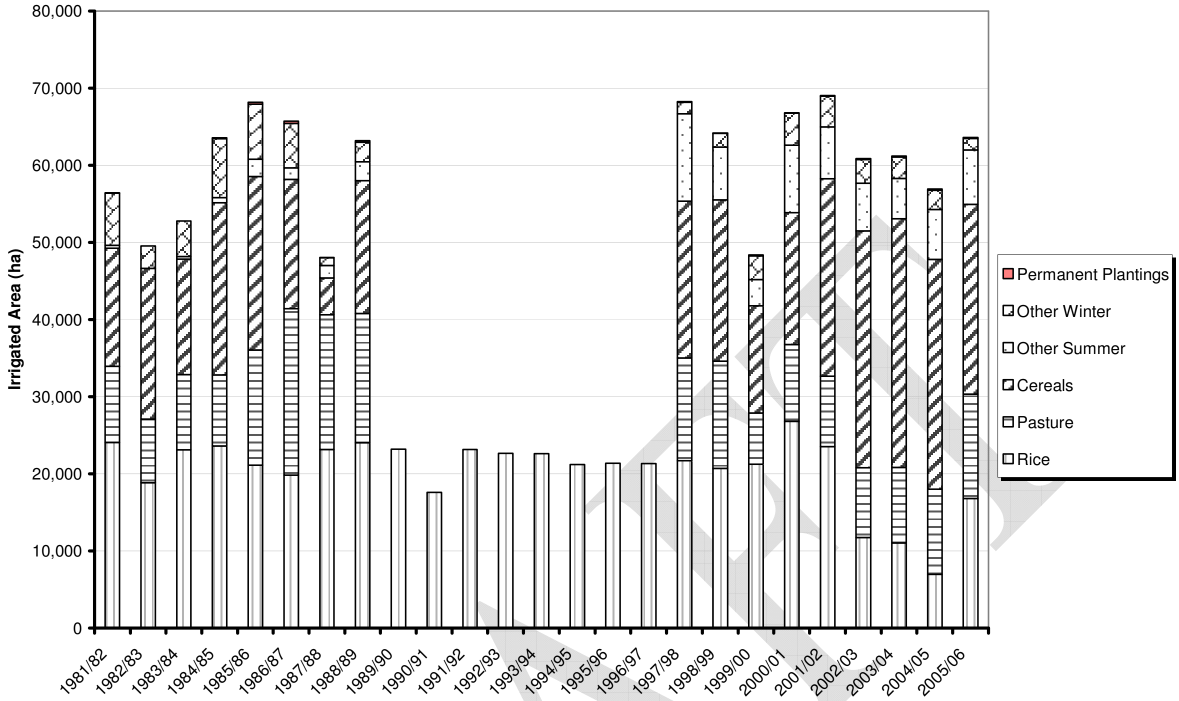


Figure 2-13 Crops Grown in the Coleambally Irrigation Area

Similar irrigated cropping information is available for the river pumpers from annual surveys conducted by departmental staff up to 1995. In 2000, a new, automated central water ordering system was put in place for users in the Yanco Creek system, which also collected crop area information for three years when it was terminated. This is presented with the previous survey data in Figure 2-13

In addition to survey/water ordering crop area data, DNR carries out remote sensing of rice areas annually as part of its environmental monitoring of rice irrigation. These measured rice areas correspond reasonably well with rice areas collected as part of the water ordering systems described above. The total measured rice area for the Murrumbidgee Valley is shown in Figure 2-14 below.

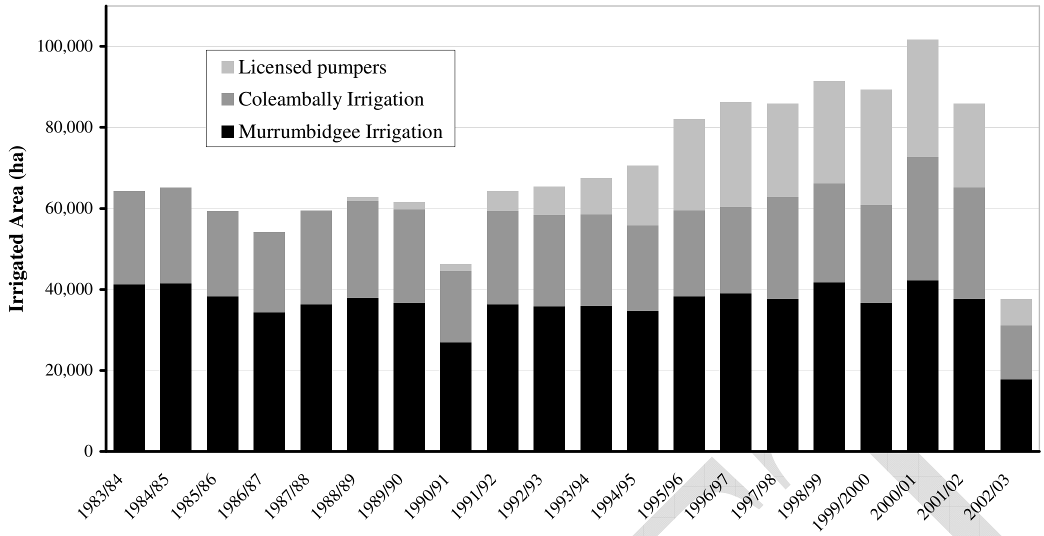


Figure 2-14 Murrumbidgee Valley Remote Rice Data

Some survey-based crop area estimates are also available from industry organisations such as the Rice Growers Cooperative and the Murrumbidgee Horticultural Council.

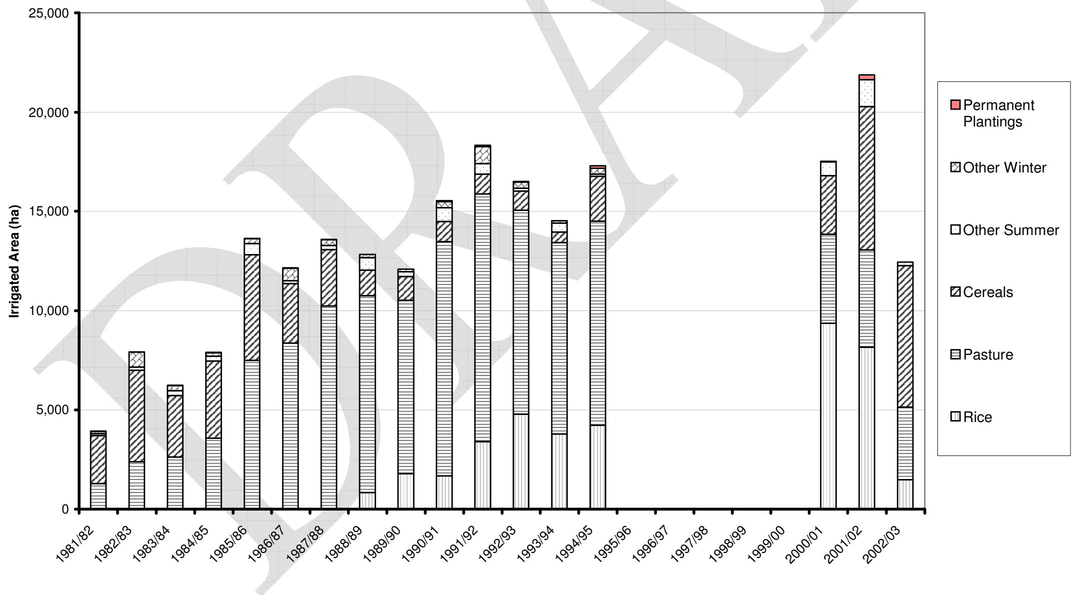


Figure 2-15 Murrumbidgee Valley River YCB Pumpers Total Crop Area

Table 2-5 Crop Mix for Different User Groups

Crop Type	River Pumpers	MIA	CIA	YCB
Rice	5259 (9%)	34757 (20%)	22056 (36%)	4470 (24%)
Summer Cereal	7393 (13%)	0 (0%)	906 (1%)	888 (5%)
Winter Cereal	2590 (4%)	56101 (32%)	14321 (24%)	702 (4%)
Lucerne	1896 (3%)	1427 (1%)	121 (0%)	904 (5%)
Winter Pasture	35034 (59%)	48907 (28%)	14321 (24%)	10463 (56%)
Summer Oil Seeds	1426 (2%)	1911 (1%)	3323 (5%)	193 (1%)
Winter Oil Seeds	486 (1%)	638 (0%)	1027 (2%)	0 (0%)
Orchards and Citrus	1063 (2%)	4797 (3%)	121 (0%)	7 (0%)
Vines	10 (0%)	6212 (4%)	60 (0%)	25 (0%)
Vegetables	1243 (2%)	3201 (2%)	604 (1%)	786 (4%)
Other	2580 (4%)	18730 (11%)	3626 (6%)	309 (2%)
Total (Ha)	58981 (100%)	176680 (100%)	60487 (100%)	18746 (100%)

2.4.5. Water Trading

There are two types of water trades that can be undertaken by regulated licences; trades in allocated water, known as temporary trades, and trades in entitlements, known as permanent trades. The historical volume of trade is shown in Figure 2-16, showing that the volume of permanent trades that occur is much lower than that for temporary trades.

Allocated water and licensed entitlement to water may both be traded throughout the valley without restriction, with the exception of trade into the Yanco Creek system. Entitlement may not be traded into the Yanco Creek system at present, and only allocated water may be traded into the Yanco Creek system. However, allocated water traded into the system does not affect shares of available flows during periods of restriction.

Intra valley Transfer of allocated water, known as temporary transfers, has applied since 1982/83. The trade in allocated water represents movements of significant volumes between river reaches each year, and this has resulted in significant changes to the distribution of water availability. Table 2-6 below, summarises the net effect of temporary trade to various sections of the regulated system. It can clearly be seen that the upper and lower sections of the Murrumbidgee River and the MIA typically sell water each year, and the middle reaches of the river, Coleambally and the Yanco Creek system typically buy water each year.

2.4.5.1 Inter valley

Allocated water or temporary trading was permitted between the Murray, Murrumbidgee and Lower Darling systems from 1991, and between Victoria and South Australia in 1994, subject to the following restrictions:

An upper limit of 100 GL to the volume required to be transferred from the Murrumbidgee valley to meet net outwards trade. The WSP has a note stating this is for operational (rather than policy) reasons.
There is a closing date of 31 January each year for the lodgement of inter-valley trade applications.
There are restrictions in other valleys, particularly the Lower Darling, related to physical supply constraints.

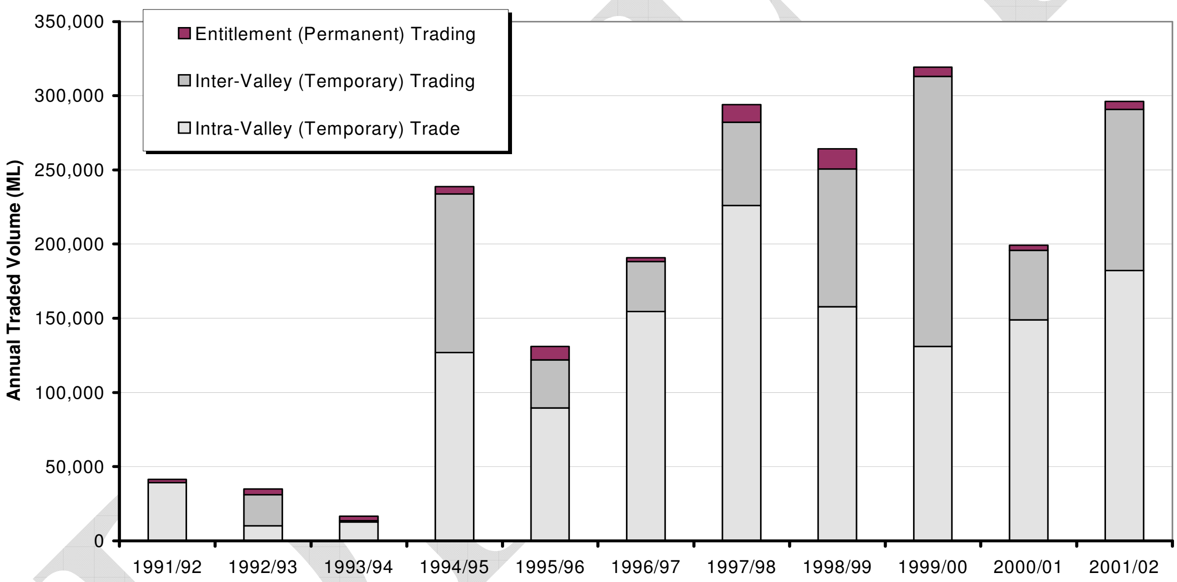


Figure 2-16 Murrumbidgee Valley Historical Trade

Table 2-6: Murrumbidgee Intra Valley Trade

	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03
MAIN RIVER													
Dams – Wagga	627	552	0	-12	-5,205	-3,673	-5,837	-11,794	-4,462	-6,965	-8,878	-9,791	-1,056
Wagga – Narrandera	852	-78	0	-699	129	-2,593	-3,656	-7,478	-3,964	-6,657	-10,118	-6,781	-970
MIA	0	-375	-3	1,077	-27,338	-28,554	-52,433	-97,800	-64,059	-41,802	-35,827	-54,166	-31,933
CIA	0	0	0	0	-2,121	3,052	16,100	11,850	9,732	11,178	9,447	14,175	443
Narrandera - Darlington Point	-6	-8,960	0	-1,065	-4,721	-9,261	-8,546	-5,147	-6,471	-3,529	-1,530	-5,247	2,607
Darlington Point - Maude	-594	15,554	2,884	5,565	44,501	40,935	52,949	95,451	52,964	28,941	32,542	51,558	30,131
Maude - Murray	0	2,805	-1,015	-1,750	-3,480	-5,287	-6,470	-7,160	-3,521	-6,644	-6,500	-3,826	-1,149
Main River Misc.	0	0	3	0	-268	0	-468	-421	-121	-460	0	-200	0
YANCO CREEK SYSTEM													
Yanco Creek	-879	-4,688	-60	6	-4,966	2,597	9,142	13,999	11,323	14,843	9,706	4,670	-2,355
Colombo Creek	-1,000	-1,794	-2,547	-700	-1,052	1,946	1,429	4,844	4,099	2,583	6,802	1,872	3,538
Billabong Creek	1,000	-3,666	88	-3,922	1,561	-1,792	-2,135	239	849	8,253	1,402	5,656	98
Forest Creek & Misc	0	650	650	1,500	2,960	2,630	-75	3,418	3,630	259	2,954	2,080	646

Note: +ve = net inwards trade.

2.5. TOWN WATER SUPPLY

Town water supplies (TWS) are high security entitlements and there is approximately 45 GL of these entitlements in the valley. This includes water supplies for most of the major towns within the Murrumbidgee Valley including Gundagai, Cootamundra, Junee, Narrandera, Leeton, Griffith, Jerilderie, Hay and Balranald. TWS licences are not currently embargoed, and may apply for additional entitlements to meet the needs of increasing population levels. TWS licences, however, may not engage in trade of allocated water or entitlements. Overall, towns, industries, stock and rural households only account for around 2% of consumptive use in the valley.

Table 2-7 Historical Town Water Supply Usage In Megalitres

Town	High Security	General Security	Total	Average Use	
				91/2 - 95/6	97/8 - 02/3
Tumut Shire Council (Tumut+Brungle)	2295	0	2295	1287	1606
Gundagai	1309	38	1347	525	641
Wagga Council + Riverina Water (Wagga)	7025	176	7201	2964	2079
Riverina Water (Morundah & Urana)	1009	0	1009	767	544
Narrandera	2000	0	2000	0	0
MIA (Leeton & Griffith)	19769	972	20741	**	*
Murrumbidgee Shire Council (Darlington Point)	5	0	5		
Carrathool	5	0	5		
Hay	2805	140	2945	1021	2018
Balranald	1300	0	1300	806	1191
Jerilderie	525	226	751	380	416
Goldenfields Water	5590	0	5590	2786	4503
TOTAL	53965	1728	55693	15553	17225

* Nearly fully utilised as part of bulk licence

** No data available

TWS are less variable than irrigation and are influenced by factors other than just climate. Consequently TWS has not been modelled in detail in the Murrumbidgee IQQM and is represented as a fixed annual demand with a monthly pattern of use.

In the regulated sections of the Murrumbidgee and Tumut Rivers, twleve significant towns were identified and modelled. The towns are Jugiong, Tumut, Gundagai, Wagga Wagga, Griffith and Yenda, Darlington Point, Carrathool, Hay, Balranald, Morundah and Urana, and Jerilderie, and they have a combined high security annual entitlement of 39 GL

2.6. STOCK AND DOMESTIC REQUIREMENTS

There are around 1,500 high security licenses for stock watering and domestic supply (S&D) purposes with a total approximately 36 GL of such entitlements in the valley. The four largest licences account for almost 20 GL of entitlement, and about three quarters of the licences are for small volumes (10 ML or less). For modelling purposes there would be ideally two types of S&D licences. (1) The large number of smaller S&D licences that are mostly held by general security irrigators and whose S&D entitlement is part of a pool of entitlement, and (2) larger S&D licences use by stock and domestic schemes who have no other entitlement. Such a differentiation has not been attempted and implicitly all S&D entitlement has been treated as part of a resource pool of entitlement.

Diversions by S&D licences held by general security irrigators are not recorded specifically and are incorporated into the general security irrigation diversions data.

2.7. INDUSTRIAL AND MINING EXTRACTIONS

Industrial and mining licences are high security entitlements and there is approximately 8 GL of such entitlements in the valley. These demands are considered to be small and are lumped into the general resource pool for irrigation.

2.8. GROUNDWATER ACCESS

In the Murrumbidgee Valley, there are approximately 500 high yielding bores (approximately 290 in the mid Murrumbidgee alluvium, and 210 licences in the lower Murrumbidgee alluvium) for irrigation, industrial and town water supplies, which are all metered. In addition there are a large number of small stock and domestic bores throughout the valley that are unmetered, many of which are unlicensed (with no licence required). In the mid Murrumbidgee alluvium there are approximately 180 of these licenced S&D bores, and in the lower Murrumbidgee Alluvium, there are 377 S&D licensed bores. The estimated annual use of the licensed stock and domestic bores in the lower alluvium is 2 GL, with unlicensed use in this area estimated to be a further 2 GL/year.

In the mid-Murrumbidgee, there are groundwater entitlements of about 55 GL/year and extractions currently average between 30-40 GL/year. The majority of groundwater extraction in the Murrumbidgee Valley occurs in the lower Murrumbidgee alluvium where annual use has risen from around 40 GL/year in the mid 1980s, to around 100 GL/year in the early 1990s, and currently averages about 300 GL/year. Groundwater entitlements and usage from the mid and lower Murrumbidgee alluvium are presented in Table 2-8 In the mid-Murrumbidgee there is substantial potential for growth in groundwater use with the sustainable yield estimated to be somewhere around 90 GL. A precise figure will be established when the mid Murrumbidgee groundwater water sharing plan is completed.

Table 2-8 Mid Murrumbidgee Groundwater Entitlement and Usage

Year	Entitlement (ML/year)	Usage (ML/Year)	Year	Entitlement (ML/year)	Usage (ML/Year)
1982/83	124,639	40,063	1994/95	325,000	148,592
1983/84	147,472	24,516	1995/96	330,000	137,843
1984/85	165,059	33,844	1996/97	372,000	161,850
1985/86	174,823	42,712	1997/98	470,000	240,567
1986/87	192,913	58,734	1998/99	494,000	241,339
1987/88	192,964	84,509	1999/00	496,000	239,542
1988/89	201,680	64,355	2000/01	529,221	233,211
1989/90	208,798	77,141	2001/02	523,333	326,270
1990/91	211,300	96,923	2002/03	523,286	381,405
1991/92	220,800	121,126	2003/04	522,486	289,684
1992/93	229,400	82,102	2004/05	523.148	323,075
1993/94	230,300	94,903	2005/06	523,148?	240,000?

(ref: Prem B Kumar, Murrumbidgee Region DNR, December 2006) Groundwater is used primarily for irrigation purposes, particularly in the Darlington Point area, but also in the alluvial plain between Wagga Wagga and Narrandera. Overall the volumes of groundwater available are much smaller than the volumes of river water, and the irrigation supported is correspondingly smaller

In terms of groundwater the model assumes the following.

- Farms using groundwater only do not have any impact on surface resources.
- There is little concurrent usage of surface and groundwater outside CICL's area of operation.
- Crop area data available is for surface water sourced irrigation.

2.9. RESOURCE ASSESSMENT

Within regulated river systems all licences are issued with an entitlement volume. In any irrigation season, the amount of water available for general security irrigation is announced as a percentage of the annual entitlement volume, known as an allocation.

The allocation announcement is the result of a resource assessment process that takes into account the following:

- All available water resources at that time, water resources expected to become available for the remainder of the water year and essential requirements for high security supplies, environmental and other reserves and expected losses.

- The remaining resources are then declared available for general security irrigation use, expressed as a percentage of the total general security entitlement. The estimate of expected water resources is conservative and uses the driest recorded sequence to estimate expected additional resources. Losses for the remainder of the water year are based on highest recorded losses.

Some of the items used in the resource assessment process are subject to change over time for a variety of reasons. From time to time transmission losses expected under drought conditions may be reviewed, or contingency reserves for supply or environmental purposes may be reassessed.

The allocation assessments are made at the beginning of the water year (1st July for the Murrumbidgee Valley). The allocations may be updated, depending on the outcome of allocation calculations, which are undertaken on a monthly basis or whenever there is a significant change in water availability.
The historical allocation announcements for the Murrumbidgee Valley are presented in Figure 2-17 Historical Regulated Murrumbidgee Valley Allocation. These records show allocation levels of 100% or more were experienced 70% of the time.

Notes

- Carryover was introduced in the Murrumbidgee Valley in the season 1999/00, with carryover to 2000/01.

- By adding carryover to announced allocation for seasons 2000/01 and onwards, an equivalent percentage in terms of resource availability is obtained.

- The resource assessment procedure had a number of changes over the period graphed. This included a cap of 100% introduced in 1994/95, and an increased loss allowance. Thus the reduced allocation levels of the latter years are not only related to dryer conditions.

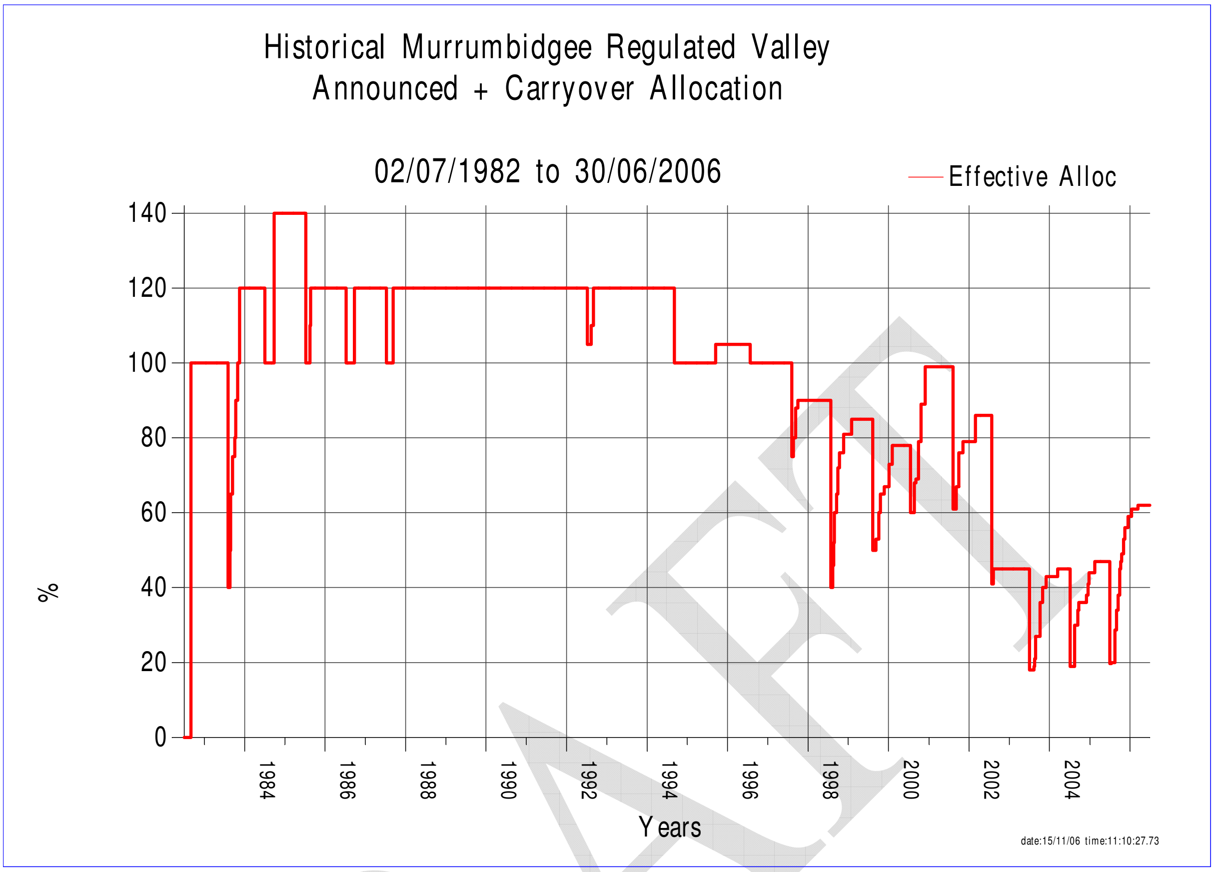


Figure 2-17 Historical Regulated Murrumbidgee Valley Allocation

2.10. RIVER AND STORAGE OPERATION

The Murrumbidgee River system is operated to ensure that maximum conservation of resource is achieved during regulated operation, and that flows in excess of the target at the end of the system are kept to a minimum.

During regulated river operation, requirements for water releases from storage are assessed each day and releases made from the major storages accordingly. This daily process, now managed by State Water, involves daily assessment of changes in flows between flow gauges along the river, corresponding to tributary inflows, losses, etc, and forecasting of trends in these flow differences.

2.10.1. Tributary utilisation

When making releases from storage to satisfy consumptive requirements, the river operator forecasts what flow contributions can be expected from downstream tributaries to meet orders, and adjusts the releases from the major storage(s) accordingly. In practice, a range of factors influence the river operator's decision, including recent rainfall and the most recently observed inflows from the various downstream tributaries.

2.10.2. Operational surpluses

During normal regulated operations, flows in excess of requirements at the end of the regulated river system usually occur as a result of the following:

- Tributary inflows below the storage exceeding forecasts;
- Rainfall on crops reducing extraction of ordered water in transit; and
- Errors in forecasting system requirements.

During high flow periods, when there is usually more rainfall, these effects are magnified, and operational surpluses are expected to be higher than in dry periods. Observed operational surplus flows, expressed as a percentage of the total flow in the system (usually taken as the flow passing Gundagai), are shown in Table 2-9 Historical Operational Surplus Murrumbidgee Operational Surpluses

Table 2-9 Historical Operational Surplus

Year	Operational Surplus (% of Gundagai Flows)
1979/80	12.7%
1980/81	2.2%
1981/82	4.2%
1982/83	0.4%
1984/85	1.2%
1985/86	0.8%
1986/87	0.1%
1987/88	6.0%
1989/90	4.5%
1990/91	3.8%
1991/92	2.9%
1993/94	12.0%
1994/95	2.7%
1995/96	7.3%
1996/97	3.8%
1997/98	2.7%

Note: some years were sufficiently wet that there was not a long enough period of regulated flows for an assessment of operational surplus to be performed.

2.10.3. Storage operating rules

The Murrumbidgee River is regulated downstream of Burrinjuck and Blowering Dams, with all of the regulated sections of the Murrumbidgee River, Tumut River and the YCB system ordering from these dams. Burrinjuck and Blowering Dams are operated conjunctively to supply water needs along these river sections.

To maximise conservation of water, releases from Blowering and Burrinjuck storages are managed to ensure that both storages maintain a similar probability of spill. On a monthly basis, forecasts are made of inflows and demand under various climatic conditions. If such forecasts indicate that one storage is more likely to spill than another, releases will be made preferentially from that storage.

Channel capacity constraints in the Tumut River may, from time to time, produce shortfalls in supply when a significant proportion of dam available water is stored at Blowering Dam. This effect is magnified by lower allocations, when water users tend to use a greater percentage of the available water during the summer period.

2.10.4. Flood mitigation releases

All major storages are operated during floods to ensure the safety of the structure by ensuring releases remain within the spillways and do not overtop dam walls. Storages are operated to minimise flooding consistent with ensuring structure safety. For dams with gated spillways, such as Burrinjuck storage, a procedure has been developed for gate operation to achieve maximum flood peak reduction consistent with structural safety, and taking account of downstream flood inflows to the river from tributaries. Historical records indicate that flood events at Burrinjuck have been contained in the storage on occasion, and significant reductions of the peak inflows are usually achieved.

Blowering Dam has a simple un-gated overflow spillway, and flood operations only require that no deliberate releases be made through other outlets that might exacerbate downstream flooding. Since the completion of Blowering in 1968 spillway releases have only occurred on one occasion, during 1992.

Both Burrinjuck and Blowering Dams are operated to maintain airspace. For Burrinjuck storage, a variable airspace police is followed, where the dam is drawn down during the winter/spring period to maximise possible flood mitigation effects during that period, with the proviso that assured inflows, based on historical records, will refill the storage for the start of the irrigation season.

Until the corporatisation of the Snowy Scheme in 2002, Blowering Dam had been operated to a fixed airspace of 190 GL, representing 12% of Blowering Dam’s storage capacity. This airspace allowed emergency power generation over a short time, using the active storage in Talbingo reservoir upstream of Blowering Dam. Whenever forecasts of storage levels indicated an intrusion into this fixed airspace under drought conditions (later under 75% exceedance inflow conditions), pre-releases would be made to ensure that the storage level just reached the airspace limit prior to the onset of irrigation demand. The Scheme maintains a reserve for payback of such releases where the storage did not subsequently refill. The reserve could be called upon for irrigation supply whenever the combined Blowering and Burrinjuck storage levels fell below 300 GL. Since corporatisation, Snowy Hydro may nominate any volume of airspace to be maintained, up to the previous limit of 190 GL

2.11. SURPLUS FLOW ACCESS

2.11.1. Regulated Licences

Off-allocation periods (now known as supplementary access periods) are announced in the Murrumbidgee River Valley downstream of Burrinjuck and Blowering Dams when flows are in excess of demands (surplus flows). Surplus flows may comprise operational excess flows, tributary inflows and flood or pre-releases from Blowering and Burrinjuck Dams that cannot be re-regulated for future use. During periods where off-allocation has been declared, diversions may be made without debit against allocations, and diverted into the Lowbidgee district to provide beneficial flooding.

Detailed records of historical off allocation extraction volumes were not readily available. What was available were operational annual totals of off-allocation use, and the off allocation announcement periods, for each river reach. Announcements for access to off allocation water are generally made on a reach by reach basis, depending on the amount of surplus flow available and the access that each reach has previously received in the water year.

When flows are determined to be excess to all known regulated requirements within the Murrumbidgee valley, off-allocation access to these flows is shared according to the following hierarchy of access for user groups:

- Murrumbidgee Regulated Water Users, then
- NSW Murray Regulated Water Users, then
- Lowbidgee District.

When each user group is deemed to have a generally "satisfactory" level of access to water in any year, the next user down in the hierarchy may also have access. The Murrumbidgee WSP formulates this with an announced Murrumbidgee general security allocation (excluding carryover) of 70% deemed to constitute "satisfactory" for user group(1) and a 60% Murray general security effective allocation (including carryover) deemed satisfactory for user group (2).

2.11.2. Supplementary Access (Off-Allocation) Quotas

In 1996, a system of annual off-allocation quotas was introduced, based on past reliance on supplementary or off-allocation diversions. A year earlier, an upper limit of 100% had been placed on general security allocations in all NSW valleys, as part of COAG reforms and Cap management actions. Users who had both a history of usage above 100% and of off-allocation diversions were allocated a quota of off-allocation access. These quotas were limited to the maximum of off-allocation access up to the announced allocation in any year between 1991/92 and 1995/96.

This resulted in 440 GL of off-allocation quotas being allocated.

This was subsequently reduced to 70% of 440GL in 1997/98 and to 50% of 440 GL in 1999/00% .In 2004/05, supplementary licences were issues as part of the Murrumbidgee WSP. These replaced the previous quota system. Converted licences equalled 155 GL and additionally with the conversion of high flow licences, the total volume of supplementary licences became178 GL.

Before 2004/05 users could only access off-allocation up to the limit of their quota in any year. From However, a general exception to this rule was made whenever general security allocations fell below 70%, when quotas didn't apply. Off-allocation accessed under these arrangements progressively becomes accounted as on-allocation diversions as the combination of off-allocation use and the announced allocation exceed 85%.

Previous to 1996 and hence defining cap conditions there was no limit on off allocation diversions.

From the commencement of the Murrumbidgee WSP, separate licences meant that usage under general access provisional was treated completely independently from usage with the Supplementary licence.

2.11.3. Lowbidgee

The Lowbidgee district receives the vast bulk of its water during periods of supplementary flows. Water can be diverted to the Lowbidgee district if the hierarchy of access in section 2.11.1 allows it to do so. As the Lowbidgee district is the only user group whose physical location is higher than their order of access (being “above” the NSW Murray system in hydrologic terms for Murrumbidgee River flows), this group will, from time to time, be denied access to off-allocation/supplementary flows when NSW Murray regulated users do not have a “satisfactory” level of water availability. Such denial of access is, however, only to the extent that such flows can be re-regulated for the benefit of NSW Murray users in Lake Victoria. If the probability of spill from Lake Victoria exceeds 75%, Lowbidgee is permitted to divert any supplementary flows that it is able to.

Such hierarchical sharing of access to excess flows first impacted the Lowbidgee user group in the 1999/00 water year. Previously, allocation levels had not fallen below the thresholds currently considered to represent satisfactory levels of water availability. However, it is the belief of DNR that the hierarchical sharing would have occurred in 1993/94, had circumstances dictated the need to implement it.

Small surplus flows are difficult to share across users in the regulated Murrumbidgee system and, if there have not been any such flows for more than 6-12 months, these flows were often made available to Lowbidgee ahead of regulated users, for stock & domestic purposes and for inundation of floodways for environmental benefit. Prior to channelisation of the floodways within Lowbidgee during the 1990s, up to 50 GL was required to satisfy these requirements. Currently, less than 20 GL is required to satisfy these requirements.

2.11.4. High Flow Licences

In 1993/94 and up until the commencement of the WSP there were a small number (69) of Special Additional Licences (i.e. additional to existing general security licences), also known as high flow licences, which may divert water from the Murrumbidgee River when flows exceed a particular flow level. Most of these licences were permitted to extract water when flows exceed 3.84m at the Hay Weir gauge, which currently equates to approximately 6,600 ML/day.

The flow trigger set for those licences was such that all diversions occurred during periods of off-allocation. As there was no effective difference between off-allocation access by the base (general security) licence and access by the Special Additional Licence, diversions have generally been recorded as off-allocation diversions against the general security licence until 1996.

With the implementation of the WSP, these licences were converted to 23 GL of supplementary licences.

2.12. RIVER FLOW REQUIREMENTS

2.12.1. Minimum flow

Between 1979 and 2004, a number of significant changes to operational and environmental flow rules were made that are described in this section.

2.12.1.1 Downstream Burrinjuck Dam

There is a minimum release requirement at Burrinjuck for riparian and environmental requirements above the Tumut River confluence. To prevent damage to outlets from cavitation, the minimum release that is currently operationally possible from the lower level valves at Burrinjuck Dam is one valve at 10% of capacity, which is

300 ML/day. In 1993/94 that was the minimum release requirement. The requirement increased in 1998 with the introduction of transparency and translucency release rules.

2.12.1.2 Downstream Blowering Dam

Until 1993/94, a minimum release from Blowering Dam of 100 ML/d was required, which was for riparian and environmental requirements. During 1993/94 the practice of releasing a minimum of 565 ML/day came into practice but was again abandoned in 1994/95 presumably because of a tighter resource situation. It seems reasonable to assume that under Cap conditions and with any scarcity, the minimum release would be 100 ML/d. Since whatever is assumed in “years of plenty” has little bearing on diversions, the model always assumes a minimum release of 100 Ml/d.

2.12.1.3 Balranald

Up to 1979, a target flow of around 780 ML/day was maintained at Balranald during periods of regulated flow. Following the construction of Balranald Weir, this was reduced to 125 ML/day and remained that way until 1995. In 1995 this was increased to 300 ML/day as a first step action towards maintaining the (then) recently announced MDBMC Cap on diversions, and as an initial step towards addressing environmental concerns. In 1998, along with a range of environmental flow rule initiatives, the minimum flow target at Balranald was decreased to 200 ML/d for allocations less than 80%, but remained at 300ML/d for allocations of 80% or greater. In 2008/09 the Murrumbidgee WSP calls for further changes to the end of system target. Detailed numbers are included in the schedules of the WSP but the target will increase in certain months.

2.12.1.4 Darlot

An operational minimum flow at Darlot of 50ML/d is maintained in addition to known user requirements between Darlot the Billabong Creek’s confluence with the Edward River.

2.12.1.5 Forest Creek

The Forest Creek system receives flows for replenishment purposes, which are measured at Warriston Weir. This flow is not for regulated licence holders and is provided for stock and domestic users who had a history of receiving flows under the previous Yanco Water Trust management. Investigations in the 1970’s indicated that only a volume of around 25 GL during the winter months was practicable for stock and domestic purposes, due to excessive weed growth. During the 1980s, it became the practice to provide 100 ML/day for the entire year, representing an annual volume of 36 GL. It remained the practice until 2005/06. This practice was formally recognised under the Murrumbidgee Water Sharing Plan in 2004. In 2005/06 as part of Snowy saving work the target was reduced to 80 ML/d in summer and 60 ML/d in winter and in 2006/07 reduced to zero..

2.12.2. Wetlands and Replenishment Flow

No formal allowance is currently made in the Murrumbidgee for replenishing flows, other than for the Forest Creek system. However, there are requirements for watering wetlands within Lowbidgee (Tier 1b only behind Stock & Domestic in priority) as a priority ahead of general flooding for agricultural benefit.

2.12.3. History of the valley

Understanding the history of the valley is important for an appreciation of trends that impact on the model's calibration and ultimately its robustness. Events like the commencement of the CIA and the consequent rising water tables and the deregulation of rice growing have had a significant impact on crop mixes and irrigation application rates. The following sections describe these major events in the valley.

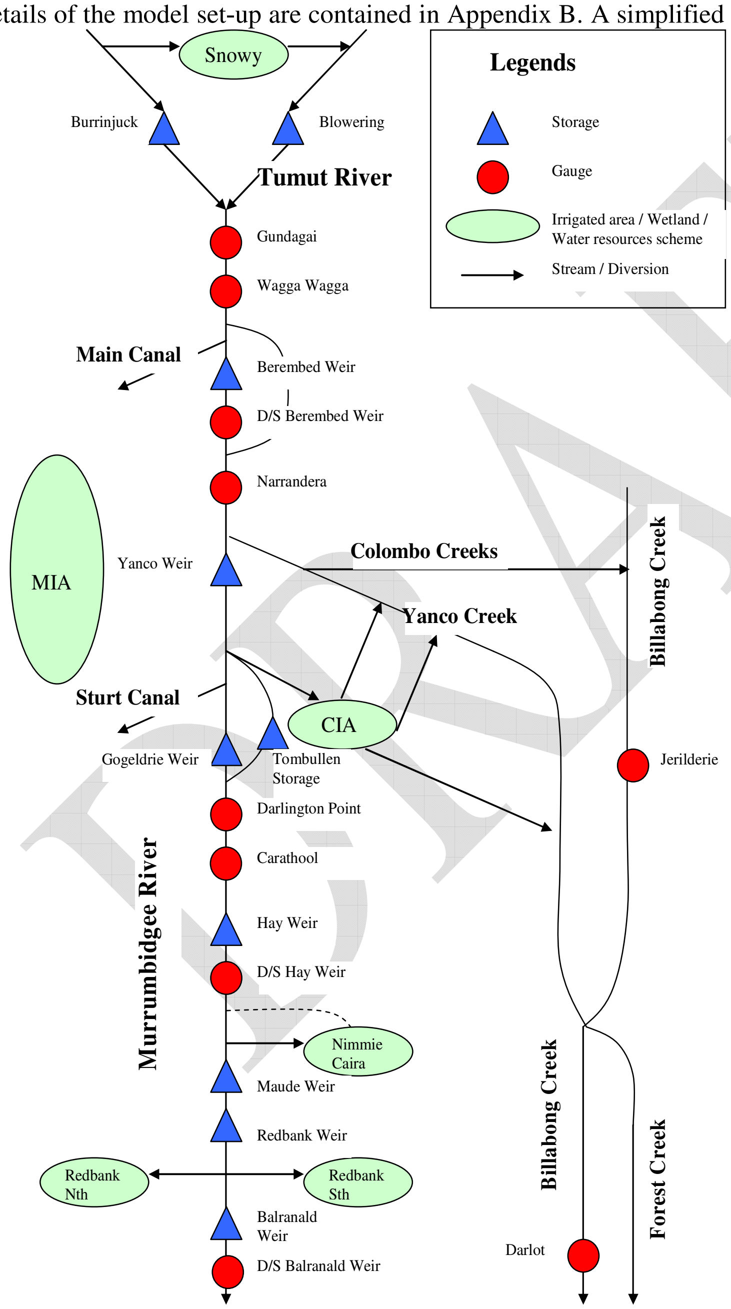
2.12.3.1 1850 to 2004

Year	Event
1840	European discovery of Edward River by John Webster and James McLaurin
1855-1902	Opening of Yanco Creek deepened by 1.2 to 1.5 m to increase diversions from the Murrumbidgee River. Previously Yanco creek was only a high flow effluent of the Murrumbidgee River flowing only when the Murrumbidgee flows exceeded 40,000ML/d (4% of the time). Numerous weirs were constructed in the YCB to rain water when flows ceased.
1884	A proposal to divert the waters of the Snowy River into the Murrumbidgee River came under notice
1896-1897	Large scale irrigation projects recommended by Colonel Home
1906	The Barren Jack Dam (subsequently renamed Burrinjuck Dam) and the Murrumbidgee Canal Construction Act passed by the NSW Government.
1906-1912	Work covered by the 1906 Act commenced and got to an advance stage whereby on the 13th July,
1912	The first irrigation water entered what is now called the MIA.
1907	Burrinjuck Dam Construction begun
1912	Burrinjuck Dam Operational
1919	Berembed Weir constructed
1923	NSW Government announces the commencement of the construction of Yanco Weir
1924	The irrigation area had grown to 47670 Hectares and the towns of Griffith and leeton were rapidly assuming prominence amongst the country towns of the State.
1926 Burrinjuck Dam completed.	Burrinjuck Dam completed.
1928	Completion of construction of Yanco Weir
1940	Maude and Redbank Weirs construction completed
1949 Commencement of construction of Snowy Scheme	
1956	Burrinjuck Dam strengthened and enlarged to present capacity
1958-1970	The Coleambally Irrigation Area (CIA) was established between 1958 and 1970 when the then Water Conservation and Irrigation Commission resumed a number of large pastoral holdings to make use of water diverted westward as a result of the Snowy Mountains Hydro-Electric Scheme.
1959	Gogelderie Weir constructed.
1969	Blowering Dam Completed
1974	Completion of construction of Snowy Scheme
1976-1980	Berembed Weir reconstructed
1979	Balranald Weir construction completed
1980	Tombullen off river storage construction completed
1980	Hay Weir construction completed
1988	Rice Deregulated on the Murrumbidgee River and Yanco, Colombo, Billabong and Forest Creeks
1997	MI and CICL come into being as privatised entities
2002	Signing of the Snowy Water Inquiry Outcomes Implementation Deed
2004	In July 2004 the management of the regulated Murrumbidgee Valley came under the Water Management Act 2000 and the Water Sharing Plan for the Murrumbidgee River Regulated Water Source 2003

3. Model Calibration and Validation

3.1. MODEL CONFIGURATION

An IQQM for the Murrumbidgee system was configured for the data and for the system described in Chapter 2. The number and types of nodes and links were selected in accordance with the aims of the modelling detailed in Section 1.2. A model containing about 500 nodes and about 50 links with hydrologic routing was adopted. Details of the model set-up are contained in Appendix B. A simplified schematic of the system appears in Figure



3-1

Figure 3-1 Simplified Schematic of Murrumbidgee Valley System

The sections below describe the functional sub-units of the model, the calibration procedure, calibrated parameters and the final validation model results.

3.1.1. Dam inflows

Inflows for Burrinjuck Dam were obtained from water balance calculations (‘backcalc”) from 1912, based on records at Burrinjuck Dam. Prior to that they were estimated using derived relationships with post 1912 observed Gundagai and Wagga Wagga flows. For Blowering Dam inflows were obtained from a Snowy Scheme Model for the period 1905 to 1974. From 1974 they were obtained from water balance calculations, based on records at Blowering Dam. Pre 1905 they are based on a relationship with Wagga and Tumut observed flows.

3.1.2. Streamflow

In the model calibration phase, streamflow data is required for all main-stream and tributary inflow gauging stations represented in the model. The main-stream gauging stations are used to derive (calibrate) tabular flow loss relationships and, Laurenson flow routing parameters for each river reach defined by upstream and downstream gauges. The historical observed tributary inflows are used to achieve mass balance within each river reach, to model extended sequences of tributary inflows, and as an input to the cap scenario, cap audit and other scenario models.

An extensive network of main-stream gauging stations measures the flows in the Murrumbidgee Valley. The following criteria were used to select an appropriate sub-set for calibration of main-stream flows:

- Sufficient sites to limit the length of river reaches represented;
- sites upstream and downstream of key features such as tributary inflows and off-takes to affluent streams or irrigation channels;
- sites with good quality, high availability (limited durations of missing) data for the intended calibration period,

There were also a number of tributary gauging stations measuring inflow contributions downstream of Burrinjuck and Blowering Dams. The following criteria were used to select an appropriate sub-set to represent the tributary flow contributions: *Inflow contributions not meeting the criteria were lumped into residual areas.*

- Long good quality record representing the most downstream gauge on a tributary or that could be used to estimate the most downstream gauge when its records are missing.
- Sites with good quality, high availability (limited durations of missing) data for the intended calibration period;
- Significance of the flow contribution from that catchment relative to the residual catchment draining between the gauge and the confluence with the main river,
- Sites with good quality records to cover the intended calibration period and long term simulation period, with a minimum number of missing periods.

Ungauged catchments’ contribution was estimated during flow calibration using simple relationships with gauged flows (see also list of improvements in Chapter 5)

3.1.3. Rainfall

Rainfall data is used in the Murrumbidgee IQQM model to drive the irrigation soil moisture accounting, for computing the contribution of rain falling onto the surface of reservoirs and river reaches and finally to approximate major irrigation canal off-take rain rejections. Rainfall data is also used for generating and extending historical tributary inflows using Sacramento rainfall-runoff modelling

Of the available rainfall stations in the valley, the following criteria were used to select an appropriate sub-set for use in the Murrumbidgee IQQM:

- adequate representation of spatial variability of the rainfall;
- availability of long term records to cover not just the intended calibration period, but also the intended long term simulation period;
- continuity and quality of data; a

Based on these criteria, rainfall stations were used to represent the spatial rainfall distribution to drive the crop water requirements, as listed in Table A-7. The data for these stations was downloaded from the Bureau of Meteorology's (BOM) databases pre 1 July 1997 and the SILO database from that date. This data has been gap-filled using regression relationships for data missing periods before 1 July, 1997. From that date SILO gap filling generated data is used..

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3.1.4. Evaporation

Pan evaporation data is used in the Murrumbidgee IQQM for modelling evaporation losses from river reaches and the evaporation/evapotranspiration processes in the Sacramento rainfall-runoff models. Of the available evaporation stations in the valley, the following criteria were used to select an appropriate sub-set for use in the Murrumbidgee IQQM:

- adequate representation of spatial variability of evaporation;
- availability of long term records to cover not just the calibration period, but also as much of the intended long term modelling period as possible. It should be noted that daily Class A pan evaporation data has only been systematically recorded since 1970. Therefore, there are very few sites that have a longer period of record than that;
- continuity and quality of data
- availability of a nearby rainfall site that could be used to generate long term evaporation data for use in model simulation. (*a standard IQQM generation technique is to derive monthly regression relationships between evaporation in a month and rain days in a month*).

Based on these criteria, 3 weather stations were used to represent the spatial evaporation distribution in the Murrumbidgee IQQM model.

3.1.5. Evapotranspiration (ETo)

CSIRO has a long term weather station located at Griffith. The weather data collected at that site (radiation, cloud cover, humidity, rainfall etc) allows for the estimation of Penmann Monteith ETo (*standard crop potential evapotranspiration*). The generated ETo data represents the best available dataset for estimating crop water requirement and is used for that purpose for all irrigation represented in the model. Some correction for spatial variation has been carried out using special SILO ETo data.

3.1.6. MIA & CIA

The representation of the MIA was based on the Barren Box Swamp (BBS) model developed by DWR (Water Studies 1990). That model development followed flood events that indicated that BBS was at risk in large floods. Also model development was initiated to aid the planning of drainage for the Benerembah District. The reader is directed to Water Studies 1990 for further detail on the basis of the model structural break-up of the MIA. However in simple terms the break up is based along drainage lines i.e. areas are differentiated on the basis of which major drain or drain segment they contribute to. The break up is also based on which area or district a sub-area belongs i.e. which of Yanco, Mirrool, Benerembah, Tabbitah or Wah Wah. The latter also matches cropping area data availability, which in certain periods was reported down to a resolution of area or district.

Data for diversions from the Murrumbidgee River into the MIA (Sturt Canal offtake and Main Canal flows downstream of Bundigerry storage) are available for the entire calibration period. Farm gate deliveries are also available. The delivery data is further broken into general and high security farms. The latter, at least until the latter 1990s was only related to cropping of citrus, vine and vegetables. In more recent years high security entitlement has been used for more diverse cropping even including rice growing.

The CIA was also structurally broken down along drainage lines. The CIA unlike the MIA does not have areas or districts within it. So the model break up was based on whether farms contributed to the southern drain (DC800) or the western drain (outfall drain). As for the MIA, modelled flows in the CIA drains are resultant from rainfall-runoff on farm areas, overflows from the channel supply system and, drainage from farms carrying rain rejections and over orders. In addition the model generates orders (and consequently flows) from the Murrumbidgee River for the Coleambally Canal for the specific purpose of augmenting flows into the Yanco Creek. Such supplementary flows are required because the top end of the Yanco Creek has a channel capacity constraint that limits the ability to meet high summer demands within the Yanco Creek system.

Historical diversions data of flows into the Coleambally Canal, net of Tombullen inflows, are available for the entire calibration period. Continuous gauges monitoring drainage flow only commenced in the early 1990s. Some data of a lesser quality is available before that time.

Farm gate delivery data is available for the entire calibration period. There is no significant high security entitlement with the CIA and no separate delivery data is available for high security farm gates. Crop area data is available throughout the calibration period although it is incomplete in some years. No data is available at a finer resolution (like along drainage contribution zones) than total CIA. So the model can only be validated on a total CIA basis.

3.1.7. Licence, Diversions and Crop Area Data

Licence, diversion and crop area data for the Murrumbidgee Valley is held by the Department of Water and Energy (and its predecessor organisations) and State Water. The model requires such data aggregated to designated reaches or channels.

Licence data (class, entitlement volume, & pump capacity) is available from 1982/83. There are some doubts about the entitlement volumes for the river pumpers in the mid 1990s. License volume data from around year

2000 was actually used (for the pumpers) because it was more reliable and not much permanent trade had occurred in the intervening period Pump capacity data in general was also thought unreliable but because no on farm storages are represented, it is thought that this is a not significant issue.

Diversion data is available from the commencement of the calibration period in 1982/83. Off allocation diversion data (even for just the dates of off allocation periods) is available from only 1989/90.

The collection of crop area data has suffered from periods of discontinuity and non-standardised recording. Figure 3-2 gives a graphical picture of data availability and its quality for different groupings in the Murrumbidgee Valley. The distinction between “MI” & “MI Areas & Districts” shows when crop data is available only at an aggregated MIA level as opposed to data that goes down to an area & district level. The colour coding shows the quality of the data when available. Dark blue is the highest quality and is used for remote sensing rice data. Red is the lowest quality and is used to represent patchy (some missing) farmer survey data. It can be seen that MIA spatial crop data is only available for a very limited period. Similarly it can be seen that river pumper data basically stops in the mid 1990s. Finally and significantly given the size of the diversions they generate, other crop data for the MIA & CIA is missing for the period late 1980s to the late 1990s.

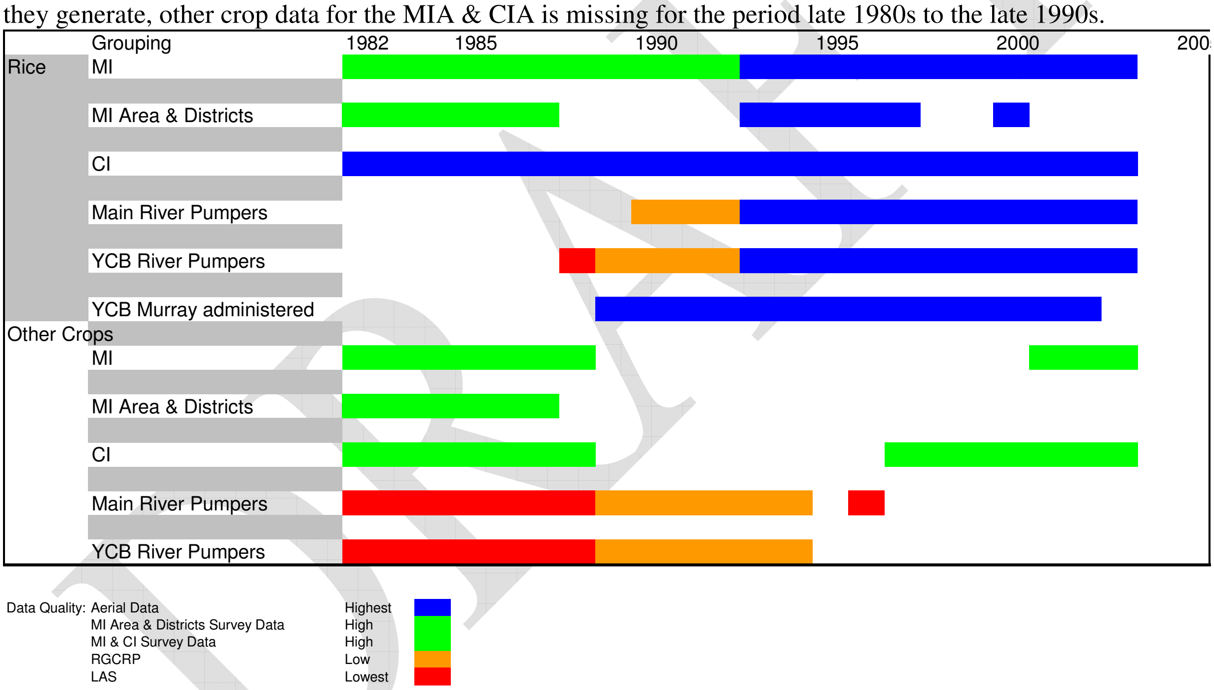

Figure 3-2 Regulated Murrumbidgee Valley Crop Area Data Availability

3.1.8. Lowbidgee

A thorough description of the Lowbidgee district can be found in Simpson (2001).

No systematic crop area data collections occurs with the Lowbidgee district. Simpson (2001) tabulates crop areas only for 1987/88 and 1997/98. Diversion "into the district" data is available from the commencement of the calibration period in 1982. Two regulators are located in the Maude Weir pool. The sum of flows in these regulators makes up the Maude Lowbidgee diversion. This is sometimes also referred to as the Nimmie-Caira diversion.

Four regulators and a few pipes in the Redbank Weir pool control flows into the Redbank forest system. Flow measurement of these is based on "once per day" height measurements taken by State Water. Diversions through these regulators have only been occasionally gauged, and are also often subject to variable backwater conditions, which further reduce the accuracy of diversion estimates. The total diverted flows are sometimes referred to as Redbank diversions.

Little or no flow measurement occurs within the district and certainly none in the calibration period.

The IQQM Lowbidgee part of the model is based on a simple empirical representation of district diversions. The model takes into account of available surplus, sharing of that surplus between the Maude and Redbank systems, environmental needs and the limited amount of access that can be accommodated in one year without major flooding occurring. The purpose of this sub-model is to simply represent diversions into the Lowbidgee district. No attempt is made to model internal flow processes beyond a crude estimate of return flows in high diversion years.

3.2. CALIBRATION OVERVIEW

Calibration of computer models involves the selection of processes that can and should be modelled and once selected, the variation of the parameters that represent those processes in the model until there is a satisfactorily reproduction of historical data over a selected period of time (*known as the calibration period*). IQQM is a complex model and there are a number of different parameters that are used to represent each process. For this reason, a calibration process has been developed to proceed sequentially, progressively eliminating unknowns. The sequential process historically adopted in most IQQM valley calibration involves four major steps. Each step estimates a specific set of parameters for the step, whilst forcing all other parameters to observed data. At the end of the four stage process, all the estimated parameters are brought together to see how well the overall model calibration reproduces historical information. The four steps are summarised below, with an indication of which parameters are calibrated during each one:

- Flow calibration - to reproduce the observed flow hydrographs at key locations, given observed storage releases, tributary inflows and water extractions. For this process, irrigation and other water extractions are fixed to those observed historically. Routing parameters and transmission losses are calibrated.
- Irrigation diversion (demand) calibration - to reproduce observed irrigation extractions from the river, given observed crop areas and crop mix. Crop factors and irrigation efficiency are calibrated.
- Area planting decision - calibrates an irrigator's decision making process to reproduce observed crop planted areas. Maximum and minimum area, crop mix and farmers planting decision process are the

parameters calibrated. During the Murrumbidgee calibration period over 1982-1995, allocations reached at least 100% in all years. So no explicit area calibration was carried out, other than to set the maximum planted areas. Instead anecdotal information and observations in the 2002-2007 post Cap drought was used to surmise risk functions.

- Storage calibration - to reproduce the observed volumes in the four major storages, throughout the calibration period. This involves calibration of the processes relating to irrigation ordering and river operation.

The selection of a calibration period was constrained by the availability of crop area data. Within this constraint, the calibration period was chosen to be representative of as wide a range of climatic conditions as possible and also representative of crop mixes like those seen in 1993/94. Rice deregulation occurred in 1988 and completely over-turned crop mixes to summer dominated. Crop mixes before that time carried less weight for the calibration because the activities (areas planted, usage & ordering) associated with them are less relevant for the Cap scenario. For river pumper diversions most weight in the calibration process was given to the 1990-1995 period. Crop data prior to 1983 was deemed not reliable and was not used for calibration.

The following periods were used for calibrating the different model components.

- Flow calibration – some differences depending on data availability, but within the range 1/7/1984 up to 30/06/2004. Main river calibration is for the entire range of the period. For the YCB system, with a number of new gauges being installed in the mid 1990s, calibrations were restricted by necessity to the post installation period. See Table A-5 for further detail
- Diversion calibration – from 1/7/1992 to 30/6/1995
- Crop area calibration could not be carried out due to the lack of allocation (resource) constrained years.
- Storage behaviour calibration – from 1/7/1982 to 30/6/1995
- Overall model validation – 1/7/1982 to 30/6/1995

Presented below is the replication achieved by the fully compiled model (except for crop areas that are forced to observed) after the completion of above mentioned calibration process.

3.3. FLOW REPLICATION

The match between observed and modelled flows is presented in this section. This is done for a selection of key sites from all the gauging station locations that were calibrated in the initial flow calibration.

The key sites selected are listed below along with the reason for the selection.

Wagga Wagga (410001) This site is upstream of most of the regulated demand and receives, after some transmission losses, most of the Murrumbidgee Valley catchment inflows. The only major inflows that don't contribute to Wagga Wagga flows are those of the Upper Billabong Ck and the ephemeral Bullenbung Creek that feeds Old Man Creek.

Narrandera (410005) This site is downstream of the main offtake into the MIA. It is also downstream of the return point of the Old Man Creek effluent. It is upstream of the offtake point into the YCB. In terms of groundwater it is the boundary between the mid and lower Murrumbidgee groundwater systems.

Yanco Creek offtake flows (410007). The gauge measures regulated flows into the YCB system.

Downstream/s Hay Weir (410136) The gauge is located downstream of most of the regulated irrigation demand. It is upstream of the Lowbidgee district which is the major user of unregulated flows, along with regulated supplementary users.

Balranald (410130) The end of system location for the Murrumbidgee river

Darlot (410134) The end of system for the YCB system.

Presented below are the calibration plots from the final calibrated assembled model (with forced areas) at the above gauge locations. The plots consist of time series match, flow duration match and annual flow match. Objective measures of the quality of model fit achieved are presented in Table 3-1 based on the quality assessment guidelines described in Appendix D (DLWC, 1999). The criteria adopted are those for *fully forced models* because no risk function is operating.

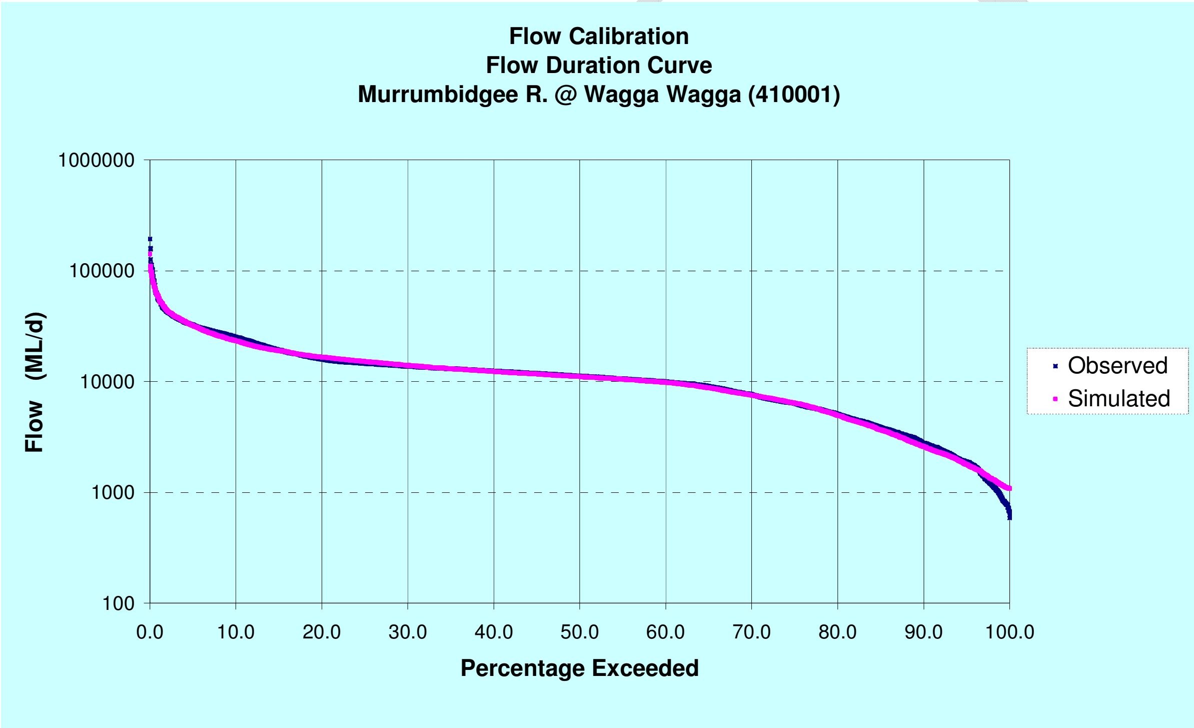

Figure 3-3 Simulated and Observed Flow Duration Curves for Wagga Wagga

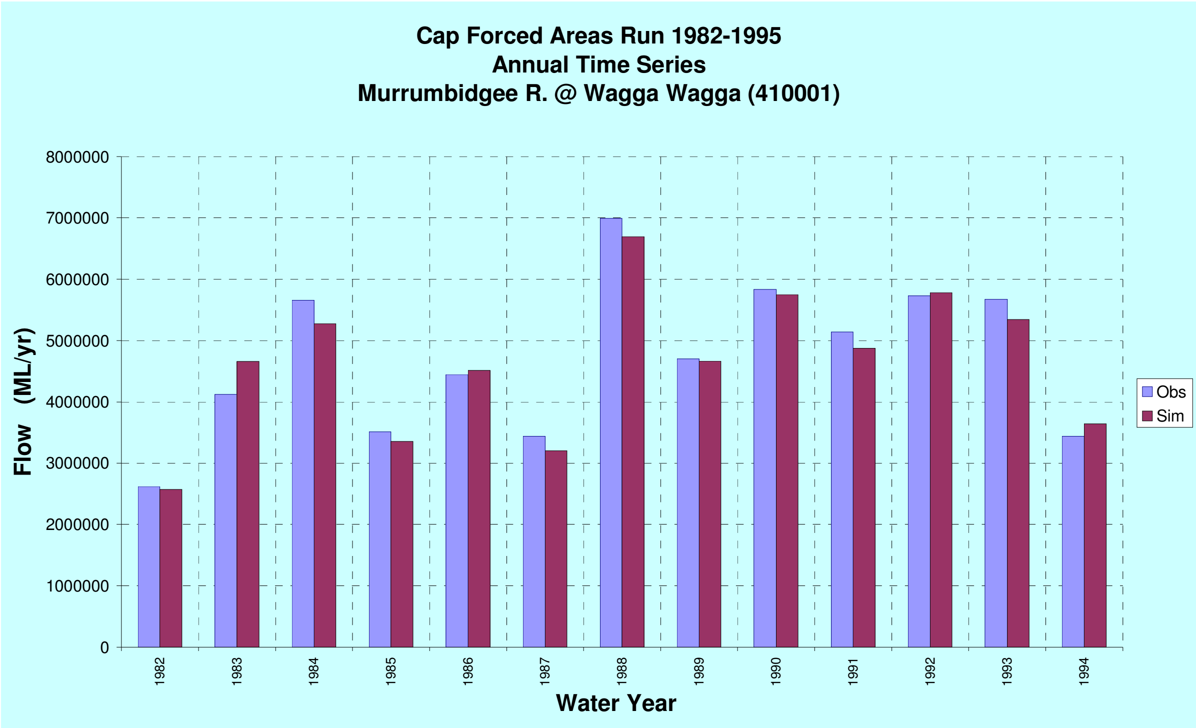

Figure 3-4 Simulated and Observed Annual Flows for Wagga Wagga

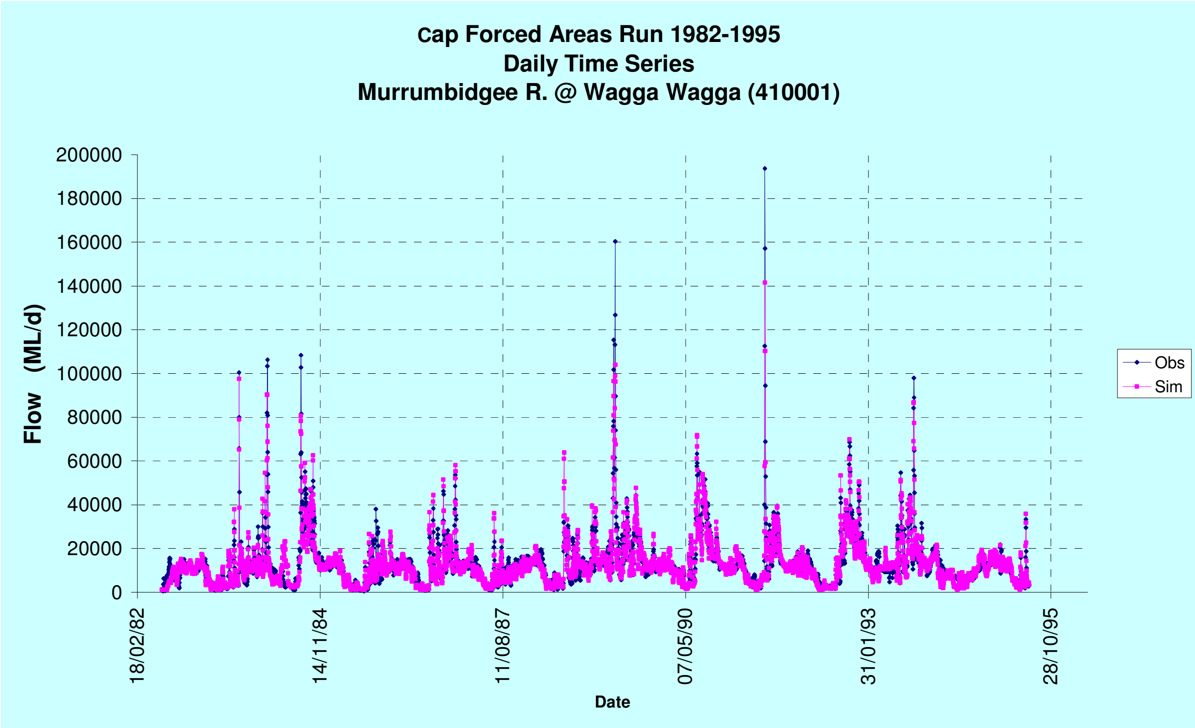

Figure 3-5 Simulated and Observed Time Series of Flows for Wagga Wagga

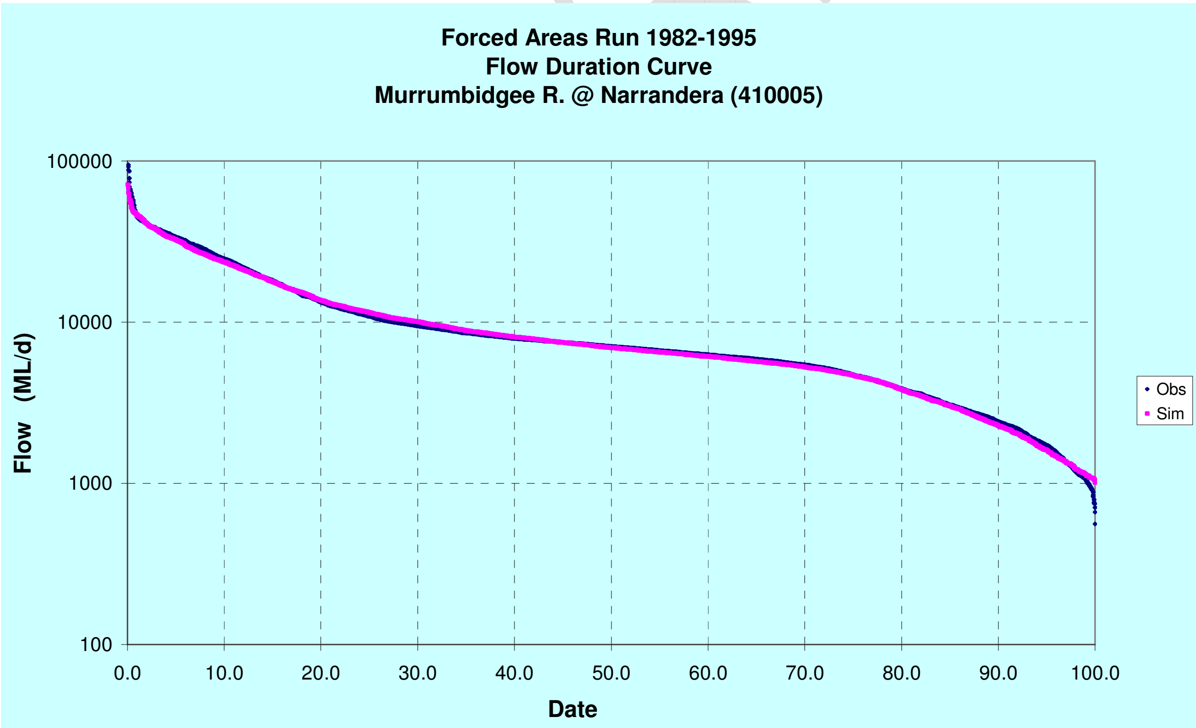

Figure 3-6 Simulated and Observed Flow Duration Curves for Narrandera

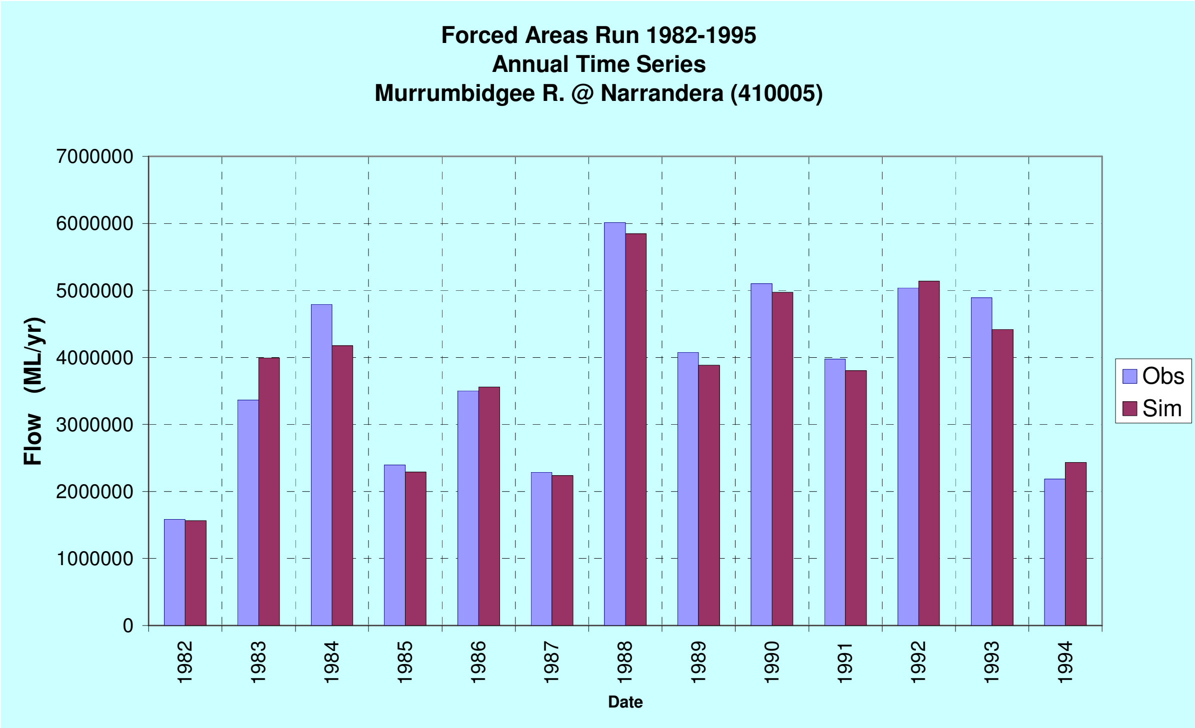

Figure 3-7 Simulated and Observed Annual Flows for Narrandera

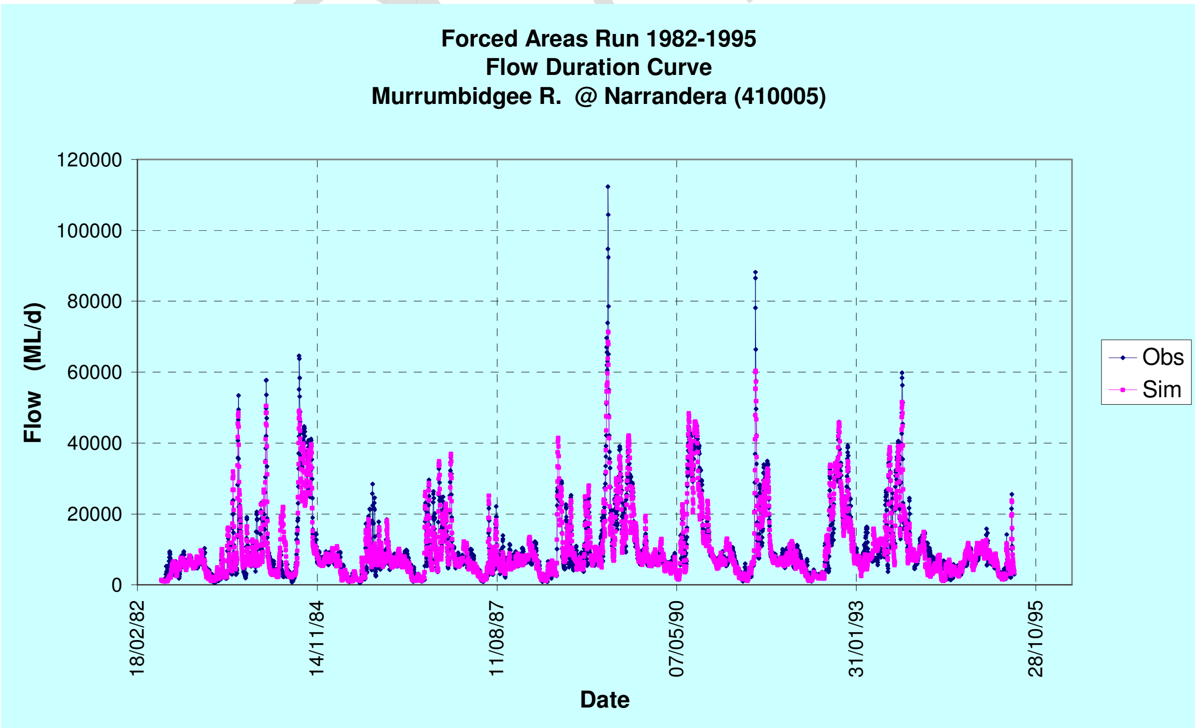

Figure 3-8 Simulated and Observed Time Series of Flows for Narrandera

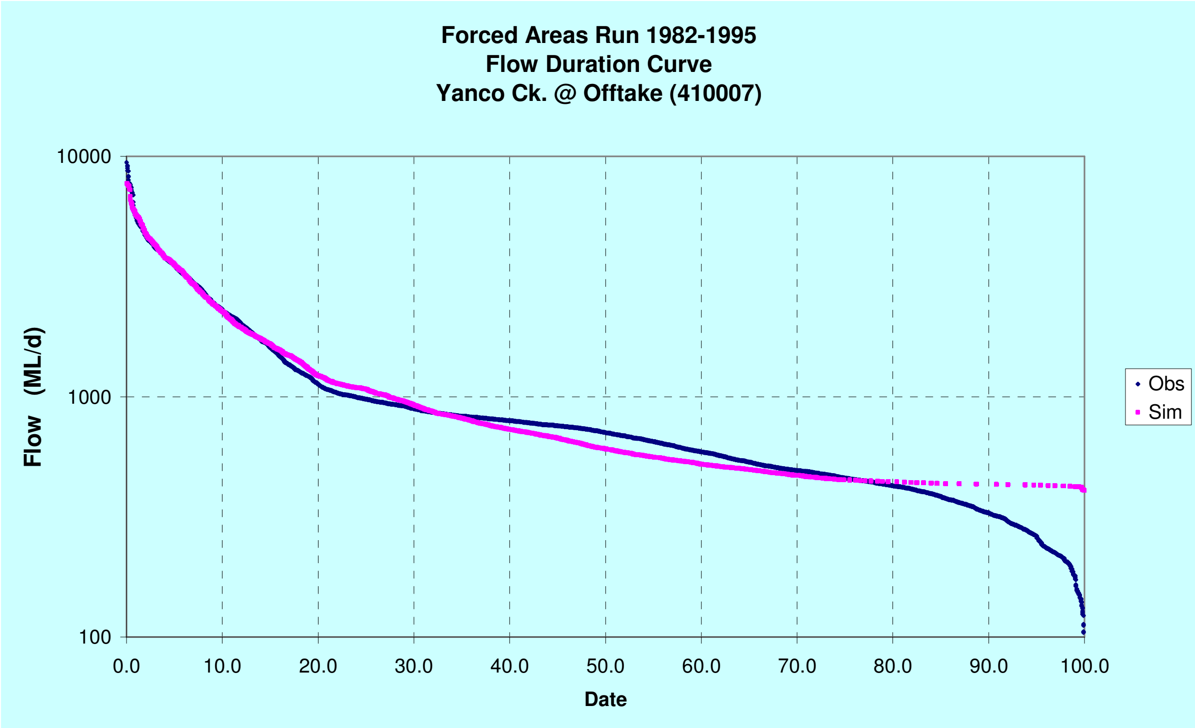

Figure 3-9 Simulated and Observed Flow Duration Curves for Yanco Ck Offtake

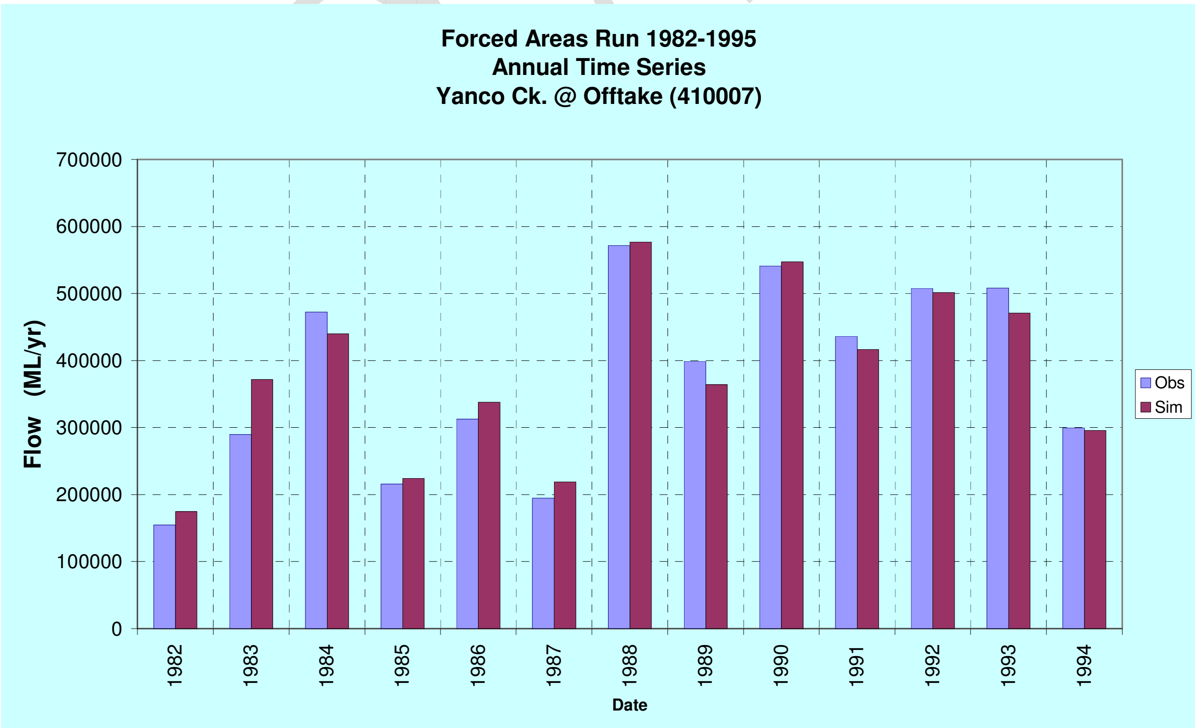

Figure 3-10 Simulated and Observed Annual Flows for Yanco Ck Offtake

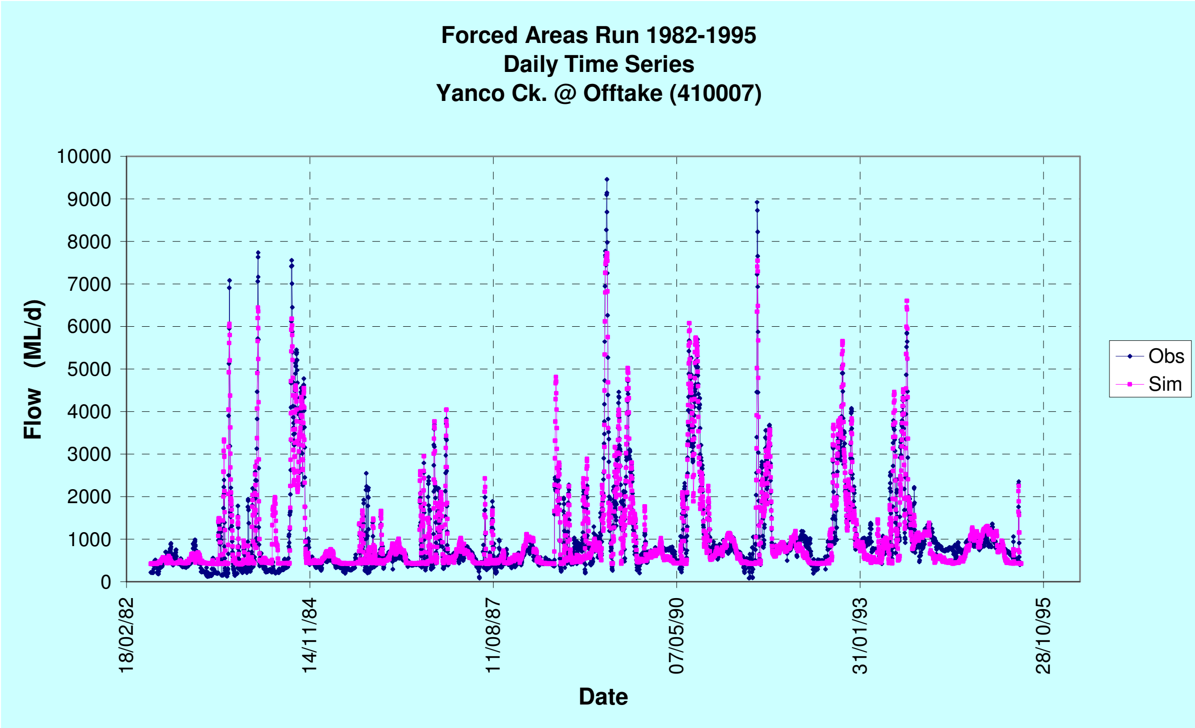

Figure 3-11 Simulated and Observed daily Time Series for Yanco Ck Offtake

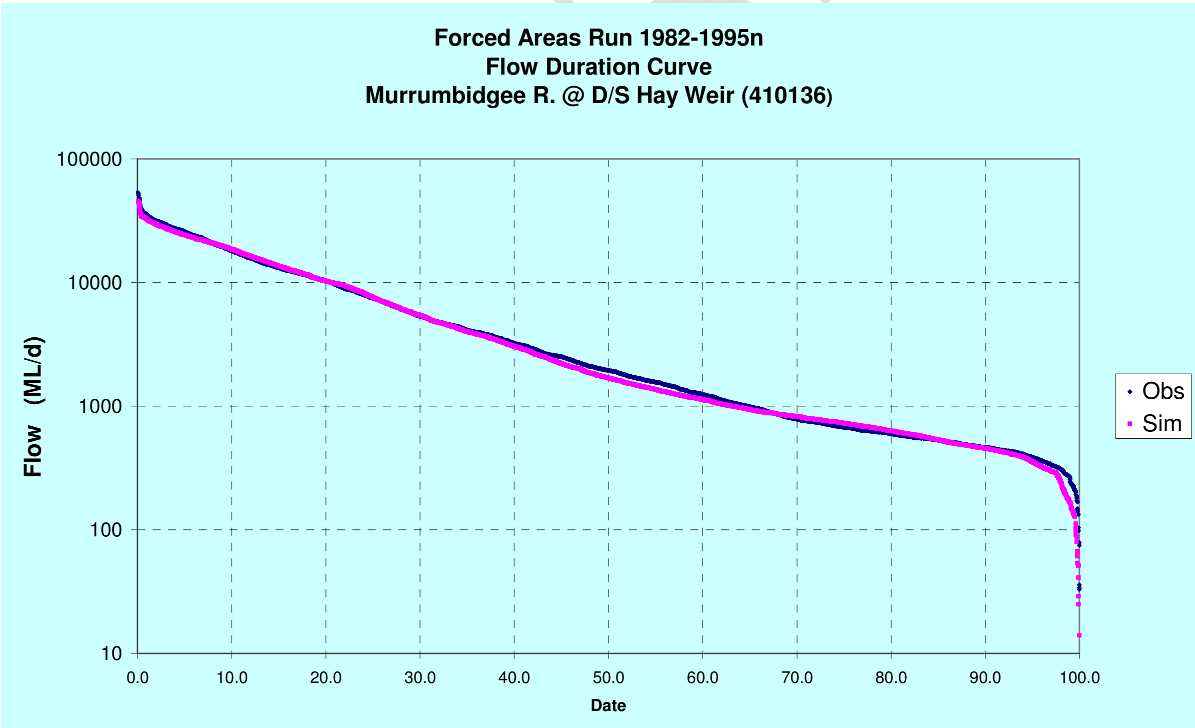

Figure 3-12 Simulated and Observed Flow Duration Curves for d/s Hay Weir

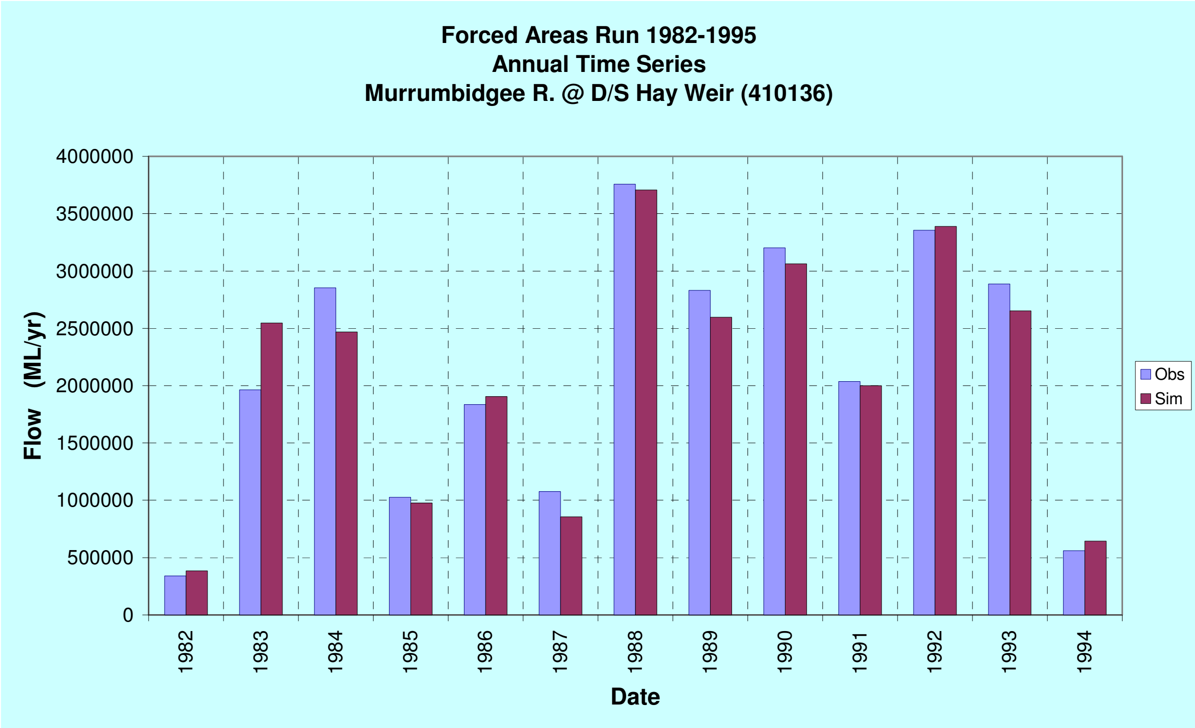

Figure 3-13 Simulated and Observed Annual flows for d/s Hay Weir

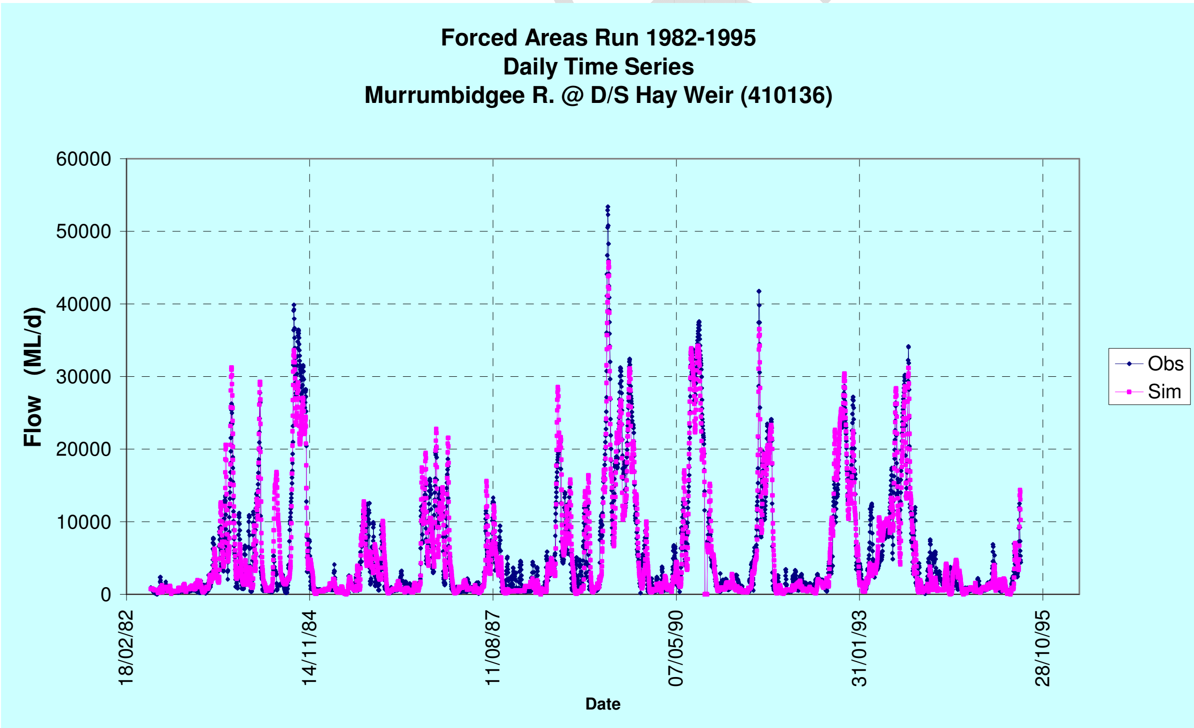

Figure 3-14 Observed and Simulated Daily Time Series of Flows at d/s Hay Weir

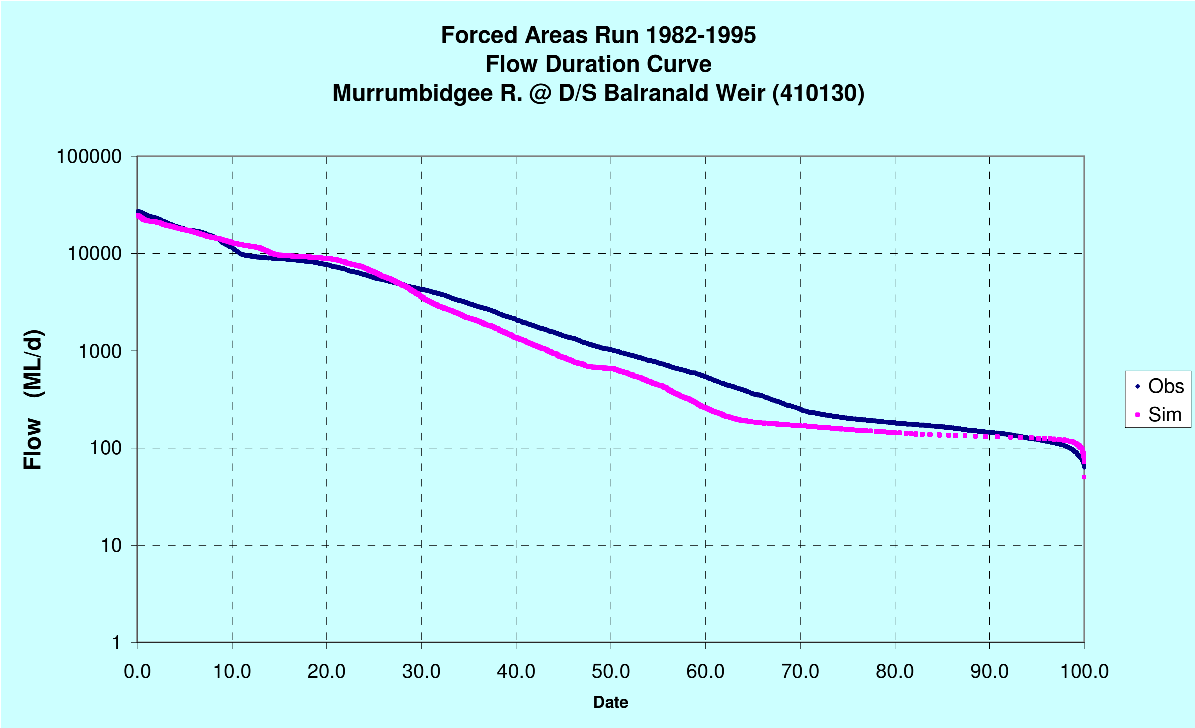

Figure 3-15 Simulated and Observed Flow Duration Curves for Balranald

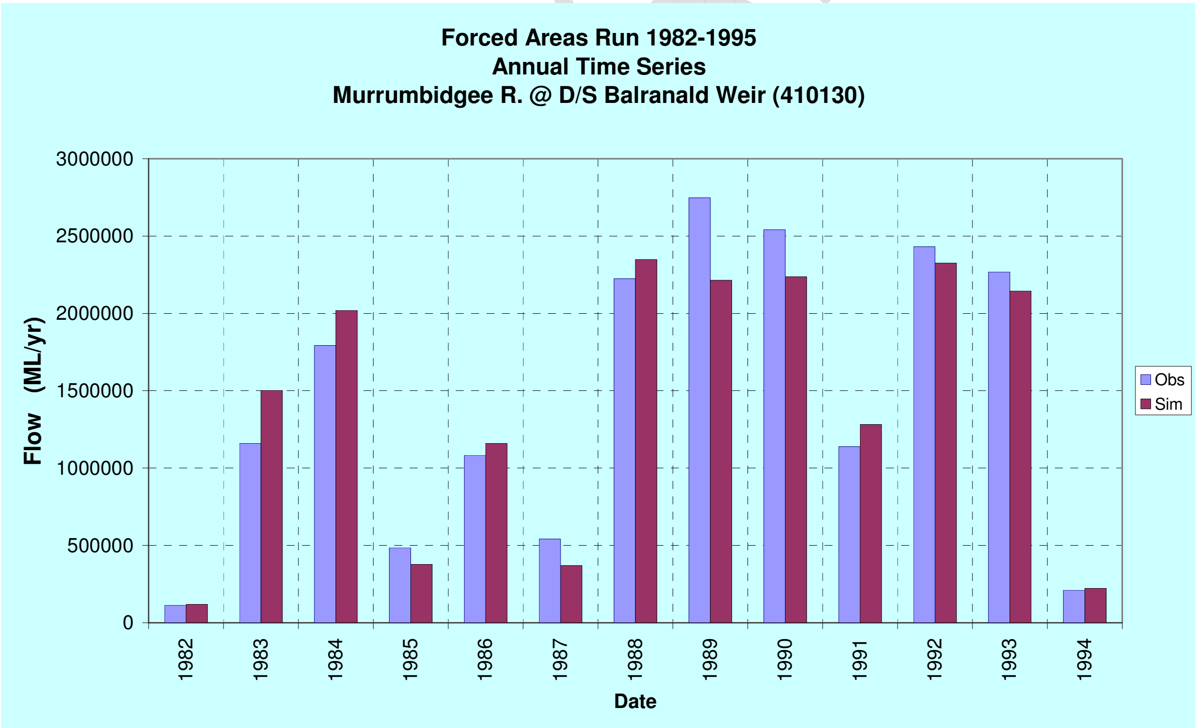

Figure 3-16 Simulated and Observed Annual Flows for Balranald

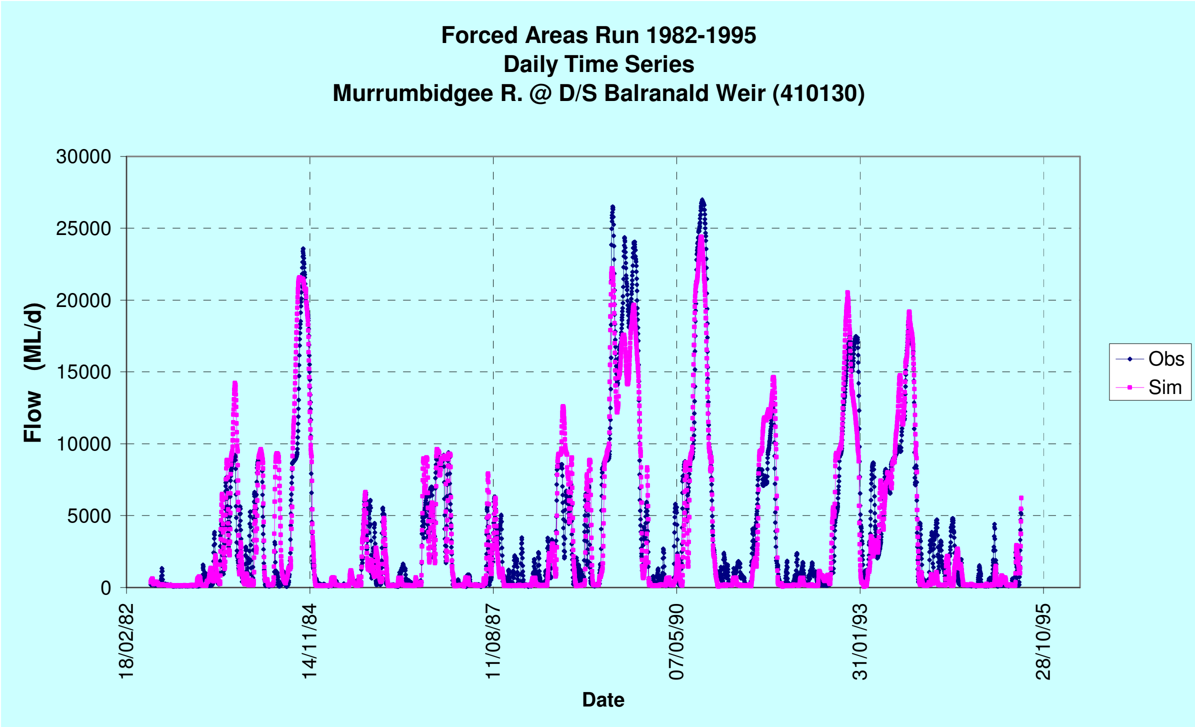

Figure 3-17 Observed and Simulated Daily Time Series of Flows at Balranald

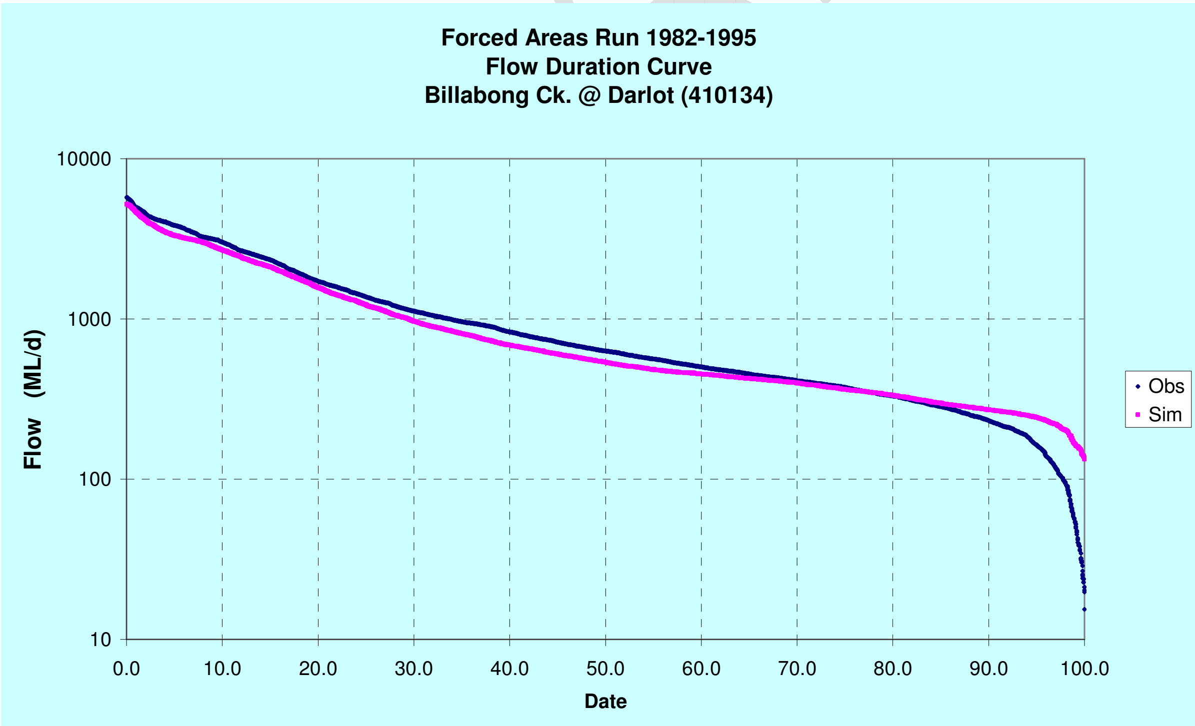

Figure 3-18 Observed and Simulated Flow Duration Curve for Darlot

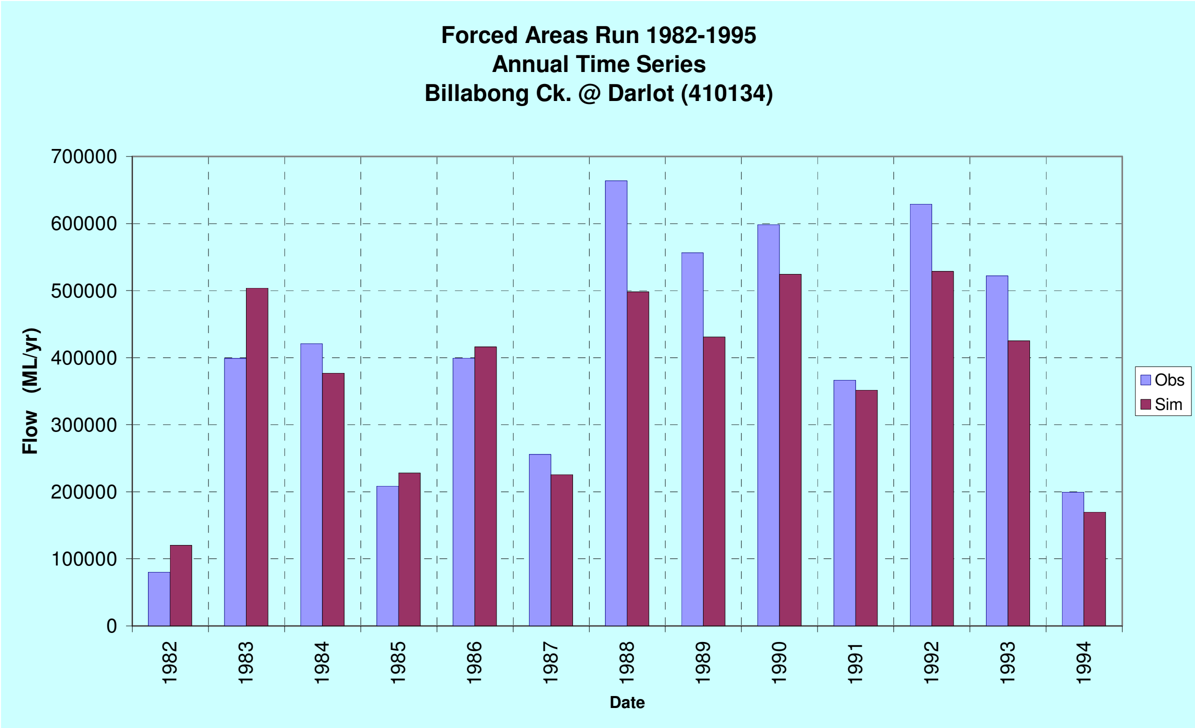

Figure 3-19 Observed and Simulated Annual Flows for Darlot

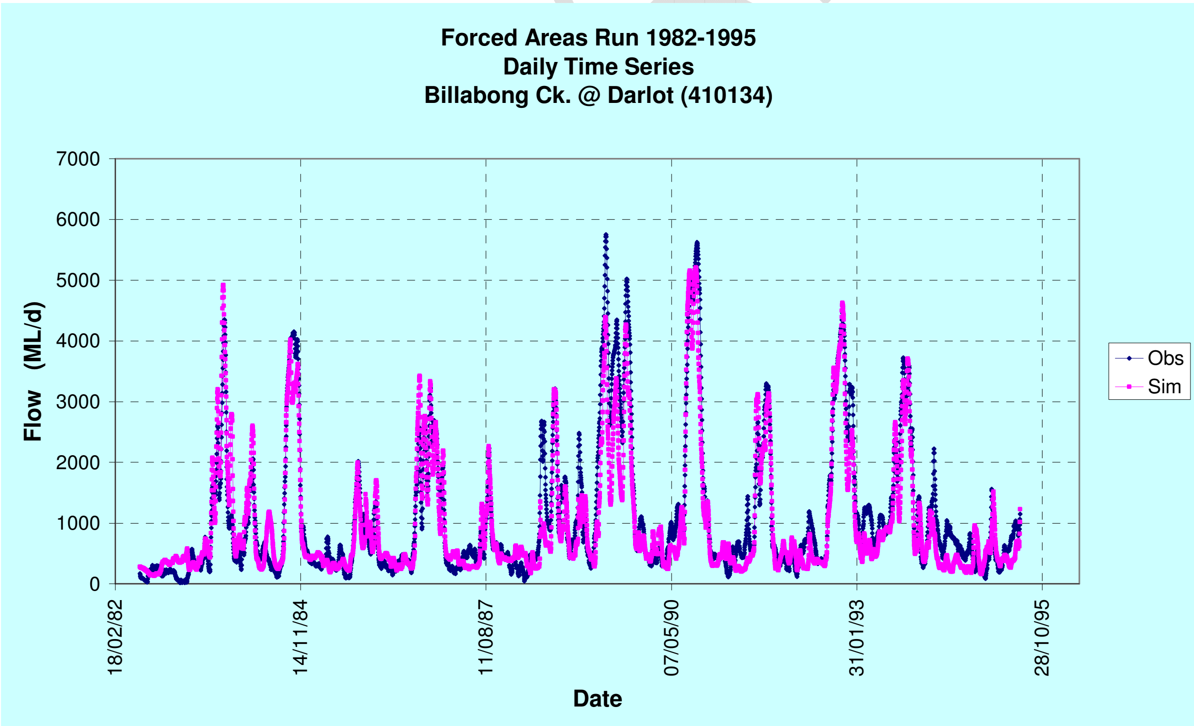

Figure 3-20 Observed and Simulated Daily Flows for Darlot

Table 3-1 Quality of Calibration

SUBJECT		Flow Frequency Match				Time Series Match	
Comparison point	Aspects Reported	Whole Range	Low Range	Mid Range	High Range	Daily "$1-r^2$"	Annual CMAAD
Murrumbidgee R.	Observed GL:	61,290	2,702	47,118	11,470	-	-
@	Simulated GL:	60,424	2,603	46,572	11,249	-	-
Wagga Wagga	Appar's Error:	-1.4%	-3.7%	-1.2%	-1.9%	8.1%	4.4%
(410001)	Rating	V. High	High	V. High	V. High	High	V. High
Murrumbidgee R.	Observed GL:	49,190	2,270	36,683	10,237	-	-
@	Simulated GL:	48,303	2,201	36,381	9,721	-	-
Narrandera	Appar's Error:	-1.8%	-3.1%	-0.8%	-5.0%	6.6%	6.0%
(410005)	Rating	V. High	High	V. High	High	High	High
Murrumbidgee R.	Observed GL:	32,376	891	23,304	8,180	-	-
@	Simulated GL:	31,075	616	22,878	7,581	-	-
Darlington Point	Appar's Error:	-4.0%	-30.8%	-1.8%	-7.3%	6.4%	7.9%
(410021)	Rating	High	Low	V. High	High	High	High
Murrumbidgee R.	Observed GL:	27,723	421	19,800	7,501	-	-
@	Simulated GL:	27,083	409	19,737	6,937	-	-
D/S Hay Weir	Appar's Error:	-2.3%	-2.9%	-0.3%	-7.5%	6.9%	7.8%
(410136)	Rating	High	V. High	V. High	High	High	High
Murrumbidgee R.	Observed GL:	18,739	134	13,360	5,245	-	-
@	Simulated GL:	18,326	122	13,371	4,833	-	-
Balranald	Appar's Error:	-2.2%	-8.8%	0.1%	-7.9%	7.3%	12.1%
(410130)	Rating	High	Moderate	V. High	High	High	Moderate
Yanco Ck.	Observed GL:	4,903	300	3,454	1,149	-	-
@	Simulated GL:	4,940	402	3,394	1,143	-	-
Offtake	Appar's Error:	0.8%	34.2%	-1.7%	-0.5%	6.7%	6.2%
(410007)	Rating	V. High	Low	V. High	V. High	High	High
Billabong Ck.	Observed GL:	5,298	205	4,024	1,070	-	-
@	Simulated GL:	4,799	250	3,585	965	-	-
Darlot	Appar's Error:	-9.4%	22.0%	-10.9%	-9.8%	7.2%	16.3%
(410134)	Rating	Moderate	Low	Moderate	High	High	Low

(#) for period from 1/07/1982 to 30/06/1995

3.4. DIVERSION VOLUME REPLICATION

3.4.1. Background and methodology

IQQM uses a soil moisture accounting model with rainfall and estimated crop evapotranspiration that, along with forced or simulated crop areas, are used to generate irrigation demands. In simulating diversions the model takes into account crop areas, crop varieties through crop factors, rainfall, evaporation, irrigation efficiency, licence volume and active licence factors.

Appropriate rainfall and evaporation data is selected to drive the crop demand module, which is then calibrated to replicate the observed diversions based on the observed areas planted. The IQQM model uses theoretical crop factors (Allen, et. al., 1998), with the unknowns being the size of the average "effective" soil moisture store, rainfall interception amount, monthly watering efficiency parameters (varying by crop) and seepage rates. Values for these parameters are adjusted based on experience and acceptable bounds until the simulated crop water demands best match the observed data (DLWC, 1998[d]).

There is considerable uncertainty associated with the measurement of farm gate deliveries and crop areas. For instance Dethridge wheel underestimation of diversion is thought to be (or at least was during the calibration period) averaging around 14%, with greater underestimation occurring at lower diversion rates. Crop areas beside rice are based on farmer estimates obtained in annual surveys and may not be that accurate. With this uncertainty it was thought undesirable to try to differentiate crop parameters amongst different irrigation groups.

This being akin to fitting a high degree polynomial to noisy data, when the true data values are perhaps closer to lying on a straight line. The only variation modelled was related to supply escape flow rates for irrigators in the CIA & MIA.

Of the available rainfall stations in the Valley, the following criteria are used to select an appropriate sub-set to use in diversion calibration.:

- adequate representation of the Murrumbidgee valleys' considerable spatial variability of rainfall;
- availability of long term records to cover not just the intended calibration period, but also the intended long term modelling period;
- continuity and quality of data; and
- availability of nearby rainfall stations that could be used to substitute missing data and/or disaggregate accumulated records.

After a review of the available rainfall stations and consideration of these criteria, there were eleven long term rainfall stations Table A-7 selected to drive the crop demand module in the model.

IQQM ideally needs long-term reference crop evapotranspiration data to derive crop water demands. In its absence long term pan evaporation data is used. It is fortunate for the Murrumbidgee Valley IQQM modelling that CSIRO has been collecting climate data at Griffith for over thirty years and with it estimating reference crop evapotranspiration. As mentioned elsewhere in this report Griffith ETo was used (with limited location adjustment) for all irrigation modelling.

Crop factors for rice, wheat pasture, and other lesser used crops were based on experimental work carried out by CSIRO at Griffith. Some changes were then made to these CSIRO crop factors in the calibration process. The crop factors used for different crops and irrigation efficiency factors are presented in Table B-2.

The pump capacities used in each of the irrigation nodes are based on the total of the estimated installed pump capacities of irrigators in that reach. With the no modelling of on farm storages pump capacity constraints are not crucial to the model.

3.4.2. Results

Plots are presented showing the match between observed and simulated for the compiled model (with forced areas). Results are presented for the total regulated system (on, off and total diversions), MIA and CIA (diversions and deliveries), river pumper diversions and Lowbidgee diversions.

Following the plots are a series of objective measures of the quality of model fit achieved are presented in Table 3-2 based on the quality assessment guidelines described in Appendix D (DLWC, 1999). The criteria adopted are those for fully forced models because no risk function is operating.

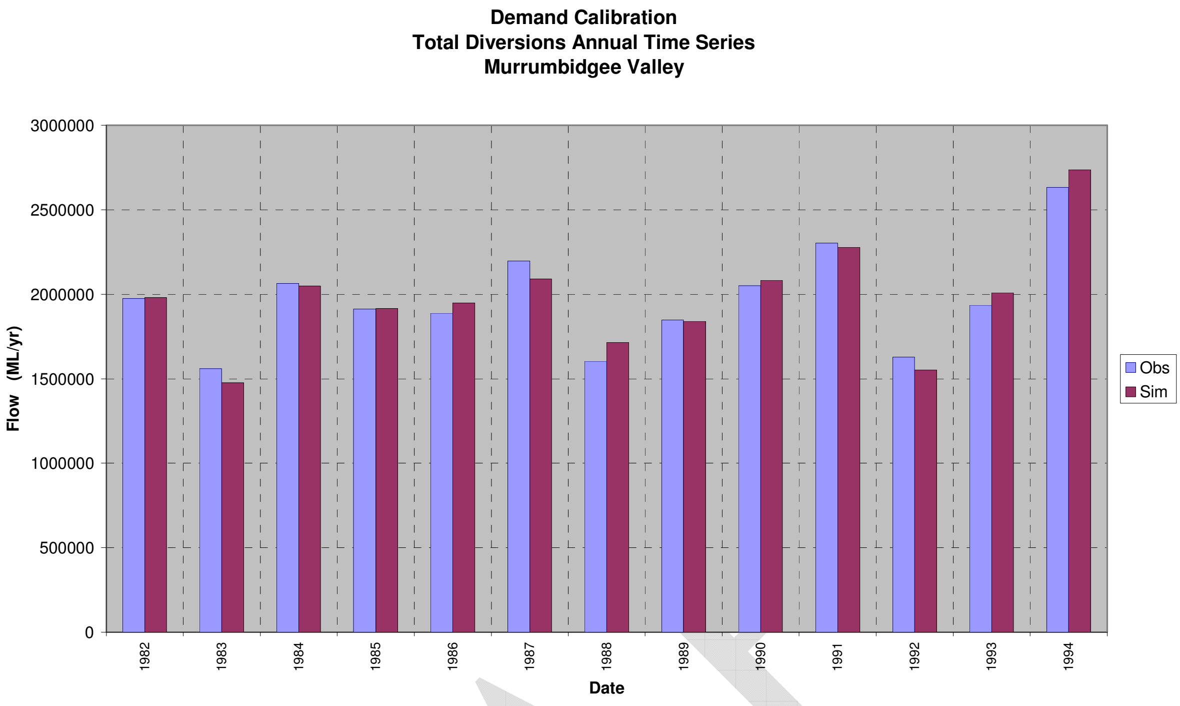

Figure 3-21 Observed and Simulated Total Diversions for Murrumbidgee Valley

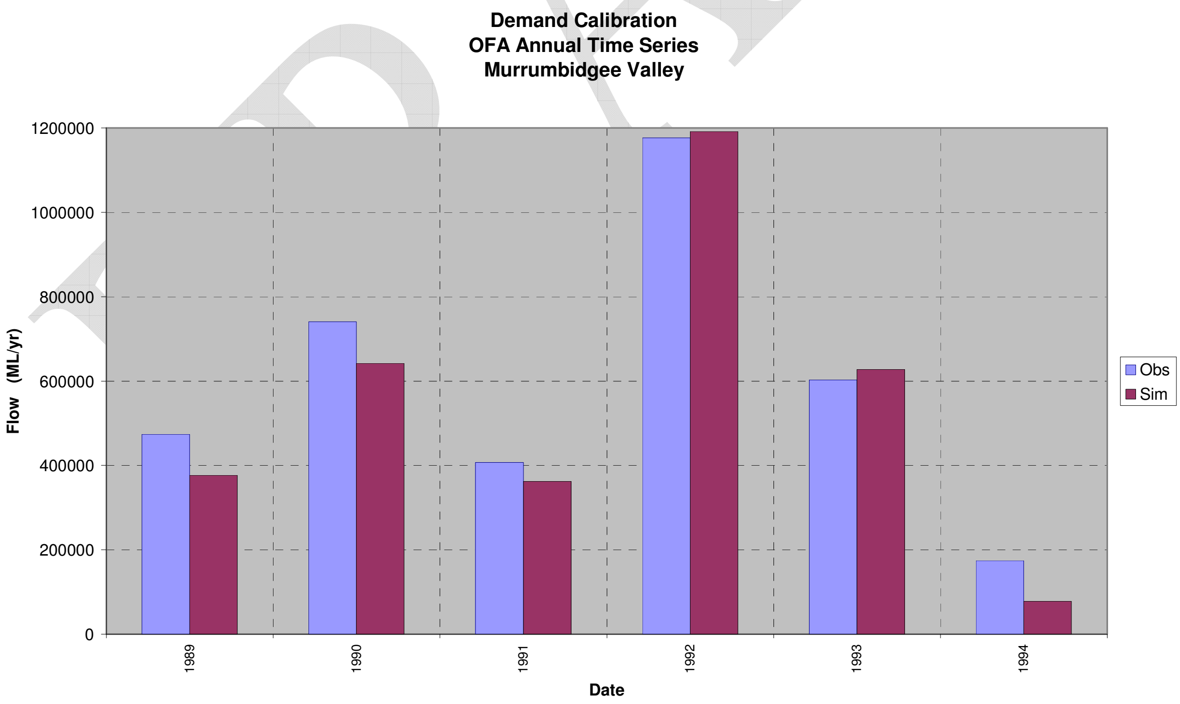

Figure 3-22 Observed and Simulated Off allocation Diversions for Regulated Murrumbidgee Valley

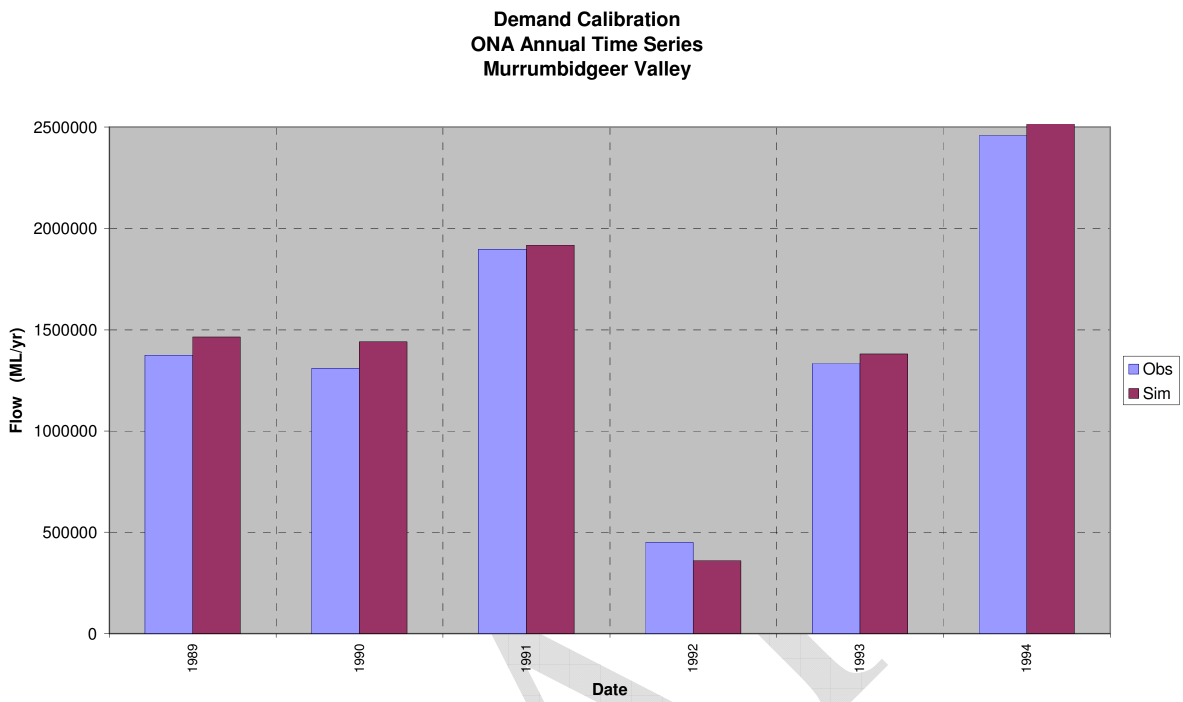

Figure 3-23 Observed and Simulated On Allocations Diversions for Regulated Murrumbidgee Valley

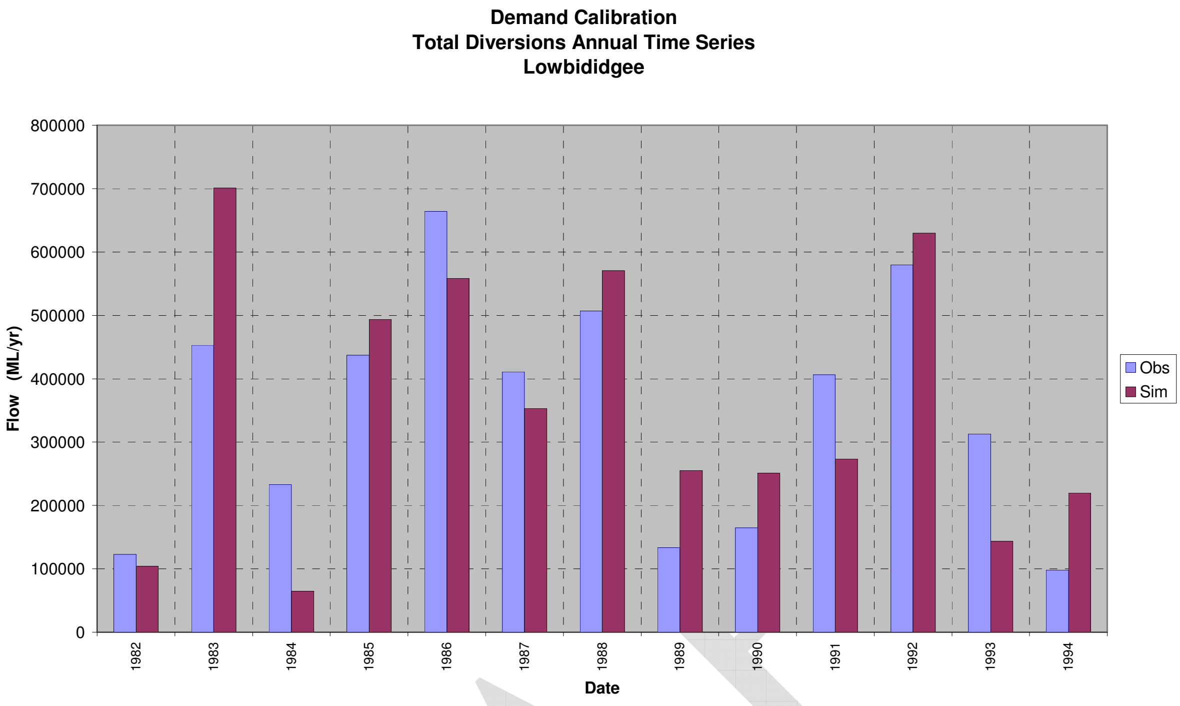

Figure 3-24 Observed and Simulated Total Diversions for The Lowbidgee District

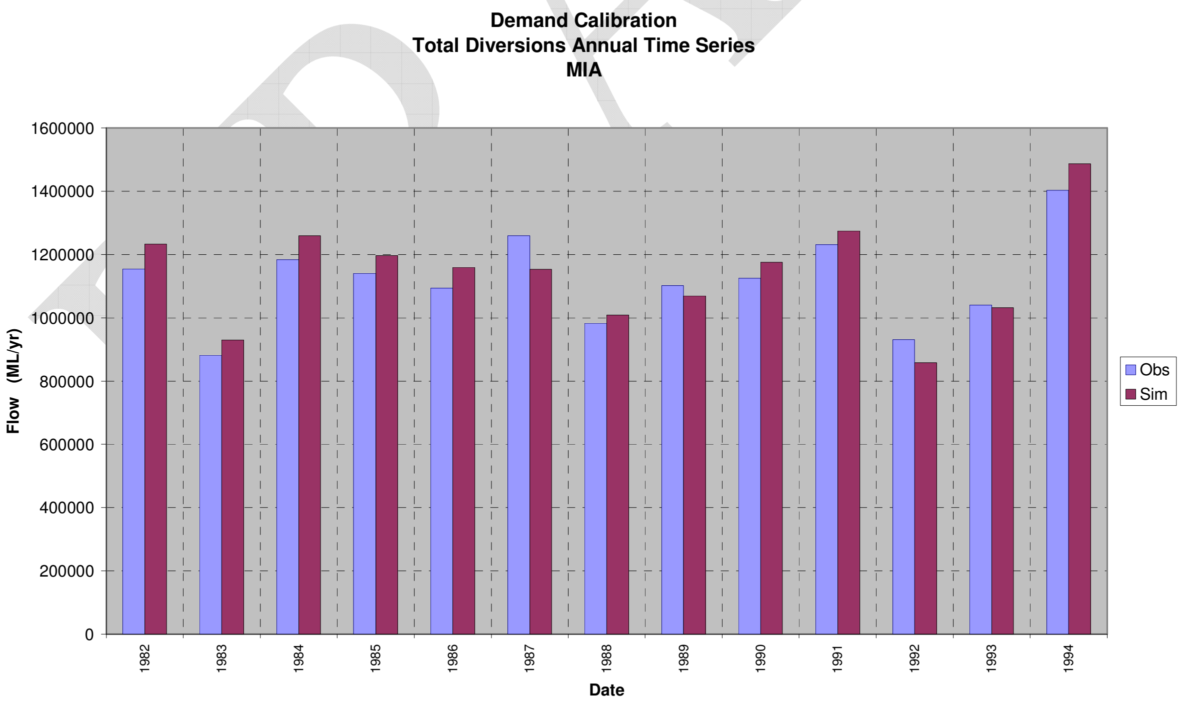

Figure 3-25 Observed and Simulated Diversions for the MIA

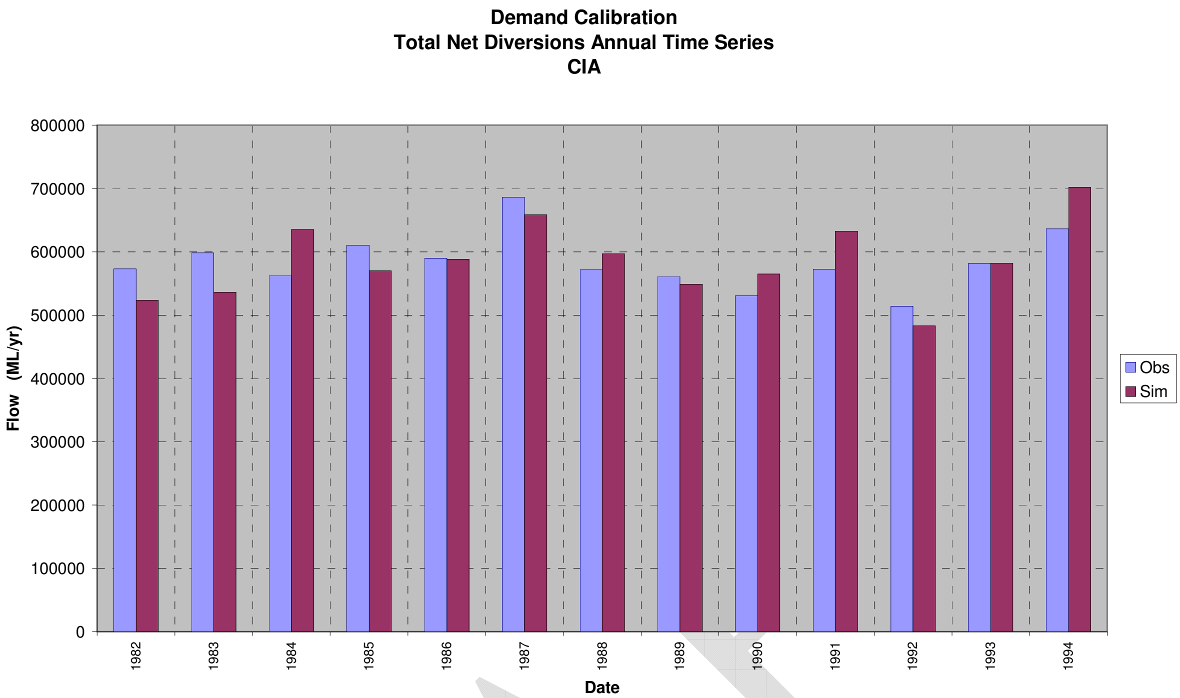

Figure 3-26 Observed and Simulated Annual Diversions for the CIA

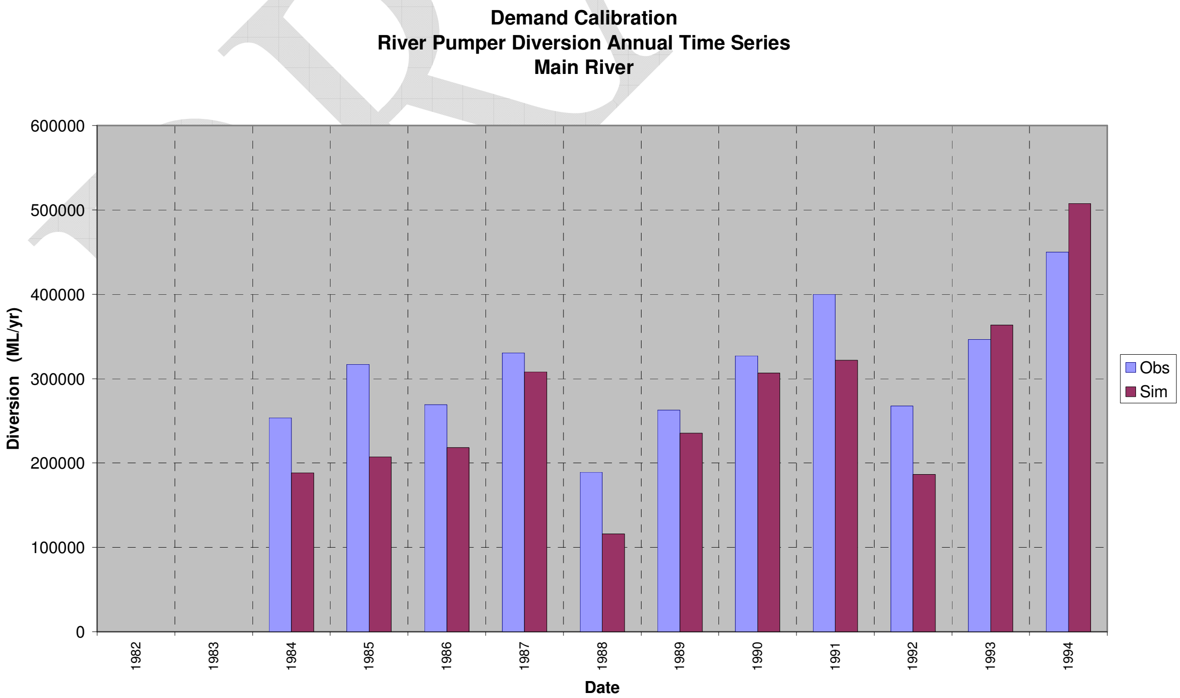

Figure 3-27 Observed and Simulated Annual River Pumper Diversions

Table 3-2 Goodness of Fit for Diversions

SUBJECT		ANNUAL DIVERSION TIME SERIES MATCH				QUALITY RATING
Irrigator Group	Quality Indicator	Observed GL	Simulated GL	Indicator Value	Apparent Error	
Murrumbidgee R. Irrigators	Volume ratio	3,413	2,960	86.7%	-13.3%	Moderate
	CMAAD				17.7%	Moderate
YCB System Irrigotors	Volume ratio	872	886	101.6%	1.6%	V. High
	CMAAD				11.0%	V. High
Irrigators Total	Volume ratio	4,285	3,846	89.7%	-10.3%	High
	CMAAD				14.3%	V. High
MIA	Volume ratio	14,529	14,841	102.1%	2.1%	V. High
	CMAAD				5.2%	V. High
CIA	Volume ratio	7,589	7,623	100.4%	0.4%	V. High
	CMAAD				6.4%	V. High
Lower Bidg	Volume ratio	4,523	4,619	102.1%	2.1%	V. High
	CMAAD				31.0%	V. Low
Total Diversion	Volume ratio	25,597	25,676	100.3%	0.3%	V. High
	CMAAD				2.7%	V. High

The diversion match gained was very high except for Murrumbidgee River pumpers. The mismatch for that group is most prominent in the earlier years of the calibration period. Some of that may be related to the lower groundwater tables of that earlier period that meant higher seepage rates. A phenomenon that was apparent in CIA application rates and was explicitly accounted for in the calibration model. The pre 1990 river pumper data has not had the same degree of scrutiny and review as the data post 1990 data and that may also account for some of the mismatch. Finally the model assumes that all areas historically recorded as pasture is really winter pasture rather than annual pasture. The further you go forward in time the more accurate that assumption is because of the increasing dominance of rice in summer. Back in the 1980s where it was less true the assumption may be the causes of some underestimation of diversions because annual pasture uses more water in a season than winter pasture.

3.5. STORAGE BEHAVIOUR REPLICATION

The degree the model replicates observed time series of storage volumes provides a good measure of the model's overall performance. This is because with the exception of the Lowbidgee part of the model and the possible exception of off allocation access, all other model components influence, to varying degrees, the pattern of drawdown and filling of the headworks storages.

The parameters that are sometimes regarded as directly relating to storage calibration are the tributary utilisation factors. The closer the factors are to their maximum value of 1.0, the smaller are the dam releases and consequently the slower the rate of reservoir drawdown. However, these same parameters also affect flows at downstream gauges, including the critical end of system gauges. Calibration then becomes a balancing act between storage drawdown, end of system flows and also between dry periods (with leaner operation) and wetter periods where some dam drawdown can be desirable.

3.5.1. Inflow to dams

For the calibration of storage behaviour, dam inflows must first be derived. This is done using a back-calculation procedure (DLWC, 1998[g]) based on information obtained from dam Officer in Charge (OIC) sheets. The back-calculation technique is simply a water balance of dam inputs and outputs as follows:

```
Inflow   =  Change in Storage + Releases + Spills + Losses – Direct Rainfall
```

After a review of the available rainfall and evaporation stations and consideration of the criteria outlined in sections 3.1.3 and 3.1.4 the rainfall and evaporation stations listed in Table A-4 were selected to drive the storage behaviour in the model. These data were used in the calibration of storage behaviour.

Net evaporation in the headwaters of the Murrumbidgee and Tumut Rivers is small and the model would be expected to be insensitive to evaporation and rainfall data used. This is less true for the for the post cap operation of translucency and transparency where daily environmental releases are a function of back calculated daily inflows and, in days where inflows are small the calculation is dominated by the evaporative term.

3.5.2. Tributary utilisation

Operationally, in working out dam releases, there is a need to forecast the downstream tributary inflows for the upcoming days. Releases to meet downstream requirements can then be discounted for by those forecast tributary inflows. The discounting in affect is saying that dam released can be substituted for by the forecast tributary inflows. For the discounting to work the forecast flows need to be forward in time by the travel time between the dams and the Murrumbidgee River-tributary confluence.

In IQQM modelling forecasting is done by an assumed recession parameter. The recession being applied to the current days known flows. The term utilisation factor refers to how much of today's known flows can be utilised to meet orders in the upcoming days.

Typically, the tributary recession factors reduce progressively down the main river because of the increasing uncertainty of predicting further into the future. In the Murrumbidgee IQQM, in a bid to achieve the tight operation observed in drought years, and also because all tributaries are mostly within two travel days of the dam, the assumed utilisation parameters have been mostly set to the maximum value of 1.0.

The tributary utilisation factors that produce the best calibration of storage behaviour over the calibration period are presented in Table B-3

3.5.3. Results

Figure 3-28 and Figure 3-29 are plots of the match between observed Burrinjuck and Blowering storages and the corresponding simulated storages in the compiled model (with areas forced to be observed), Table 3-3 summarises the calibration results in terms of the quality guidelines outlined in Appendix D.

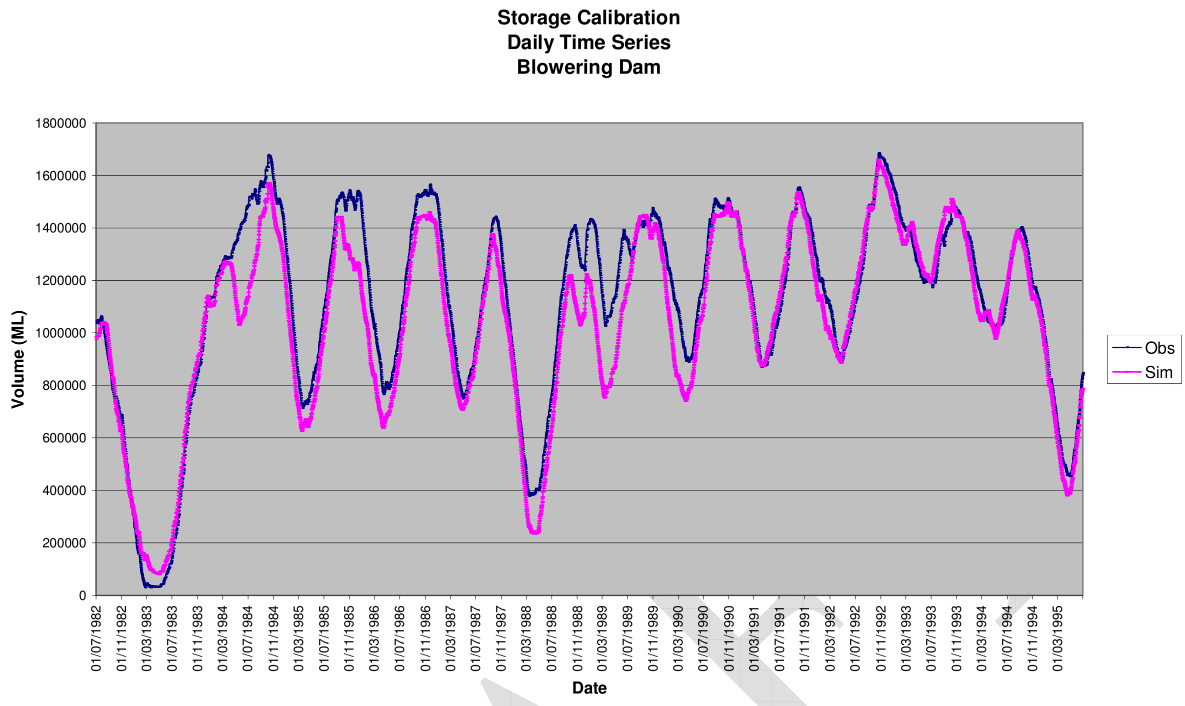

Figure 3-28 Observed and Simulated Blowering Dam Storage

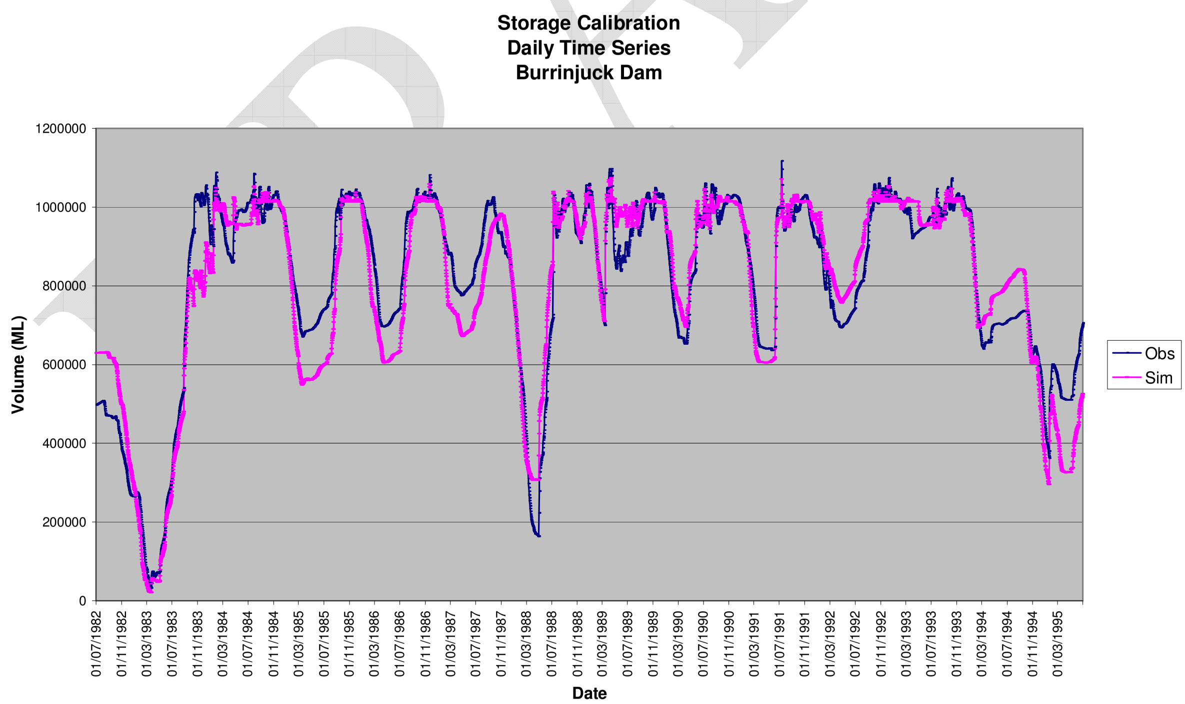

Figure 3-29 Observed and Simulated Burrinjuck Dam Storage

Table 3-3 Goodness of Fit Storage Volume

SUBJECT		Apparent Error	QUALITY RATING
Irrigator Group	Quality Indicator		
Burrinjuck	CAASDD	3.90%	Very High
Blowering	CAASDD	3.00%	Very High

3.6. RESOURCE ASSESSMENT

A general description of the resource assessment procedure is given in section 2.9. The following factors are taken into consideration in IQQM representation of resource assessments:

- Current volume available in the headworks dam and any downstream storages;
- Usable flows in transit between the dam and ordering nodes(ordering for irrigation, town water supply and minimum flow targets).
- minimum expected inflow to the dam including the minimum recession that can be expected on current inflows;
- minimum expected useful tributary inflow downstream of the dam including the minimum recession on current tributary inflows;
- expected evaporation and transmission losses over the remainder of the irrigation season;
- all the essential requirements for the rest of the season placed on available resources including meeting high security needs. .

The model carries out resource assessments every 14 days. In practice they are carried out monthly and whenever inflow events have significantly changed the resource position.

This part of the model is configured to represent policies and practices for specific points in time, rather than calibrated across long periods of time, and the parameters used for the Cap scenario are discussed in Chapter 4.

3.7. OVERALL MODEL CALIBRATION

The overall model calibration quality has been assessed using a combination of selected key indicators (see Appendix D). The results of applying this evaluation process are summarised in Table 3.5.

Table 3-4 Overall Model Goodness of Fit

Calibration	Subject Period			Location	Individual Ratings									
					Overall Ratio					Pattern Match				
	Start	End	Length		**Achieved**	Category	Upper	Lower	**tandardise**	**Achieved**	Category	Upper	Lower	**tandardise**
Flow	1982	1994	13	Narrandera	**-1.8%**	1	0.0%	2.0%	**-4.5%**	**6.0%**	1	0.0%	10.0%	**3.0%**
Demand	1982	1994	13	Whole valley	**0.3%**	1	0.0%	7.0%	**0.2%**	**2.7%**	1	0.0%	15.0%	**0.9%**
Storage 1	1982	1994	13	Burrinjuck	**5.3%**	3	5.0%	8.0%	**10.5%**	**3.9%**	1	0.0%	4.0%	**4.8%**
Storage 2	1982	1994	13	Blowering	**3.3%**	2	2.0%	5.0%	**7.2%**	**3.0%**	1	0.0%	4.0%	**3.7%**
SubTotal							**4.5%**					**2.7%**		
Average									**3.6%**					
Overall			13				**2.1%**					**V. High**		

4. 1993/94 Development Conditions (Cap) Scenario

The Murrumbidgee River Valley is a designated river valley under Schedule F of the Murray-Darling Basin Agreement (MDBMC, 2000), and is consequently required to be managed to ensure that diversions do not exceed those expected under 1993/94 levels of irrigation infrastructure and management rules (ie the MDBMC Cap). DNR will use the Murrumbidgee IQQM to estimate this diversion limit and therefore provide an indication of the valley's compliance with the MDBMC Cap.

The previous chapters of this report have outlined how the IQQM has been configured and calibrated for the Murrumbidgee Valley. This chapter outlines how the IQQM has been further developed to perform a simulation of the valley with 1993/94 levels of development and long term climatic conditions (i.e. the Cap scenario). This chapter also outlines how the Cap scenario has been used for short term Cap auditing, i.e. the Cap audit scenario.

Licenced water users extracting water from unregulated streams have not been included in the Murrumbidgee Valley IQQM. Up until 2000 these licences had been operating on the basis of a maximum authorised irrigable area and a commence to pump and/or cease to pump limit for pumping (usually a visible flow at the nearest flow gauging station). In 2000 these types of licences were converted to have an annual volumetric limit. Past operation of these licences has not been closely monitored and there has generally been very little data collected on water extractions and cropping by these licences. Consequently, the Cap benchmark described in this report only relates to the regulated system. It is intended that, if sufficient information should become available, the model would be expanded to represent unregulated licences.

It should also be noted that the tributary inflows used in the Murrumbidgee Valley IQQM either are, or have been calibrated using, observed streamflow at gauging stations for the periods of their records. Inherent in the stream flow data is the effect of extractions by unregulated licences that are outside influence of regulated flows from Burrinjuck and Blowering Dams. For the purposes of determining Cap for the regulated Murrumbidgee system, this effect has been deemed to be negligible.

4.1. CAP IN BRIEF

The Murrumbidgee River IQQM was used to simulate Cap conditions over the 116 year period from 1st October 1890 to 30th June, 2006 to determine long term average annual diversions. For model "warm up" reasons long term statistics are calculated over 1 July 1892 to 30th June 2006. For Cap auditing purposes under Schedule F, the model has been run for the period 1 Oct 1990 to 30 June 2006 with auditing statistics obtained for the period 1 July 1997 to 30 June, 2006. The following assumptions were used to represent Cap conditions:

- Dams, on and off river storage infrastructure and operation policy as per 1993/94 conditions;
- Pump capacity as installed in the 1993/94 irrigation season;
- The crop mix and max areas as the observed average over seasons 1992/93 to 1994/95.
- Management rules applicable in the 1993/94 irrigation season as best can be discerned. Some dryer climate operational issues never arose until the late 1990s and it was necessary to infer how these would have been managed if they had happened in 1993/94.
- Snowy inflows as if no trade had occurred between irrigators and Snowy Hydro and no Snowy Hydro flexi generation arrangements.

4.2. CLIMATIC DATA

4.2.1. Rainfall

For the long term simulations, the rainfall stations selected based on the criteria outlined in Section 3.1.3 are extended and gap-filled to cover the intended simulation period.

4.2.2. Evaporation

For the long term simulations, the evaporation data is generated based on a relationship between monthly evaporation totals and number of rain days in the month. As explained in Section 3.1.4, eight long-term rainfall stations were used for generation of evaporation data for the eight geographic zones (Table A.1).

4.3. FLOW DATA

4.3.1. Streamflows

The observed data for the tributary gauging stations selected for use in the model (Table A-6) were collated, gap-filled and extended using Sacramento rainfall-runoff models (DLWC, 1998[c] and DLWC, 1999[a]) such that they covered the intended simulation period.

The ungauged catchment contributions were then derived based on applying simple relationships with gauged inflows.

4.3.2. Inflows into the dams

To derive the required long-term inflow sequence to Burrinjuck and blowering Dams, the OIC sheet mass balance approach was used when available. For the period before Blowering dam became fully operational, a Snowy Hydro (or at least one of its predecessor organisations) model run was used. Regression relationships with downstream gauges were used to gap fill the very early part of the record.

4.4. IRRIGATION INFORMATION

Where possible, observed charactertstic data was used to configure the model for physical infrastructure including pump capacities and on-farm storages (Section 2.4) rather than calibrating the configuration

Parameters such as crop irrigation efficiencies and tributary utilisation factors have been determined during calibration and validation periods (1983– 1998 (DLWC, 2000). A full listing of parameters describing the Murrumbidgee IQQM Cap scenario is included in Appendix E.

4.4.1. Irrigation licences

For the Irrigation Areas & Districts, entitlements have been set to 1993/94 levels. Data for the 1999/00 irrigation season was used for river pumper regulated entitlement (Section 2.4.1 and Table E) as data around 1993/94 was deemed less reliable and no significant river pumper entitlement changes occurred between 1993/94 and 1999/00.

The 1993/94 Cap scenario described in this report only relates to the regulated system at present. It is intended that, if sufficient information should become available, the model would be expanded to represent unregulated licence diversions.

4.4.2. Irrigation extraction and storage infrastructure

The regulated pump capacities observed data for the 1993/94-irrigation season were used for 1993/94 Cap scenario.

No on farm storage survey was carried until about 1997/98 when 16 GL of on farm storage capacity was itemised. The cap scenario assumes zero on farm storage. It is likely that no more than half of 16 GL existed in 1993/94 i.e. lesser than 8 GL. So the zero on farms storage capacity assumption should not significantly impact the model's Cap scenarios.

4.4.3. Crop areas (planting decision determination)

Murrumbidgee allocations equalled or exceeded 100% in each water year from 1982/83 to 1997/98. This yielded little information on the farmers planting strategy and for IQQM modelling, the planting decision function. This created the need to "logically" work out a risk function, possibly using the post year 2000 drought years as a guide. Advice received indicated that taking risk on rice planting was not economically viable with the set up costs prohibitive. So no risk is assumed for rice. Other crop data in recent years is only available for the Irrigation Corporations but it is influenced by the introduction of carryover in 1999/00. The simplest assumption then is to also assume no risk for all crops and that is what was adopted for 1993/94 development conditions.

However, no risk does not necessarily mean constraining summer cropping to available resource in the model's planting decision. In reality planting does occur after the IQQM functionality constrained single summer decision date. This has been incorporated into the model's summer area decision by using IQQM's facility of having a different risk function for dry, medium or wet conditions. In IQQM the determination of which condition applies is related to a specified time series file. That file was created so that if the October and November inflows are small then it is deemed dry, if the same inflows are medium then the risk is medium and lastly if the same inflows are large then the conditions are deemed wet. In this way it is possible on 1 October for the model to plant more depending on the upcoming October-November inflows. This is not "model cheating" as may be first thought. It is simply a mechanism to make the model simulate the planting decision within the constraints of the software functionality, including that the planting decisions that can be taken in October-November without risk

4.4.4. Crop Mix and Maximum Area

The deregulation of rice in the 1980s resulted in a shift in river pumper crop mixes from winter dominated to summer rice dominated crops. The years from 1990 to 1995 showed a particularly strong shift. Things to settle in the late 1990s however, resource constraint years subsequent to year 2000 may have further shifts The Irrigation Areas were always rice dominated and crop mix shifts have been more stable, except for small change like the growth in Canola areas.

Given the trend to rice, the general inaccuracy in crop data information and the constraints of rotations, it was decided the crop mix would be determined by the average of that observed (and estimated) for 1992/93 to 1994/95. Without those reasons it may have been possible to determine the crop mix from just the 1993/94 season. The adopted crop mix is given in Table xx below

The valley crop mix is given in Table 4-1

Table 4-1 Cap Scenario Crop Mix

Crop Name	MIA	CIA	Murrumbidgee Pumpers	YCB Pumpers
SUMMER CEREALS	0%	2%	8%	5%
WINTER CEREALS	34%	25%	5%	3%
CITRUS	0%	0%	1%	0%
COTTON	0%	0%	2%	0%
LUCERNE	1%	0%	3%	5%
MAIZE	0%	0%	6%	0%
SUMMER OILSSEEDS	1%	6%	2%	1%
WINTER OIL SEEDS	0%	2%	1%	0%
ORCHARD	5%	0%	0%	0%
WINTER PASTURE	30%	25%	62%	58%
RICE	21%	38%	8%	26%
VEGETABLES	2%	1%	2%	2%
VINES	4%	0%	0%	0%
FODDER	2%	2%	0%	0%

Notes: Cap crop mix as per system file capppe20.iqq

4.4.4.1 Maximum and Minimum areas

The general lack of resource constrained years in the Murrumbidgee Valley over the calibration period has resulted in observed irrigated areas that only provide an indication of the IQQM maximum planted areas. The IQQM maximum planted area specified in IQQM is planted when there are sufficient resources availableMinimum area

The no risk assumption means no minimum areas need to be specified.

4.4.5. End-of-year diversions

Since the Murrumbidgee Valley does not have significant on farm storages, the diversion data did not show any significant end of year diversions in June. There is also the possibility of pre-watering with end of water year account water (use it or lose it!) but if that was part of Cap practice then the high resource climate regime did not allow it to be exhibited.

4.4.6. Transfer market

For the Murrumbidgee Valley no intra-valley trade has been assumed in the cap model. Indeed no significant trade occurred in the years leading to and including 1993/94 (the first large trade year was 1994/95). However the lack of trade was probably due to allocations being at or over 120% for the period to 1993/94, meaning there was little demand for trading in water. In 1994/95 a cap on allocations of 100% was introduced and this immediately led to an increase in trade activity. It is reasonable to conclude that trade should be part of the cap model and its omission will tend to cause underestimation of diversion in dry to medium conditions. However, the reduced diversion may only be of a delaying nature only with underestimation in one year leading to a catch up extra usage in the following year with more water having been left in the dams. So the issue may not be that significant. Lack of data of the MIA sub-model hampered the building of a trade model.

4.4.7. High security irrigation

Similar to general security irrigators, the average of 1992/93 to 1994/95 area planted was adopted for the high security crop mix. The maximum high security irrigator area of 1,900 ha was used for the Cap run.

4.4.8. Unregulated use

The unregulated licences have not been included explicitly in the Murrumbidgee IQQM. Consequently, the 1993/94 Cap scenario described in this report only relates to the regulated system at present.

It is important to note however, that the tributary inflows used in the Murrumbidgee IQQM have been calibrated using observed streamflow at gauging stations over a variety of periods. Inherent in the observed streamflows is the effect of extractions by unregulated licences that are upstream of the gauging stations. For this reason, some of the unregulated extractions have been included implicitly in the model. For the purposes of determining the Cap for the regulated Murrumbidgee system, this effect has been deemed to be negligible.

TOWN WATER SUPPLY

The average annual TWS diversions observed in the 1992-95 period were approximately 20 GL and this was adopted for Cap Run. The calculated average monthly town water supply requirements adopted for the various towns are shown in Table B.2 in Appendix E.

4.5. STOCK AND DOMESTIC

Stock and Domestic entitlement was pooled with other resources available to general security holders and made available for model crop area plant.

4.6. INDUSTRIAL AND MINING EXTRACTIONS

These amounts are negligible relative to irrigation amounts and have not been represented explicitly in IQQM.

4.7. GROUNDWATER ACCESS

In this present IQQM calibration process no allowance was made for concurrent surface groundwater use or for the possible impact of groundwater use on river flow losses. Such allowances will however be considered as part of future model calibration refinements (see Chapter 5).

4.8. RESOURCE ASSESSMENT

The typical information required to make resource assessments for the Murrumbidgee Valley was determined and the model configured appropriately. The main features of the resource assessment system that were in place for the 1993/94 season are listed below:

- The system is operated as one system with all but a few reaches near the headworks dams not accessible by both headworks dams.
- Maximum allocation of 120%
- No carryover of unused allocation
- No borrow from the following year's allocation;
- No storage reserve
- Loss allowance as a function of allocation, much smaller than the present day allocation.
- Only 100 GL reserved for high security.
- An assumed 10% under use of allocations.

- Snowy inflows are as if no direct trade takes place between irrigators and Snowy Hydro and as if there are no flexi arrangements for Snowy hydro to vary the Required Annual Release
-

A full listing of parameters used can be found in a D.

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4.9. RIVER AND STORAGE OPERATION RULES

4.9.1. Tributary utilisation

Appropriate tributary utilisation factors were determined during the calibration and validation period 1983 – 1998 (DLWC, 2000). The adopted factors for the Cap scenario are listed in Table E.1

Utilisation factors reflect operation priority. In the 1980s to early 1990s the greatest issue was flood control, with resources abundant. Later years saw a shift towards maximising irrigation resources. All this meant affectively higher tributary utilisation in later years. With IQQM not having the facility for modelling a variable tributary factor, the tighter operation tributary factor was chosen to apply in all periods. In "years of plenty" the model is expected to be relatively insensitive to the factor, especially with respect to diversions. So the use of an incorrect utilisation factor in "years of plenty" should not cause significant problems.

4.9.2. Operational surplus

For the Murrumbidgee IQQM, the fixed over-order factor of 1.0 produced the best calibration of storage behaviour over the calibration period. The same factors is adopted for the Cap scenario.

4.10. SURPLUS FLOW ACCESS (OFF-ALLOCATION)

The off allocation threshold described in Table B.6 were adopted for the Cap scenario.

4.11. RIVER FLOW REQUIREMENTS

4.11.1. Minimum flows

Table 4-2 shows the adopted minimum flow requirements at various locations for the Cap case.

Table 4-2 Cap Scenario Minimum Flow Requirement

Location	Minimum flows ML/d
Downstream Burrinjuck	300
Downstream Blowering	150
Balranald	125
Darlot	50

4.12. COMPARISON OF TIME SERIES RUN WITH CAP SCENARIO OVER 1992-1995 PERIOD

To assess the robustness of the Cap scenario, it has been a common practice to examine how it matches observed data in the seasons around and including 1993/94. Mostly the seasons 1992/93 to 1994/95 are examined. However in the case of the Murrumbidgee model, a comparison of the cap scenario and the time series calibration scenario shows (see Figure 4-1 to Figure 4-6) only very minor differences over the period 1992/93 to 1994/1995. This is because allocations were at least 100% in all those making them non resource constraint with the model planting maximum areas. Those maximum are based on the average of the observed areas in 1992/95. So the comparison of observed vs forced area calibration finishes up being virtually exactly the same as observed vs full simulating cap scenario.

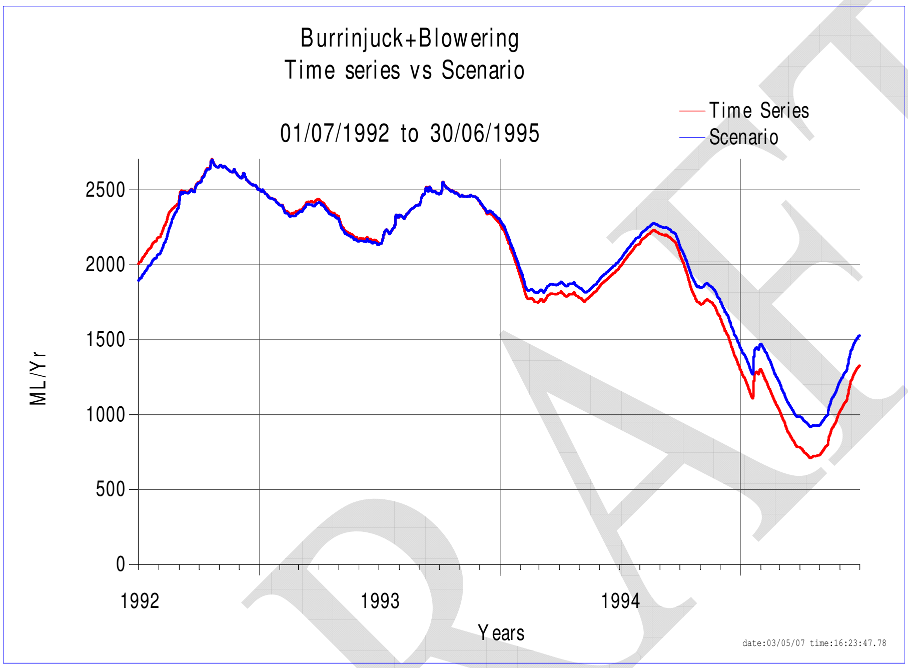

Figure 4-1 Fully Simulated and Areas Forced Burrinjuck + Blowering Storage

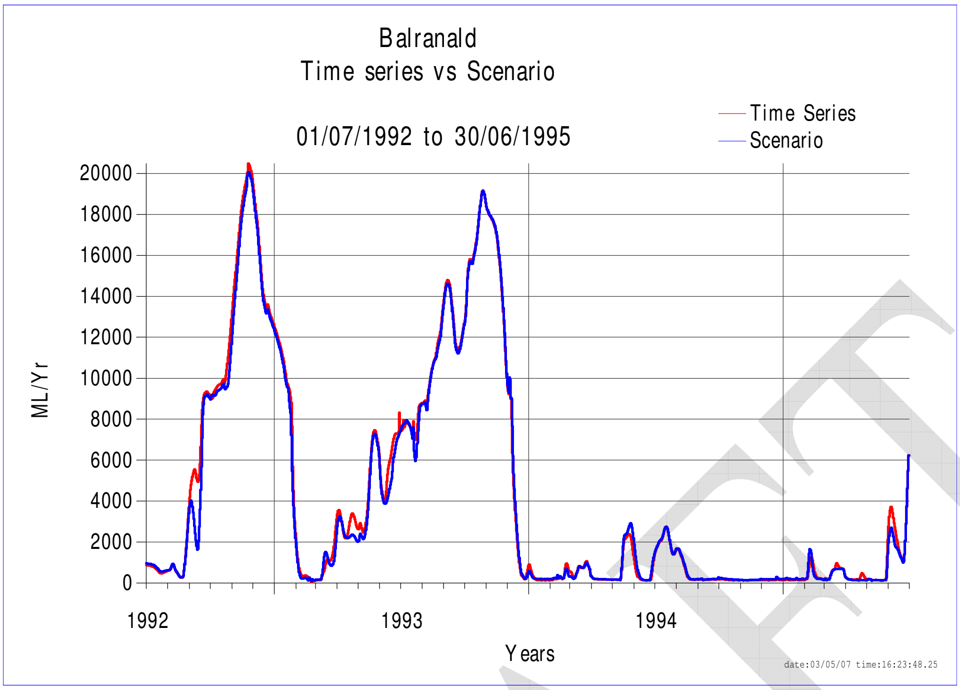

Figure 4-2 Fully Simulated and Areas Forced Daily Time series of Flows for Balranald

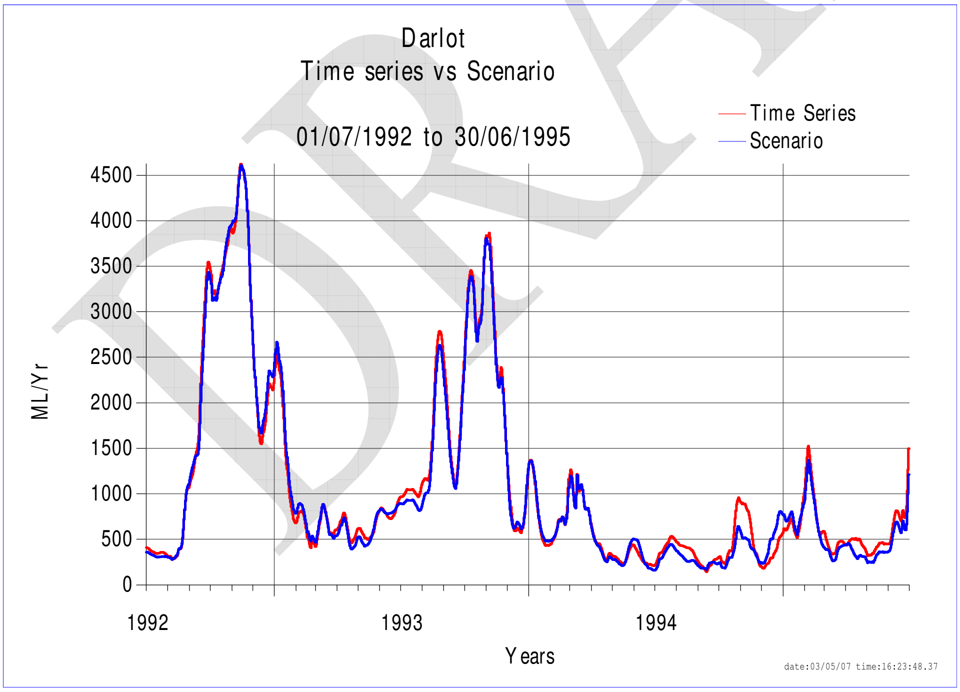

Figure 4-3 Fully Simulated and Areas Forced Daily Time series of Flows for Darlot

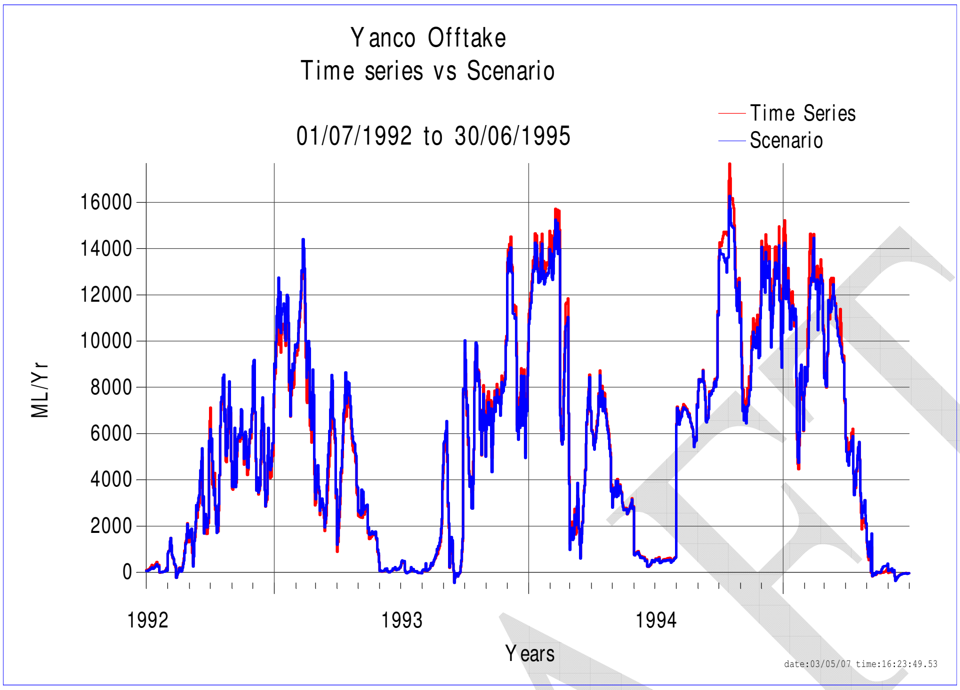

Figure 4-4 Fully Simulated and Areas Forced Daily Time series of Flows for Yanco Ck Offtake

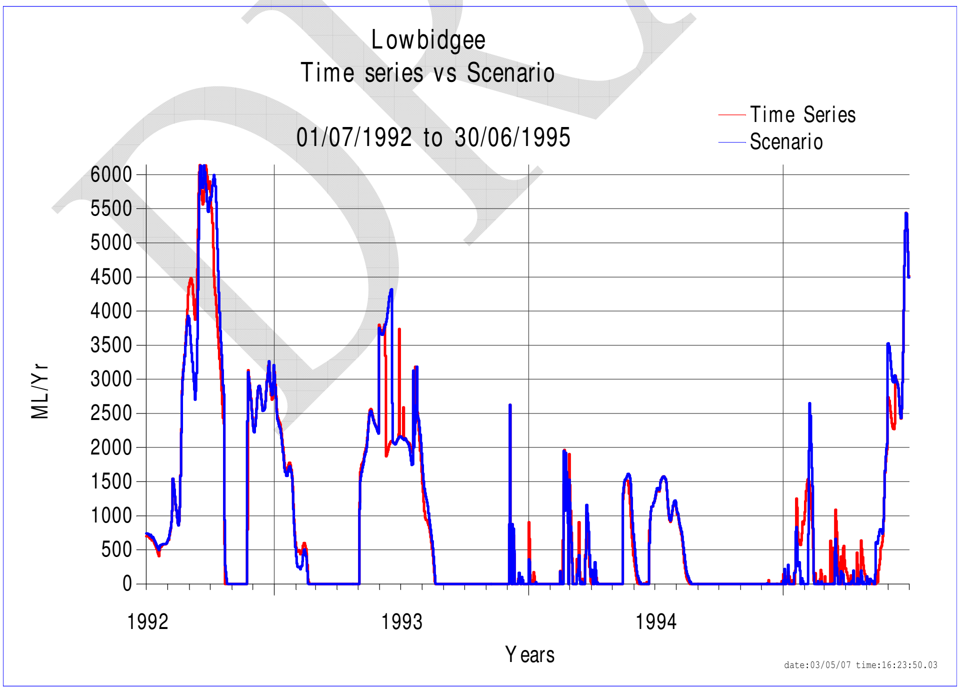

Figure 4-5 Fully Simulated and Areas Forced Daily Time series of Flows for Darlot

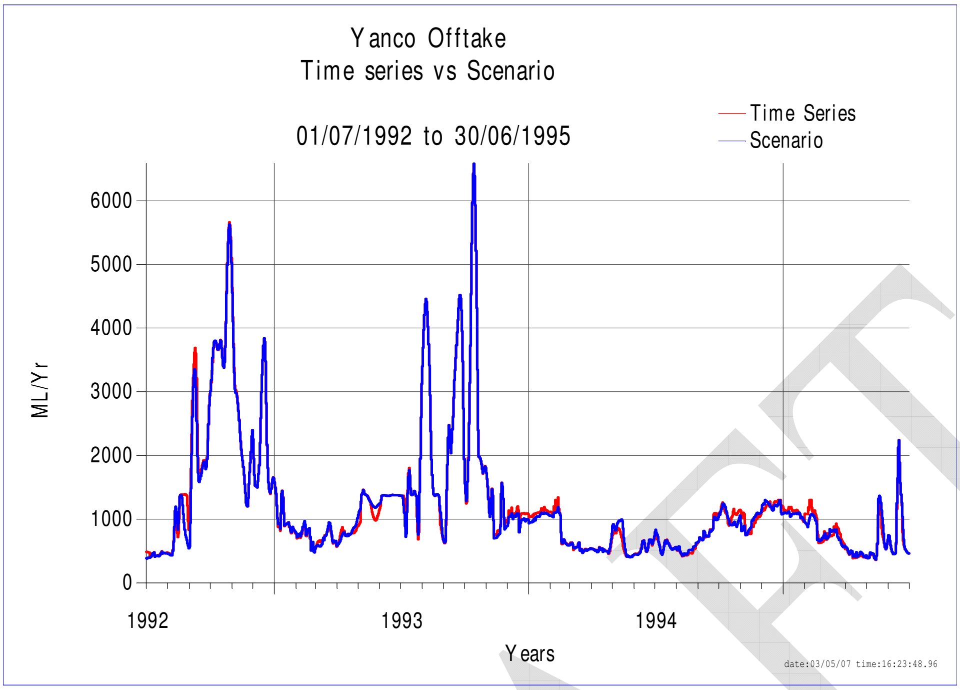

Figure 4-6 Fully Simulated and Areas Forced Daily Time series of Flows for Yanco Ck Offtake

4.13. RESULTS

Key results from the Cap Scenario are presented in the following sections.

4.13.1. Summary of the Cap scenario results

The summary results for the 103 year IQQM Cap simulation are presented in Table 4.4. Figure 4.5 shows annual time series general security diversions.

Table 4.4: Summary of the Cap scenario results (as set up in *Run pe20*)

Summary Aspect	Sub-aspect	Average (ML/year)
Water usage	Total Regulated diversions	2015.7 GL
	Total Lowbidgee diversions	302.8 GL
	High security irrigation	96.2 GL
	Town water supply (excluded within MIA)	12.1GL
	Total off allocation	315.6 GL
	Total	2742 GL
Crop model	Average area planted in water year	114,500 Ha
	Maximum area planted in a water year	166,800 Ha
River flows	Murrumbidgee at Wagga	4269 GL
	Murrumbidgee at Darlington Point	2044 GL
	Murrumbidgee at Balranald	1099 GL
	Billabong Creek at Darlot	329 GL

Murrumbidgee Supply Reliability on 01/01	60%	80%	100%	120%
(% of years that achieved ≥ stated % allocation)	99	84	72	52

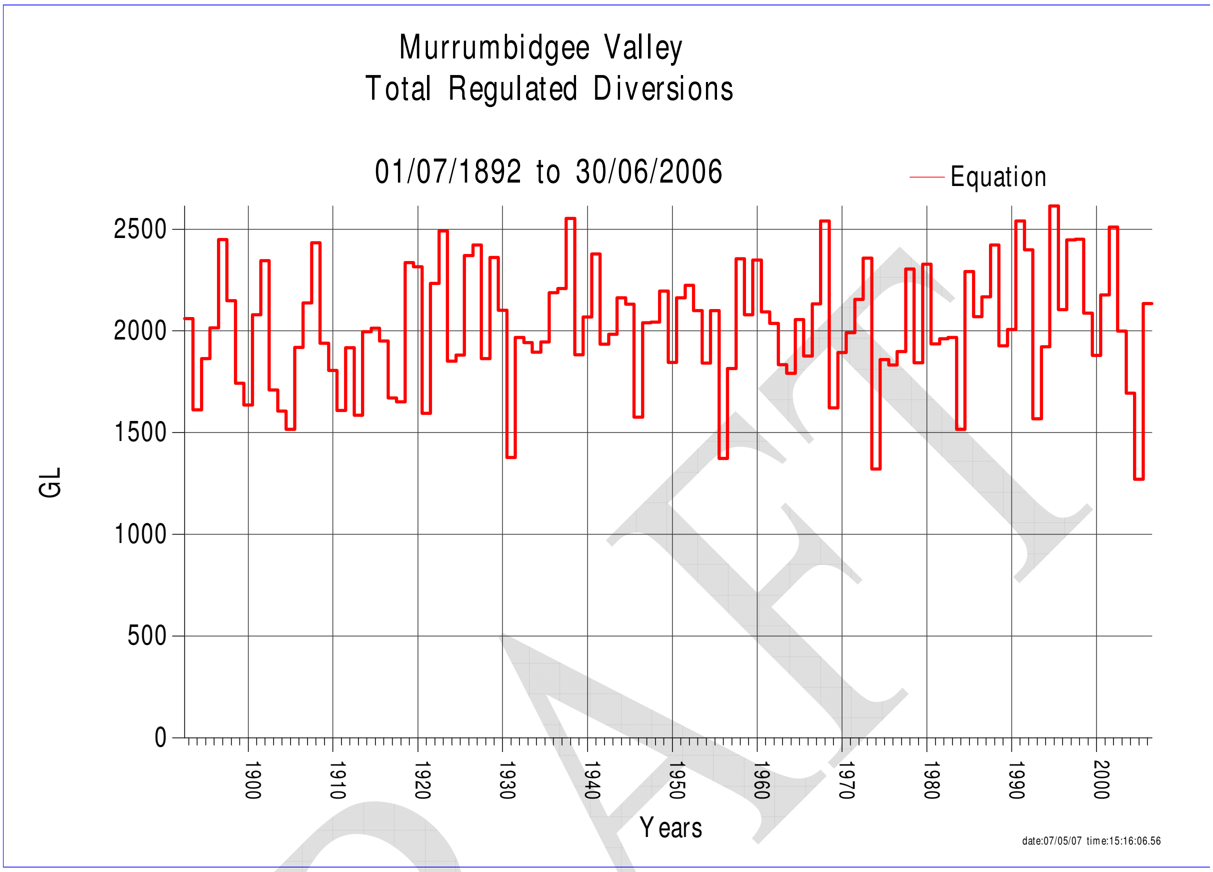

Figure 4-7 Murrumbidgee Valley Cap scenario simulated total annual diversions

4.13.2. Cap audit (Schedule F accounting simulation)

To assess Cap performance in each valley designated in Schedule F of the Murray-Darling Basin Agreement (MDBMC, 2000), annual Cap simulations using the relevant IQQM are performed. In the Murrumbidgee Valley, the Cap simulation commenced at the start of the 1997/98 water year (July), with storage levels initialised at observed values. The IQQM model then simulates continuously through subsequent water years using the observed climatic data as input and development and management rules fixed at 1993/94 levels.

To commence the Cap audit scenario, IQQM is started a few years before the commencement of the 1997/98 water year, to allow for the river system to fill with water, to provide a better starting soil moisture store and to get some stability in the winter to summer crop mix. Storage levels are set such that, at the commencement of the 1997/98 water year, they are the same as those observed in 1 July, 1997.

Table 4-3 Schedule F accounting For Regulated System

Water year	Observed							Modelled with **IQQM**					Difference	Cumulative
	Gross On-allocation diversions	Gross Off-allocation diversions	High flow license usage	Net inter-valley transfers from valley	CIA Return Flows	Mirrool & Cudgel Ck pumpers	Total diversions	Net On-allocation diversions	Net Off-allocation diversions	CIA Return Flows	Simulated IVT	Cap estimate from model	IQQM	IQQM
1997/98	2,471	25	0	33	-113	8	2,417	2,364	49	-139	10	2,413	-3	*-3*
1998/99	1,976	140	49	38	-124	8	2,079	1,725	332	-146	10	2,057	-22	-25
1999/00	1,641	118	1	114	-120	3	1,754	1,718	179	-172	10	1,897	142	118
2000/01	2,049	173	46	21	-149	7	2,139	1,793	368	-155	10	2,162	22	140
2001/02	2,250	54	4	-31	-130	6	2,146	2,450	2	-152	10	2,452	306	446
2002/03	1,711	39	1	14	-65	5	1,700	2,061	5	-109	10	2,065	365	811
2003/04	1,535	150	0	35	-44	6	1,676	1,645	60	-108	10	1,705	29	840
2004/05	1,483	202	0	-8	-30	6	1,646	1,229	58	-74	10	1,288	-359	481
2005/06	1,431	260	0	5	-44	0	1,651	2,049	20	-140	10	2,070	418	899
Cumulative	16,545	1,161	100	221	-819	48	17,209	17,034	1,074	-1,195	90	18,108	899	

Table 4-4 Schedule F accounting For Lowbidgee System

Water year	Observed			Modelled with **IQQM**			Difference between observed and modelled
	Maude Weir Diversions	Redbank Weir Diversions	Total diversions	Maude Weir Diversions	Redbank Diversions	Total Simulated Diversions	IQQM
1997/98	85	75	160	68	28	96	-64
1998/99	254	168	422	264	193	457	35
1999/00	105	87	192	158	54	212	20
2000/01	308	279	587	329	240	569	-18
2001/02	97	32	128	63	17	80	-48
2002/03	31	34	65	39	21	60	-5
2003/04	56	36	93	108	78	187	94
2004/05	30	47	77	61	30	91	14
2005/06	123	124	247	187	159	345	98
Cumulative	1,088	883	1,971	1,276	821	2,097	126
Long-term average Cap estimate:							296
20% of Long-term average Cap estimate:							59
Cumulative Cap performance:							**Below Cap**

Valley preliminary Schedule F account

5. Improvement Plans

The Cap Model represents conditions around 1993/94. This is now over 13 years ago. Many of the staff associated with the period have gone and the memories of those who have stayed have faded. This limits improving the area most important to any modelling effort of this kind and that is the data and operational knowledge that underpins it. Also if such information wasn't collected or documented then "archaeological" strategies to create it are always going to have limited success. The question also arises as to how much longer will 1993/94 remain a benchmark year. At the time of writing Water Plans foreshadowed by the Federal government and supported by the Federal Opposition suggest the benchmark has a life of no longer than five years. All this impacts on the return from investing in further improvements to the Cap Model.

Improvements to the cap model need also to be considered in the context of what the model is to be used for. That is to predict total valley diversions and end of system valley flows under cap levels of development and operating rules. Many possible improvements, whilst adding to predictive capability for many aspects of the system, are unlikely to significantly improve on the model's purpose for existence.

Nevertheless some improvements could add to model fitness for purpose and these are listed below.

Representation of non-substitution behaviour in supplementary periods. In a rare off allocation event during the 1994/95 season, it was observed that supplementary diversions seemed higher than would have been expected without there being a off allocation call. This was likely due to early pre-watering, extra filling of rice bays and filling the small number of on farm storage. In dry years, as in more recent time, such extra watering has become more important and its non representation can lead to underestimation of cap targets.

Representation of the variation in losses as the head gradient between the river and groundwater changes. In recent years, unaccounted for losses in the mid Murrumbidgee have increased markedly and not related to flow regime changes. The model's reliance on a single "average" flow loss relationship means it does not predict these extra losses and consequently may overestimate dry years cap targets. Further investigation may lead to a simple empirical dry years loss adjustment and seems worthy of being carried out.

Use of GUI software. The cap model's software can't take advantage of a wide variety of improvements and debugging that were part of the building of GUI IQQM. Whilst calibration and validation over a variety of conditions suggests reasonable model robustness there is no guarantee that GUI code would not provide different more robust Cap targets. As such the completion of a Murrumbidgee GUI cap model seems highly desirable.

Use of back calculated residual inflows. Cap auditing ideally requires that differences between Cap simulated and actual diversions be purely related to levels of development, irrigator behaviour and operating rules. Not due to inflow differences. The use of back calculated residual inflows would bring the modelling a step closer to the ideal. There are issues related to viability and consistency across all MDB cap models and these should be examined before further model development occurs in this area.

Modelling intra-valley trade. In years with allocations less than 120% trade provides for greater model utilisation of available resources. The river pumpers group in particular is reliant on such trade to be able to plant its desired areas of rice and other crop. The lack of trade representation leads to low cap targets if resource constrained years are followed by spill i.e. if not modelling trade results in greater end of system flows rather than just delaying usage. So further research into simple ways that can capture some of the trade processes seems warranted.

In reading this section it should be borne in mind that earlier chapters have demonstrated that the Murrumbidgee IQQM model does a reasonable job at reproducing historical behaviour. Also that Schedule F cap auditing does have a built in error margin. The emphasis here is more about ensuring that the Murrumbidgee IQQM model stay within that margin.

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Appendix A Climatic and Streamflow Stations

Table A-1 Rainfall stations used for Sacramento rainfall-runoff modelling

Catchment	Station	Name	Thiessen Weight
Hillas Ck. @ Mount Adrah (410043)	72000	Adelong P.O.	0.80
	72004	Batlow P.O.	0.20
Billabung Ck. @ Sunnyside (410045)	73124	Eurongilly	0.78
	73009	Cootamundra	0.22
Kyeamba Ck. @ Ladysmith (410048)	72008	Tarcutta	1.00
Gilmore Ck. @ Gilmore (410059)	72004	Batlow P.O.	0.50
	72044	Tumut	0.50
Brungle Ck. @ Red Hill (410071)	72044	Tumut	1.00
Bullenbung Ck @ Above Old Man Ck. (410087)	74021	The Rock	0.18
	74074	Mittagong Hend	0.34
	74053	Henty P.O.	0.23
	74195	Pulletop	0.25
Jugiong Ck. @ Jugiong (410025)	73029	Murrumburrah P.O.	1.00
Yass R. @ Yass (420026)	70042	Gundaroo	0.56
	70091	Yass	0.25
	70030	Bungendore	0.19
Adjungbilly Ck. @ Darbalara	72044	Tumut	0.58
	73125	Gundagai	0.42
Muttama Ck. @ Coolac (410044)	73009	Cootamundra P.O.	0.84
	73124	Eurongilly	0.16
Tarcutta Ck. @ Old Borambola (410047)	72042	Tarcutta P.O.	0.67
	72043	Tumbarumba P.O.	0.33
Goobarragandra R. @ Lacmalac (410057)	72044	Tumut	1.00
Adelong Ck. @ Batlow Road (410061)	72000	Adelong P.O.	0.34
	72004	Batlow P.O.	0.66
Billabong Ck. @ Walbundrie (410091)	74117	Walla Walla P.O.	0.15
	74188	Culcairn Bowling Club	0.25
	72022	Holbrook P.O.	0.40
	72008	Tarcutta	0.20
Houlaghans Ck. @ Downside (410103)	73124	Eurongilly	1.00

Table A-2 Evaporation stations used for catchment Sacramento rainfall-runoff modelling

Catchment	Station	Name	Thiessen Weight
Hillas Ck. @ Mount Adrah (410043)	72150	Wagga AMO	1.00
Billabung Ck. @ Sunnyside (410045)	72150	Wagga AMO	1.00
Kyeamba Ck. @ Ladysmith (410048)	72150	Wagga AMO	1.00
Gilmore Ck. @ Gilmore (410059)	72150	Wagga AMO	1.00
Brungle Ck. @ Red Hill (410071)	72150	Wagga AMO	1.00
Bullenbung Ck @ Above Old Man Ck. (410087)	72150	Wagga AMO	1.00
Jugiong Ck. @ Jugiong (410025)	72150	Wagga AMO	1.00
Yass R. @ Yass (420026)	?	?	1.00
Adjungbilly Ck. @ Darbalara	72150	Wagga AMO	1.00
Muttama Ck. @ Coolac (410044)	72150	Wagga AMO	1.00
Tarcutta Ck. @ Old Borambola (410047)	72150	Wagga AMO	1.00
Goobarragandra R. @ Lacmalac (410057)	72004	Batlow P.O.	1.00
Adelong Ck. @ Batlow Road (410061)	72150	Wagga AMO	1.00
Billabong Ck. @ Walbundrie (410091)	72150	Wagga AMO	1.00
Houlaghans Ck. @ Downside (410103)	72150	Wagga AMO	1.00

Table A-3 Rainfall stations used for dam inflow back-calculation

Catchment	Station	Name	Thiessen Weight
Murrumbidgee R. @ Burrinjuck Dam (410131)	73007	Burrinjuck Dam	1.00
Tumut R. @ Blowering Dam (41002)	410102	Blowering Dam	1.00

Table A-4 Evaporation stations used for dam inflow back-calculation

Catchment	Station	Name	Thiessen Weight
Murrumbidgee R. @ Burrinjuck Dam (410131)	73007	Burrinjuck Dam	1.00
Tumut R. @ Blowering Dam (41002)	72056	Blowering Dam	1.00

Table A-5 Main-stream gauging stations used in Murrumbidgee IQQM

Gauge Number	Gauge Name	Period of Record [1]
Main River		
410001	Murrumbidgee R. @ Wagga	23/12/1968 – 30/06/2004
410003	Murrumbidgee R. @ Balranald	(to be confirmed)
410004	Murrumbidgee R. @ Gundagai	16/10/1969 – 30/06/2004
410005	Murrumbidgee R. @ Narrandera	01/07/1984 – 30/06/2004
410006	Tumut R. @ Tumut	04/04/1970 – 30/06/2004
410008	Murrumbidgee R. @ D/S Burrinjuck Dam	01/01/1990 to 07/08/2006
410021	Murrumbidgee R. @ Dartlington Point	01/07/1984 to 30/06/2004
410023	Murrumbidgee R. @ D/S Berembed Weir	14/05/1999 to 30/06/2004
410036	Murrumbidgee R. @ D/S Yanco Weir	01/07/1984 to 30/06/2004
410039	Tumut R. @ Brungle Bridge	04/04/1970 – 30/06/2004
410040	Murrumbidgee R. @ D/S Maude Weir	(to be confirmed)
410073	Tumut R. @ Oddys Bridge	22/10/1975 to 08/08/2006
410078	Murrumbidgee R. @ Carrathool	(to be confirmed)
410082	Murrumbidgee R. @ D/S Gogeldrie Weir	01/07/1984 to 30/06/2004
410130	Murrumbidgee R. @ D/S Balranald Weir	(to be confirmed)
YCB system		
410007	Yanco Ck @ Offtake	11/01/1979 to 29/10/2006
410012	Billabong Ck @ Cocketgedong	07/05/1973 to 09/11/2006
410014	Colombo Ck @ Morundah	01/10/1978 to 09/11/2006
410015	Yanco Ck @ Morundah	08/03/1977 to 09/11/2006
410016	Billabong Ck @ Jerilderie	01/10/1984 to 09/11/2006
410017	Billabong Ck @ Conargo (Puckawidgee)	31/07/1968 to 15/08/2006
410091	Billabong Ck @ Walbundrie	13/05/1981 to 20/07/2006
410108	Coleambally Drainage Canal 800 @ Outfall	03/12/1992 to 04/07/2006
410110	Drainage Canal 500 @ Outfall	09/03/1977 to 29/08/2006
410133	Coleambally Outfall Drain @ Near Bundy	26/02/1993 to 13/11/2006
410134	Billabong Ck @ Darlot	29/04/1978 to 22/08/2006
410135	Coleambally Catchment Drain @ Farm 544	13/11/1992 to 03/07/2003
410148	Forest Ck @ Warriston Weir	01/09/1980 to 20/11/2006
410168	Billabong Ck @ D/S Hartwood Weir	21/09/1995 to 16/11/2006
410169	Yanco Ck @ Yanco Bridge	18/09/1995 to 06/07/2006
410170	Billabong Ck @ U/S Innes Bridge	21/09/1995 to 04/07/2006
410191	Coleambally Catchment Drain @ Outfall into Yanco Ck	01/10/2002 to 04/07/2006
41010309	Forest Ck @ Offtake [2]	14/04/2006 to 07/01/2007

Notes: (1) Period of record used for calibration of Murrumbidgee IQQM

(2) River operational data 01/08/1995-16/09/2006

Table A-6 Tributary gauging stations used in Murrumbidgee IQQM

Gauge Number	Gauge Name	Period of Record [(1)]
410012	Billabong Ck @ Cocketgedong	08/05/1973 to 30/06/2006
410013	Main Canal @ Berembed	(need to be checked)
410024	Goodradigbee R. @ Wee Jasper	19/09/1914 to 30/06/2006
410025	Jugiong Ck. @ Jugiong	01/02/1914 to 30/06/2006
410038	Adjungbilly Ck. @ Darbalara	31/05/1967 to 30/06/2006
410044	Muttama Ck. @ Coolac	05/05/1938 to 30/06/2006
410047	Tarcutta Ck. @ Old Borambola	07/05/1938 to 30/06/2006
410057	Goobarragandra R. @ Lacmalac	24/05/1957 to 30/06/2006
410061	Adelong Ck. @ Batlow Road	11/09/1947 to 30/06/2006
410083	Yanco Main Southern Drain @ Outfall	(need to be checked)
410091	Billabong Ck. @ Walbundrie	12/05/1981 to 30/06/2006
410093	Old Man Ck. @ Kywong	22/07/1976 to 30/06/2006
410103	Houlaghans Ck. @ Downside	24/06/1965 to 30/06/2006
410137	Beavers Ck. @ Mundowey	13/05/1999 to 30/06/2006

Notes: (1) Period of record used for input to Murrumbidgee IQQM

Table A-7 Evaporation and rainfall stations used by river pumper in IQQM

Geographic Zone	Evap Station	Name	Rain Station	Name
Murrumbidgee R: Tumut R. to Wagga	73125	Gundagai	73015	Gundagai
	72150	Wagga AMO	72150	Wagga AMO
Murrumbidgee R: Wagga to Old Man Ck return	74148	Narrandera Airport	72150	Wagga AMO
Murrumbidgee R: Old Man Ck return to Darlington Point	75174	Griffith	74062	Leeton
Murrumbidgee R: Darlington Point to Carrathool	75174	Griffith	75067	Carrathool
Murrumbidgee R: Carrathool to Hay	75174	Griffith	75067	Carrathool
			75031	Hay
Murrumbidgee R: Hay to Maude	75174	Griffith	75031	Hay
Murrumbidgee R: Maude to Redbank Weir	75174	Griffith	49002	Balranald
Murrumbidgee R: Redbank Weir to Balranald	75174	Griffith	49002	Balranald
Main Canal	75174	Griffith	75174	Griffith
			74062	Leeton
			74094	Barellan
			75142	Merriwagga
Sturt Canal	75174	Griffith	75174	Griffith
			74062	Leeton
Barren Box Swamp	75174	Griffith	75142	Merriwagga
			75140	Gunbar
Coleambally Canal	75174	Griffith	74249	Coleambally WRC
Yanco Ck: OT-Morundah	75174	Griffith	74062	Leeton
Yanco Ck: Morundah - Yanco Br	75174	Griffith	74249	Coleambally WRC
Yanco Ck: Yanco Br-Puckawidgee	75174	Griffith	74249	Coleambally WRC
Colombo Ck/Billabong Ck	75174	Griffith	74249	Coleambally WRC
			74128	Deniliquin
Billabong Ck: Yanco Junction to Darlot	75174	Griffith	74128	Deniliquin

Table A-8 Evaporation stations used in IQQM for Reservoir and River Net Evaporation

Geographic Zone	IQQM Reaches	Evap Station	Name
Murrumbidgee R: Burrinjuck Dam to Tumut R.	RS01	73007	Burrinjuck Dam
Tumut R: Blowering Dam to Murrumbidgee R.	RS02	72056	Blowering Dam
Murrumbidgee R: Tumut R. to Wagga	RS03	73007	Burrinjuck Dam
		72150	Wagga AMO
Murrumbidgee R: Wagga to Old Man Ck return	RS05	72150	Wagga AMO
	RS06	72150	Wagga AMO
Murrumbidgee R: Old Man Ck return to Darlington Point	RS07	75028	Griffith CSIRO
Murrumbidgee R: Darlington Point to Carrathool	RS09	75028	Griffith CSIRO
Murrumbidgee R: Carrathool to Hay	RS11	75028	Griffith CSIRO
	RS13	75028	Griffith CSIRO
Murrumbidgee R: Hay to Maude	RS15	49002	Balranald
Murrumbidgee R: Maude to Redbank Weir	RS17	49002	Balranald
Murrumbidgee R: Balranald to Flow to Murray	RS23	49002	Balranald
Coleambally Canal	RS48	75028	Griffith CSIRO
Yanco Ck: OT-Morundah	RS49	75028	Griffith CSIRO
Yanco Ck: Morundah - Yanco Br	RS51	75028	Griffith CSIRO
	RS53	75028	Griffith CSIRO
	RS56	75028	Griffith CSIRO
Yanco Ck: Yanco Br-Puckawidgee	RS57	74128	Deniliquin PO
	RS59	74128	Deniliquin PO
Colombo Ck/Billabong Ck	RS60	75028	Griffith CSIRO
	RS62	74128	Deniliquin PO
		75028	Griffith CSIRO
Billabong Ck: Yanco Junction to Darlot	RS63	74128	Deniliquin PO
	RS64	74128	Deniliquin PO

Table A-9 Rainfall stations used in IQQM for reach net evaporation

Geographic Zone	IQQM Reaches	Rain Station	Name
Murrumbidgee R: Burrinjuck Dam to Tumut R.	RS01	73007	Burrinjuck Dam
		73015	Gundagai
Tumut R: Blowering Dam to Murrumbidgee R.	RS02	72044	Tumut
		73015	Gundagai
Murrumbidgee R: Tumut R. to Wagga	RS03	73015	Gundagai
		72150	Wagga AMO
Murrumbidgee R: Wagga to Old Man Ck return	RS05	72150	Wagga AMO
		74062	Leeton
Murrumbidgee R: Old Man Ck return to Darlington Point	RS07	74062	Leeton
Murrumbidgee R: Darlington Point to Carrathool	RS09	75174	Griffith
Murrumbidgee R: Carrathool to Hay	RS11	75067	Carrathool
	RS13	75067	Carrathool
		75031	Hay
Murrumbidgee R: Hay to Maude	RS15	75031	Hay
Murrumbidgee R: Maude to Redbank Weir	RS17	49002	Balranald
Murrumbidgee R: Balranald to Flow to Murray	RS23	49002	Balranald
Coleambally Canal	RS48	74249	Coleambally WRC
Yanco Ck: OT-Morundah	RS49	74062	Leeton
Yanco Ck: Morundah - Yanco Br	RS51	74249	Coleambally WRC
	RS53	74249	Coleambally WRC
	RS56	74249	Coleambally WRC
Yanco Ck: Yanco Br-Puckawidgee	RS57	74128	Deniliquin PO
	RS59	74128	Deniliquin PO
Colombo Ck/Billabong Ck	RS60	74249	Coleambally WRC
	RS62	74249	Coleambally WRC
		74128	Deniliquin PO
Billabong Ck: Yanco Junction to Darlot	RS63	49002	Balranald
		74128	Deniliquin PO
	RS64	49002	Balranald
		74128	Deniliquin PO

Appendix B Model Configuration

Table B-1 Functional elements represented in IQQM

Element Type	*Number of Items*	*Description of Items*
Direct tributary inflows	5	• Burrinjuck Dam inflows from back-calculation (13,100 sq.km) • Blowering Dam inflows from back-calculation (adjusted for Snowy) (1,630 sq.km) • At gauge 410103 – Houlaghans Ck @ Downside (1,130 sq.km) • At gauge 410087 – Bullenbung Creek @ Above Old Man Creek (1,350 sq.km) • At Finley Escape – Finley Escape Inflow (N/A)
Direct tributary inflows - routed to mainstream junction.	11	♦ From gauge 410057 – Goobarragandra River @ Lacmalac (673 sq.km) ♦ From gauge 410059 – Gilmore Creek @ Gilmore (277 sq.km) ♦ From gauge 410071 – Brungle Creek @ Red Hill (114 sq.km) ♦ From gauge 410038 - Adjungbilly Creek @ Darbalara (391 sq.km) ♦ From gauge 410025 – Jugiong Creek @ Jugiong (2,120 sq.km) ♦ From gauge 410044 – Muttama Creek @ Coolac (1,025 sq.km) ♦ From gauge 410061 – Adelong Creek @ Batlow Road (144 sq.km) ♦ From gauge 410045 - Billabung Creek @ Sunnyside (827 sq.km) ♦ From gauge 410043 – Hillas Creek @ Mount Adrah (568 sq.km) ♦ From gauge 410047 - Tarcutta Ck @ Old Borambola (1,660 sq.km) ♦ From gauge 410048 - Kyeamba Ck @ Ladysmith (530 sq.km)
Residual catchment inflows	8	➢ 150 sq.km area between Oddys Bridge and Tumut ➢ 423 sq.km area between Tumut and Brungle Bridge ➢ 1,565 sq.km area between D/S Burrinjuck Dam and Gundagai ➢ 338 sq.km area between Batlow Road and outlet of Adelong Creek ➢ 994 sq.km area between Sunnyside and outlet of Billabung Creek ➢ 252 sq.km area between Mount Adrah and outlet of Hillas Creek

		➢ 128 sq.km area between Old Borambola and outlet of Tarcutta Creek ➢ 278 sq.km area between Ladysmith and outlet of Kyeamba Creek
Mainstream river flow calibration reaches	24+	▪ Oddys Bridge (410073) to Tumut (410006) ▪ Tumut (410006) to Brungle Bridge (410039) ▪ D/s Burrinjuck Dam (410008) to Gundagai (410004) ▪ Gundagai (410004) to Wagga Wagga (410001) ▪ Mundowey (410137) (Old Man Ck) to Kywong (410093) (Old Man Ck) ▪ Wagga Wagga (410001) to D/S Berembed (410023) ▪ D/S Berembed (410023) to Narrandera (410005) ▪ Narrandera (410005) to D/S Yanco Weir (410036) ▪ D/s Yanco Weir (410036) to D/S Gogeldrie Weir (410082) ▪ D/s Gogeldrie Weir (410082) to Darlington Point (410021) ▪ Darlington Point (410021) to Carrathool (410078) ▪ Carrathool (410078) to D/s Hay Weir (410136) ▪ D/s Hay Weir (410136) to D/s Maude Weir (410040) ▪ D/s Maude Weir (410040) to D/s Redbank Weir (410041) ▪ D/s Redbank Weir (410041) to Balranald (410003) / D/s Balranald Weir (410130) ▪ Yanco Ck Offtake (410007) to Morundah (410015) ▪ Yanco Morundah (410015) to Yanco Bridge (410169) ▪ Yanco Bridge (410169) to Puckawidgee (410017) ▪ Colombo Morundah (410014) to Innes Bridge (410170) ▪ Innes Bridge (410170) to Jerilderie (410016) ▪ Jerilderie (410016) to D/S Hartwood Weir (410168) ▪ Forest Ck Offtake (41010309) to Warriston Weir (410148) ▪ DC500 Outfall (410110) to Bundy (410133) ▪ Puckawidgee (410017) to Darlot (410134)
Storages (on and off-river types)	9	❑ Burrinjuck Dam ❑ Blowering Dam ❑ Berembed Weir ❑ Yanco Weir ❑ Tombullen Storage ❑ Gogeldrie Weir ❑ Hay Weir ❑ Maude Weir

		❑ Redbank Weir
Stream gauge points suitable for transmission loss & flow calibration	33+	These are the 27+ gauge points listed above under mainstream river reaches. This list does not include the 13 tributary inflow gauge points (see beginning of table, above).
General security Irrigator Group extractions	26	One group cluster in each defined river flow reach, plus Murrumbidgee Irrigation and Coleambally Irrigation Areas.
High security Irrigator Group extractions	11	Only the following reaches had HS licences: Main Canal and Sturt Canal.
Stock and Domestic (subsistence) extractions	1	Forest Creek
Wetland replenishments	N/A	N/A
TWS extractions	11	(Table 2-7)
Effluent offtakes that return	11	Murrumbidgee River to Beavers Creek Murrumbidgee Rvier to Yanco Creek Yanco Creek to Colombo Creek Billabong Creek to Forest Creek Murrumbidgee River d/s Redbank Weir Gauge out to in Murrumbidgee River to Lowbidgee Sturt Canal to Mirrool Creek (x 2) Barren Box Swamp to Wah Wah Irrigation Area Coleambally Canal to Catchment Drain Coleambally Canal to Drainage Canal
Effluent offtakes that don't return	2	Lowbidgee flood breakout Coleambally Outfall Drain loss
Transmission loss allowance points	24+	In each of the flow calibration reaches
Confluences	32	Murrumbidgee River and Tumut River Murrumbidgee and Old Man Creek Murrumbidgee River and Lowbidgee Mirrool Creek and Little Mirrool Creek Mirrool Creek and Main Drain J Mirrool Creek and Main Canal (x 2) Main Canal and Sturt Canal Coleambally Canal and West CIA Drain Yanco Creek and Catchment Drain

		Yanco Creek and Drain Canal Yanco Creek and Billabong Creek Billabong Creek and Coleambally Outfall Drain Virtual confluence (19)
Off-allocation reaches	28	In all reaches d/s Kyeamba Creek Confluence with off-allocation access
Minimum Flow control nodes	17 (9.0) 33 (9.1)	Murrumbidgee River immediately d/s of Burrinjuck Dam (9.0) Murrumbidgee River at Burrinkuck Dam translucent/transparent release (9.0) Murrumbidgee River d/s Kyeamba Creek Confluence (9.1) Murrumbidgee River u/s Wagga TWS (9.1) Murrumbidgee River d/s Wagga gauge (9.1x2) Beavers Creek u/s Beavers Creek gauge (9.1) Tumut River immediately d/s of Blowering Dam (9.0) Murrumbidgee River d/s of Old Man Creek return (9.0x1, 9.1x1) Murrumbidgee River d/s Sturt Canal diversion (9.1x3) Murrumbidgee River u/s Darlington Point TWS (9.1) Murrumbidgee River u/s Carrothool TWS (9.1) Murrumbidgee River u/s Hay TWS (9.1) Murrumbidgee River d/s Hay Weir (9.1) Murrumbidgee River d/s Maude Weir (9.1) Murrumbidgee River u/s Balranald TWS (9.1) Murrumbidgee River u/s Balranald Weir gauge (9.1) Murrumbidgee River u/s flow into River Murray (9.1) Murrumbidgee River at flow into River Murray (9.0) Murrumbidgee River at IVT requirement (9.0) Main Canal d/s inflow (9.1) Sturt Canal d/s inflow (9.1) Mirrool Creek at MI Tabbita re-order (9.0) Mirrool Creek at adjusted order for anticipation of Brays Dam return (9.0) Mirrool Creek u/s Benerembah 4 irrigation (9.1) Mirrool Creek Sturt Canal to Mirrool Creek supplementary (9.1) MIA at Wah Wah North off-allocation (9.1) MIA at Wah Wah South (9.1) Mirrool Creek d/s of Barren Box Swamp (9.0) Coleambally Canal d/s diversion inflow (9.0x1, 9.1x1) Yanco Creek d/s offtake (9.0x1, 9.1x1)

		Yanco Creek d/s Colombo Creek diversion (9.0) Yanco Creek d/s Catchment Drain Confluence (9.1) Yanco Creek u/s DC800 Confluence (9.1) Yanco Creek d/s DC800 Confluence (9.0x1, 9.1x1) Yanco Creek u/s Billabong Creek Confluence (9.1) Colombo Creek d/s Colombo Creek inflow (9.0x1, 9.1x1) Colombo Creek u/s Billabong Creek inflow (9.1) Billabong Creek d/s Forest Creek diversion (9.0) Billabong Creek u/s Puckawidgee Gauge (9.1) Billabong Creek u/s Darlot Gauge (9.1) Billabong Creek d/s Darlot (9.0) Forest Creek d/s Forest Creek inflow (9.0)

Table B-2 IQQM Crop Factors

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MIA												
W Cereal	0.00	0.00	0.25	0.25	0.32	0.39	0.73	0.84	0.84	0.66	0.28	0.00
Fallow & Misc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fodder	0.63	0.63	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.56	0.63
Lucerne	1.30	1.28	1.23	1.15	0.96	0.74	0.65	0.71	0.91	1.15	1.28	1.30
S Oil seed	0.75	0.96	0.89	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
W Oil seed	0.00	0.00	0.00	0.30	0.43	0.58	0.69	0.74	0.74	0.64	0.42	0.00
Orchard	0.52	0.52	0.56	0.56	0.56	0.56	0.56	0.56	0.52	0.49	0.49	0.49
S Pasture	0.70	0.70	0.70	0.66	0.00	0.00	0.00	0.00	0.42	0.56	0.70	0.70
W Pasture	0.00	0.25	0.39	0.56	0.59	0.56	0.56	0.56	0.52	0.35	0.25	0.00
Rice	0.94	0.94	0.77	0.25	0.00	0.00	0.00	0.00	0.00	0.70	0.80	0.87
Vegetable	0.64	0.56	0.43	0.38	0.49	0.54	0.54	0.51	0.45	0.59	0.64	0.65
Vine	0.56	0.49	0.39	0.00	0.00	0.00	0.00	0.32	0.42	0.52	0.52	0.52
CIA												
S Cereal	0.85	0.85	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.50	0.70
W Cereal	0.00	0.00	0.25	0.25	0.32	0.39	0.73	0.84	0.84	0.66	0.28	0.00
Citrus	0.35	0.35	0.35	0.35	0.42	0.42	0.42	0.42	0.42	0.42	0.35	0.35
Fodder	0.63	0.63	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.56	0.63
Lucerne	1.30	1.28	1.23	1.15	0.96	0.74	0.65	0.71	0.91	1.15	1.28	1.30
S Oil seed	0.75	0.96	0.89	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
W Oil seed	0.00	0.00	0.00	0.30	0.43	0.58	0.69	0.74	0.74	0.64	0.42	0.00
W Pasture	0.00	0.25	0.39	0.56	0.59	0.56	0.56	0.56	0.52	0.35	0.25	0.00
Rice	0.94	0.94	0.77	0.25	0.00	0.00	0.00	0.00	0.00	0.70	0.80	0.87
Vegetable	0.64	0.56	0.43	0.38	0.49	0.54	0.54	0.51	0.45	0.59	0.64	0.65
Vine	0.35	0.35	0.35	0.35	0.42	0.42	0.42	0.42	0.42	0.42	0.35	0.35
Individual Irrigators												
S Cereal	0.94	0.80	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.38	0.77
W Cereal	0.00	0.00	0.25	0.25	0.32	0.39	0.73	0.84	0.84	0.66	0.28	0.00
Citrus	0.50	0.50	0.50	0.50	0.60	0.60	0.60	0.60	0.60	0.60	0.50	0.50
Cotton	1.17	1.20	1.10	0.74	0.00	0.00	0.00	0.00	0.00	0.28	0.36	0.75
Fava Bean	0.00	0.00	0.00	0.00	0.31	0.35	0.35	0.49	0.76	0.80	0.60	0.27
Legume	0.80	0.58	0.24	0.24	0.31	0.35	0.35	0.49	0.76	0.80	0.94	0.97
Lucerne	1.30	1.28	1.23	1.15	0.96	0.74	0.65	0.71	0.91	1.15	1.28	1.30

Maize	1.20	1.17	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.41	0.97
S Oil seed	0.75	0.96	0.89	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
W Oil seed	0.00	0.00	0.00	0.30	0.43	0.58	0.69	0.74	0.74	0.64	0.42	0.00
Orchard	0.35	0.35	0.35	0.35	0.42	0.42	0.42	0.42	0.42	0.42	0.35	0.35
Other Perennial	0.35	0.35	0.35	0.35	0.42	0.42	0.42	0.42	0.42	0.42	0.35	0.35
S Other	0.70	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.56	0.63
S Other	0.00	0.07	0.42	0.56	0.56	0.42	0.42	0.49	0.63	0.63	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W Pasture 1	0.00	0.25	0.39	0.56	0.59	0.56	0.56	0.56	0.52	0.35	0.25	0.00
W Pasture 2	0.00	0.25	0.39	0.56	0.59	0.56	0.56	0.56	0.52	0.35	0.25	0.00
Rape	0.00	0.00	0.00	0.30	0.43	0.58	0.69	0.74	0.74	0.64	0.42	0.00
Rice	0.94	0.94	0.77	0.25	0.00	0.00	0.00	0.00	0.00	0.70	0.80	0.87
Soya Bean	0.75	0.96	0.89	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Turf	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Vegetable	0.64	0.56	0.43	0.38	0.49	0.54	0.54	0.51	0.45	0.59	0.64	0.65
Vine	0.56	0.49	0.39	0.00	0.00	0.00	0.00	0.32	0.42	0.52	0.52	0.52
Wheat	0.00	0.00	0.24	0.24	0.31	0.38	0.73	0.84	0.84	0.66	0.28	0.00

Table B-3 Tributary utilisation factors

Gauge Number	Gauge Name	Utilisation
410057	Goobarragandra R	100%
	Res 073-006	100%
410059	Gilmore Ck	100%
	Res 006-039	100%
410071	Brungle Ck	100%
410038	Adjungbilly Ck	100%
410025	Jugiong Ck	100%
	Res 008-004-1	100%
	Res 008-004-2	100%
410044	Muttama Ck	100%
410061	Adelong Ck	90%
	Res 061	90%
410045	Billabung Ck	90%
	Res 045	90%
410043	Hillas Ck	85%
	Res 043	85%
410047	Tarcutta Ck	85%
	Res 047	85%
410048	Kyeamba Ck	85%
	Res 048	85%
410103	Houlaghans Ck	40%
410012	Billabong Ck	0%
	Nowranie and bypassing	0%
410087	Bullenbung Ck	100% ?

Table B-4 Streamflow calibration reaches in Murrumbidgee IQQM

Rch	Upstream Location			to	Downstream Location		
	Stream	***Station***	***No.***		***Stream***	***Station***	***No.***
	Tumut	Oddys Bridge	410073		Tumut	Tumut	410006
	Tumut	Tumut	410006		Tumut	Brungle Bridge	410039
	Murrumbidgee	D/S Burrinjuck Dam	410008		Murrumbidgee	Gundagai	410004
	Murrumbidgee	Gundagai	410004		Murrumbidgee	Wagga Wagga	410001
	Murrumbidgee	Wagga Wagga	410001		Murrumbidgee	D/S Berembed Weir	410023
	Murrumbidgee	D/S Berembed Weir	410023		Murrumbidgee	Narrandera	410005
	Murrumbidgee	Narrandera	410005		Murrumbidgee	D/S Yanco Weir	410036
	Murrumbidgee	D/S Yanco Weir	410036		Murrumbidgee	D/S Gogeldrie Weir	410082
	Murrumbidgee	D/S Gogeldrie Weir	410082		Murrumbidgee	Dartlington Point	410021
	Murrumbidgee	Dartlington Point	410021		Murrumbidgee	Carrathool	410078
	Murrumbidgee	Carrathool	410078		Murrumbidgee	D/S Hay Weir	410136
	Murrumbidgee	D/S Hay Weir	410136		Murrumbidgee	D/S Maude Weir	410040
	Murrumbidgee	D/S Maude Weir	410040		Murrumbidgee	D/S Redbank Weir	410041
	Murrumbidgee	D/S Redbank Weir	410041		Murrumbidgee	D/S Balranald Weir	410130
	Beavers/Old Man	Mundowey	410137		Beavers/Old Man	Kywong	410093
	Yanco	Offtake	410007		Yanco	Morundah	410015
	Yanco	Morundah	410015		Yanco	Yanco Bridge	410169
	Colombo	Morundah	410014		Billabong	U/S Innes Bridge	410170
	Billabong	U/S Innes Bridge	410170		Billabong	Jerilderie	410016
	Billabong	Jerilderie	410016		Billabong	D/S Hartwood Weir	410168
	Yanco Billabong	Yanco Bridge D/S Hartwood Weir	410169 410168		Billabong	Puckawidgee	410017
	Billabong	Puckawidgee	410017		Billabong	Darlot	410134
	Forest	Offtake	41010309		Forest	Warriston Weir	410148

Table B-5 Wagga Wagga Rising Limb Surplus Thresholds for OFA Announcements

Location	Flow (surplus) thresholds in ML/d											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wagga Wagga	5000	6500	5500	4500	4500	4500	4500	3500	4500	4500	5500	5500

•

Appendix C Modelling the Planting Decision

C1 IQQM planting decision

IQQM is capable of simulating a planted area for each irrigation node, based upon water availability, for a summer and winter crop each year. Each crop type that is specified is modelled separately as either a summer crop (generally configured to commence in October) or a winter crop (generally configured to commence in March), and has a series of monthly crop factors and crop watering efficiency factors.

Analysis of irrigator behaviour has indicated that there is a complex inter-relationship between numerous climatic, economic and social influences and the decision to plant particular areas of various crop types. To attempt to represent all of these influences is considered too complex to model within IQQM. To develop the IQQM planting decision, some fundamental assumptions regarding irrigators' behaviour as a group have been made, based on observed behaviour and numerous discussions with irrigation representatives.

It has been assumed that irrigators would generally seek to plant some maximum area for a notional level of development and set of economic and social conditions, given sufficient water availability. As resources are constrained due to climatic variability, they would respond by planting smaller areas based on an apparent application rate. This application rate (or "Irrigators' Planting Risk") would represent a number of influences not specifically modelled within IQQM. At some point of resource constraint, irrigators would seek to plant a minimum area based on possible future resources becoming available, economic pressures and the need to maintain perennial crops.

The irrigators' planting risk will reflect the influence of a number of factors including commodity prices, individual farm finances, antecedent climatic conditions and water availability in recent seasons. However, the ability to represent these influences explicitly within IQQM has not been developed yet, in part due to a lack of reliable information. It is clear, however, that the available water at the planting decision date is the most influential variable on the area planting decision. Consequently, a relationship between the planted area and water availability only has been adopted.

The total area to be planted is determined by the following relationship:

Total Area = Current Water Available / Irrigators' Planting Risk

Limited to a maximum and minimum planted area, where:

Current Water Available = Current Announced Allocation * Licensed Entitlement + Water in Storage on Farm + Carryover water (from last season)

Irrigators' Planting Risk = An "apparent application rate" based on the Total Area and the Current Water Available at the planting decision date. This apparent application rate will reflect a number of influences including: the actual crop water requirements, expectations that the irrigators may have in regard to further increases in announced allocation, future access to off-allocation, rainfall on the crop during the growing season and a range of economic considerations.

An irrigator's planting decision is generally regarded as being specific to a particular model scenario (eg 1993/94 development), and is calibrated as part of the scenario development. The selection of a calibration period for a model scenario is based on the assumption that irrigator behaviour (including climatic, social and economic influences) not specifically addressed within IQQM will remain constant. The further away from the chosen scenario period the data used to base the IQQM planting decision, the less likely the assumption regarding stability with regard to the external influences is to remain true.

The mix of crop types that make up the total area and their relative portion of the total area are specified as input for a given simulation and remain unchanged for the entire simulation period.

C2 Calibration

As mentioned above, the area planting decision in IQQM can be performed separately for both the summer and winter crops. When calibrating the planting decision module, parameters derived in earlier calibration stages are used, while off-allocation extractions are forced to observed data. The main objective of this calibration stage is to generate the observed planted areas (DLWC, 1998[d]) over a period of time that is appropriate for the scenario in which it will be used. Consequently, the planting decision is intended to be calibrated such that it is appropriate for each scenario run.

There are several important factors that need to be considered in this process, including:

- The effects of growth in utilisation of entitlement;
- Changes to the crop mix;
- Effects of trade on available water at each irrigation node; and
- The representation of irrigator behaviour under resource constrained conditions.

Periods in which substantial growth is occurring will have ever increasing maximum areas (and could well have a different level of irrigators' risk in each season) and are generally considered inappropriate for planting decision calibration. Similarly, varying crop mixes will also affect the relationship between the total planted area and water availability within IQQM. For example, the total planted area in a valley may decrease for the same water availability, but this may not indicate a decrease in risk if the crop mix is changing from a low water use crop to a high water use crop.

C3 Irrigators' planting risk

As resources are constrained due to climatic variability, they would respond by planting smaller areas based on an apparent (or planned) application rate. This application rate (or "Irrigators' Planting Risk") would represent a number of influences not specifically modelled within IQQM. Clearly, the major factor is resource availability, and it is upon this variable that IQQM makes its planting decision. Each grouping of irrigation is separately configured to plant area using the apparent application rate that provides the best calibration with observed data.

C4 Maximum area

The maximum planted area specified is planted in IQQM every time there are sufficient resources available to do so. In practice, it is observed that this is not the case and that there will be some variation from year to year, even if economic conditions remain largely unaltered. This is thought to be due to the need to rotate land on the farms, and variations in local climate affecting soil moisture at the planting decision date. To best represent this variation, the average maximum area for the entire valley over the calibration period is used.

This maximum planted area was disaggregated to the irrigation nodes based on the maximum observed planted area in that irrigation node up to the 1989/90 irrigation season, with a sanity check based on the maximum area that each could plant given their licence and on-farm storage volumes and approximate application rates.

C5 Minimum area

The concept of a minimum planted area is based on the notion that, at some point of severe resource constraint, irrigators will not continue to reduce their planted areas. This is assumed to be the result of a number of factors which include the need to keep perennial crops such as lucerne alive, the costs associated with replacing them, and an attempt to maintain a minimal amount of production from opportunistic resource availability to provide cash flow.

For those valleys where extreme shortages of available resource have been observed over several seasons, the apparent risk taken by irrigators' has shown significant variation. It seems likely that, in the first season of extreme resource constraint, irrigators' will take a significantly higher risk than in subsequent seasons of drought.

Similarly to maximum areas, to represent such variability in the minimum areas planted by irrigators in drought conditions, an average minimum instead of absolute minimum observed area is used in IQQM.

This planted area was distributed to the irrigation nodes that have access to on-farm storages and was disaggregated based on the ratio of their licence volumes.

Where no season of appropriately low resource availability has been observed, it is assumed that the minimum area should at least be equivalent to the identified perennial cropping.

C6 Effects of temporary trade

Currently IQQM is not capable of modelling the temporary trade activities of irrigators explicitly. However, the impacts of this trade still need to be considered as temporary trading between irrigation groups may be important to the sustainability of the observed planted areas. To ensure that irrigation groups within IQQM are not artificially constrained to plant less than their maximum area due to the lack of trade representation within IQQM, appropriate adjustments to irrigation group entitlements are made. These adjustments reflect the degree of temporary trade occurring.

Where there is significant under-utilisation and there have not been any observed years in the calibration period of significant resource constraint, the level of transfers that would appear to be necessary to support observed crop areas in certain irrigation groups may not have occurred. However, if the transfer market exists and is being used, it is logical to assume that "spare" water will be traded in resource constrained years in an attempt to maintain the observed crop areas where possible.

A consequence of manually adjusting entitlement levels between irrigation groups to represent temporary trade is that, when resources become sufficiently constrained, the irrigation group with a manually reduced entitlement will be artificially constrained, while the group with increased entitlement will be artificially high. The result will be that the planted areas and hence diversions will be skewed, and consequently distort the flow distribution. However, the effect on total diversions is expected to be minimal as long as (a) there are few periods of such extreme resource constraint, or (b) the degree of entitlement adjustment is small.

The definition of "spare" or unused water should be based on entitlement over and above that needed to meet the observed crop area requirements at that irrigation group under drought conditions.

Summaries of temporary trade within the valley indicate that only a small percentage of the total valley entitlement was traded annually during the calibration period. This volume was considered too small to warrant adjustment of entitlements for the various irrigation nodes.

C7 Range of observed behaviour / sensitivity analyses

In many cases there may not be sufficient observed behaviour across all levels of water availability to satisfactorily calibrate the resource availability – planted area relationship, especially for behaviour under various levels of resource constraint.

Where there is no observed behaviour under resource constrained conditions during the calibration period an assumed relationship needs to be adopted. This may be based on other similar areas where appropriate observed behaviour is available, or based on observed behaviour outside the calibration period. If there are no similar areas or periods outside the calibration period from which to base resource constrained behaviour, then an assumption of "risk" is required.

A sensitivity analysis of adopted resource availability – planted area relationships is an important indicator of the likely impact of incorrect assumptions being made, and for what purposes the final model scenario is considered valid. A number of relationships considered to represent the likely range of variability should be trialed to determine the sensitivity of the desired output from the model scenario. Use of the model scenario to provide long-term statistics may be relatively insensitive to the adopted relationship at the lower resource availability levels.

Whenever the observed behaviour is adopted from other areas or periods outside the calibration period, the assumptions regarding climatic, economic and social influences not modelled within IQQM remaining the same becomes less likely to be true. If the sensitivity analysis indicates that the desired output from the model scenario in question is sensitive to the adopted relationship at lower resource availabilities, then it may be necessary to investigate more closely whether the assumption that influences not modelled within IQQM (mentioned previously) are similar is appropriate.

Appendix D Quality Assessment Guidelines

This Appendix describes the latest draft practice notes for assessing the quality of model calibration or validation – as outlined in Section 1.6.

They are based on rating the confidence that the model can be used to closely replicate both the time series and statistical distribution behaviour of the real system, under a specified set of development conditions. These quality rating guidelines are presented for each significant quality indicator identified by senior modelling and operational staff.

The five categories used for expressing the quality rating of a particular indicator, or of the model as a whole, are:-

- Very high confidence
- High confidence
- Moderate confidence
- Low confidence
- Very low confidence

The apparent error associated with each quality indicator is calculated and placed within one of the five quality ranges, to define the calibration quality in that indicator. The primary quality indicator used is generally the percentage (ratio) of the model simulated volume or area versus the actual recorded volume or area, over the entire period analysed. Supplementary to this indicator but of equal importance, is a new indicator of time series variability, called the coefficient of mean absolute annual differences (CMAAD) as described below:-

```
CMAAD    =  ∑Absolute value(Simulated-Observed) / ∑Observed                        %
```

Where the Simulated and Observed volumes or areas refer to the total amounts relevant to a particular water year or other time period
There is a further variation of this indicator used to assess the apparent error associated with storage volume time series, call the coefficient of mean absolute storage drawdown deviation as described below:

```
CMASDD   =  ∑Absolute value(SMDS-OMDS) / (Max Observed Drawdown * No months)      %

Where    SMDS =  Simulated monthly change in storage volume
         OMDS =  Observed monthly change in storage volume
```

To define an overall model confidence, the quality of the observed data needs to be considered. However, as noted at the end of Chapter 1, objective means of determining measurement uncertainty and climatic representativeness are not readily available. In the interim period prior to such means being developed, these guidelines have incorporated the effects of these two sources of uncertainty by:

- Using record length as a surrogate for climatic representativeness;
- Formulating quality rating tolerance bands relevant to the known greater or lesser measurement uncertainty of the observed data. As an example planted area uncertainty's moderate confidence rating is for simulated areas within ±15% of observed, whereas to achieved the same confidence rating in diversion replication a match to within ±10% must be achieved – indicating the greater inherent measurement uncertainty allowed for in the planted area data.

D1 Flow calibration quality indicators and ratings

Set out below are the latest draft practice notes for assessing the quality of model calibration or validation achieved – as outlined at the end of Chapter 1.

They are based on rating the confidence that the model can be used to closely replicate both the time series and statistical distribution behaviour of the real system, under a specified set of development conditions. These quality rating guidelines are presented for each significant quality indicator identified by senior modelling and operational staff.

The five categories used for expressing the quality rating of a particular indicator, or of the model as a whole, are:

- Very high confidence
- High confidence
- Moderate confidence
- Low confidence
- Very low confidence

The apparent error associated with each quality indicator is calculated and placed within one of the five quality ranges, to define the calibration quality in that indicator. The primary quality indicator used is generally the percentage (ratio) of the model simulated volume or area versus the actual recorded volume or area, over the entire period analysed. Supplementary to this indicator but of equal importance, is a new indicator of time series variability, called the coefficient of mean absolute annual differences (CMAAD) as described below:-

```
CMAAD    =  ∑Absolute value(Simulated-Observed) / ∑Observed                  %
```

Where the Simulated and Observed volumes or areas refer to the total amounts relevant to a particular water year or other time period

There is a further variation of this indicator used to assess the apparent error associated with storage volume time series, call the coefficient of mean absolute storage drawdown deviation as described below:

```
CMASDD   =  ∑Absolute value(SMDS-OMDS) / (Max Observed Drawdown * No months)      %

Where    SMDS= Simulated monthly change in storage volume
```

```
OMDS= Observed monthly change in storage volume
```

Table D-1 Comparing actual gauged with model simulated flows over a period

PRIMARY FOCUS	*QUALITY INDICATOR*	*SUB-ASPECT (see note 2)*		*QUALITY RATING GUIDELINES (See note 1)*
		Definition	*Apparent Error (AE)*	
FLOW FREQUENCY REPLICATION (ranked daily flows)	VOLUME RATIO (vr) Where “vr” = 100 * (Simulated / Observed) Expressed as a %	Whole flow range	AE = (“vr” – 100)	Very High: AE within ±2% High: AE within ±5% Moderate: AE within ±15% Low: AE within ±30% Very Low: AE within ±40%
		Low flow range from X%ile to 100%ile (see note 4)	AE = (“vr” – 100)	Very High: AE within ±3% High: AE within ±7% Moderate: AE within ±20% Low: AE within ±35% Very Low: AE within ±45%
		Mid flow range from Y%ile to X%ile (see note 4)	AE = (“vr” – 100)	Very High: AE within ±2% High: AE within ±5% Moderate: AE within ±15% Low: AE within ±30% Very Low: AE within ±40%
		High flow range from 0%ile to Y%ile (see note 4)	AE = (“vr” – 100)	Very High: AE within ±4% High: AE within ±10% Moderate: AE within ±25% Low: AE within ±40% Very Low AE within ±50%
FLOW TIME SERIES REPLICATION	Daily flow time series – line of best fit: r^2	“r^2” coefficient of determination, (or the degree of scatter around the line of best fit)	AE = 100 * $(1- r^2)$	Very High: AE within 5% High: AE within 10% Moderate: AE within 25% Low: AE within 40% Very Low: AE within 50%
	Annual flow time series: Individual reach calibration stage CMAAD	CMAAD – Coefficient of Mean Absolute Annual Differences	AE = CMAAD (see note 3)	Very High: AE within 5% High: AE within 10% Moderate: AE within 15% Low: AE within 20% Very Low: AE within 25%
	Annual flow time series: Assembled reach calibration stages: CMAAD	CMAAD – Coefficient of Mean Absolute Annual Differences	AE = CMAAD (see note 3)	Very High: AE within 10% High: AE within 15% Moderate: AE within 20% Low: AE within 25% Very Low: AE within 30%

Notes:-

1. Where range specifications are not mutually exclusive, the range conforming to the maximum quality rating should be adopted
2. Unless explicitly stated, all indicator values should be calculated in absolute value terms
3. CMAAD = 100* ∑Absolute value(Simulated annual – Observed annual) / ∑ (Observed annual values)
4. The “X%ile” and “Y%ile” points should be defined from examination of the ranked flow-duration plot of daily flows over the calibration period. The “X%ile” point should be identifiable as the point of convexity on a log-scale plot, where the lower flow region of the curve starts to turn downwards (usually around the 70 to 90%ile zone). The “Y%ile” point should be similarly identifiable as the point of concavity on a log-scale plot, where the higher flow region of the curve starts to turn upwards (usually around the 5 to 10%ile zone).

D2 Storage calibration quality indicators and ratings

Table D-2: Comparing actual gauged with model simulated storage over a period

PRIMARY FOCUS	*QUALITY INDICATOR*	*SUB-ASPECT (see note 2)*		*QUALITY RATING GUIDELINES (see note 1)*
		Definition	*Apparent Error (AE)*	
STORAGE VOLUME REPLICATION (time series of storage volumes)	Storage volume time series CMASDD	CMASDD – Coefficient of Mean Absolute Storage Drawdown Deviation	AE = CMASDD (see note 3)	Very High: AE within ±2% High: AE within ±5% Moderate: AE within ±8% Low: AE within ±10% Very Low: AE within ±15%

Notes:-
1. Where range specifications are not mutually exclusive, the range conforming to the maximum quality rating should be adopted
2. Unless explicitly stated, all indicator values should be calculated in absolute value terms
3. CMAAD = 100* ∑Absolute value(SMDS – OMDS) / (Observed maximum drawdown*Number of months)

D3 Diversion calibration quality indicators and ratings

Table D-3: Comparing actual gauged with model simulated diversions over a period

(applicable for ONA, OFA and TOTAL diversions)

PRIMARY FOCUS	*QUALITY INDICATOR*	*SUB-ASPECT (see note 2)*		*QUALITY RATING GUIDELINES (see note 1)*
		Definition	*Apparent Error (AE)*	
Whole of Valley , and irrigator groups	VOLUME RATIO "vr" based on Total period diversion Where "vr" = 100 * (Simulated / Observed) Expressed as a %	ONA total	AE = ("vr" – 100)	Very High: AE within ±2% High: AE within ±5% Moderate: AE within ±15% Low: AE within ±30% Very Low: AE within ±40%
		OFA total	AE = ("vr" – 100)	Very High: AE within ±3% High: AE within ±7% Moderate: AE within ±20% Low: AE within ±35% Very Low: AE within ±50%
		Total Diversions	AE = ("vr" – 100)	Very High: AE within ±2% High: AE within ±5% Moderate: AE within ±15% Low: AE within ±30% Very Low: AE within ±40%
	Annual diversion time series comparison (ONA, OFA and Total): CMAAD	CMAAD – Coefficient of Mean Absolute Annual Differences	AE = CMAAD (see note 3)	Very High: AE within 10% High: AE within 15% Moderate: AE within 20% Low: AE within 25% Very Low: AE within 30%

Notes:-
1. Where range specifications are not mutually exclusive, the range conforming to the maximum quality rating should be adopted
2. Unless explicitly stated, all indicator values should be calculated in absolute value terms
3. CMAAD = 100* ∑Absolute value(Simulated annual – Observed annual) / ∑ (Observed annual values)

D4 Planted crop area calibration quality indicators and ratings

Table D-4: Comparing actual recorded with model simulated planted crop areas

PRIMARY FOCUS	*QUALITY INDICATOR*	*SUB-ASPECT (see note 2)*		*QUALITY RATING GUIDELINES (see note 1)*
		Definition	*Apparent Error (AE)*	
Whole of Valley, and irrigator groups	AREA RATIO Whole period total area ratio (ar): Where "ar" = 100 * (Simulated / Observed)	Overall % (ar)	AE = ("ar" – 100)	Very High: AE within ±3% High: AE within ±7% Moderate: AE within ±20% Low: AE within ±35% Very Low: AE within ±50%
	Annual cropped area time series comparison CMAAD	CMAAD – Coefficient of Mean Absolute Annual Differences	AE = CMAAD (see note 3)	Very High: AE within 15% High: AE within 20% Moderate: AE within 25% Low: AE within 30% Very Low: AE within 35%

Notes:-

1. Where range specifications are not mutually exclusive, the range conforming to the maximum quality rating should be adopted
2. Unless explicitly stated, all indicator values should be calculated in absolute value terms
3. CMAAD = 100* ∑Absolute value(Simulated annual – Observed annual) / ∑ (Observed annual values)

D5 Representativeness of calibration period

As noted in Chapter 1, the observed data quality should ideally be based on a combination of measurement uncertainty of the data, and the representativeness of the calibration period. At this stage, however, only record length is readily available, as an indicator of climatic representativeness, as presented in Table D.5.

Table D-5: Climatic representativeness classification guideline

PRIMARY FOCUS	*QUALITY INDICATOR*	*SUB-ASPECT*		*QUALITY RATING GUIDELINES*
		Definition	*Ideal value*	
RECORD LENGTH	Available "valid" data record length	Length for IQQM calibration (L)	10 years	Very High: L > 10 years High: 5.0 < L< 10.0 years Moderate: 2.0 <L< 5.0years Low: 1.0 <L< 2.0 years Very Low L < 1 year

Another aspect that should be considered by the modeller/analyst is whether or not the period adequately represents the degree of development that will be represented in the model for long term simulation purposes. For example does it include 1993/94, if the model is to be used for CAP simulation purposes. At this stage no explicit allowance for this aspect has been made, but it is mentioned here for completeness.

D6 Overall model quality rating

There are a number of methods for evaluating the overall quality of a model calibration. The evaluation of a calibration should take into account the intended use of the model and appropriate indicators should be chosen. Given that the major use of IQQM to date is CAP compliance and scenario comparisons the following indicators have been chosen:
Numbering??

- Total diversion for the valley (Volume ratio and CMAAD)
- End of system flows (Volume ratio and CMAAD)
- Combined storage behaviour (CMASDD)
- Key gauge site (Mid range volume ratio and CMAAD)

These criteria have been chosen on the basis that they represent the major components of the model that will be used for evaluating various options. The first three criteria give a reasonable assessment of the mass balance validity of the model while the fourth criteria gives an indication of the suitability of the model for assessing environmental flow options. As each of these criteria is of equal importance they have been given an equal weighting in the overall assessment of the model.

Each of the eight indicators has an associated quality guideline that is described in the preceding tables. Each of the guidelines has five sets of confidence limits of various magnitudes. To be able to combine these criteria with equal weighting these indicators need to be transformed into a standard rating system as follows:

- Very High 0%<=x<=5%
- High 5%<x<= 10%
- Moderate 10%<x<=15%
- Low 15%<x<=20%
- Very low 20%<x<=30%

The transformation is carried out as follows:

```
SI       =  (I-LL)*(SU-SL)/(UL-LL) + SL

Where    SI   =  Standardised indicator
         I    =  Indicator for selected criteria
         UL   =  Upper limit of the confidence band that I lies between
         LL   =  Lower limit of the confidence band that I lies between
         SU   =  Standardised upper confidence limit of equivalent indicator
                 confidence limit
         SL   =  Standardised lower confidence limit of equivalent indicator
                 confidence limit
```

To obtain an overall quality indicator (OI) each of the eight indicators are standardised and averaged (AI). That is, AI = ∑ SI,s / 8. This average quality indicator is then adjusted for climatic representativeness of the calibration period on the following basis:

$$OI = AI * 3.0 * NY^{-0.65}$$

Where OI = Overall quality indicator

AI = Average standardise quality indicator

NY = Number of years model is calibrated over

The adjustment for climatic representativeness takes into account that indicators in the preceding tables have been formulated assuming a calibration period of approximately five years. This adjustment allows for a decrease in confidence with a shorter calibration period and an increase in confidence with a longer calibration period. However, it should be noted that calibration period length is a surrogate for climatic representativeness, and that if this period does not contain dry and wet periods then this adjustment may not be appropriate.

The overall quality indicator gives an indication of what the model may be used for.

- "OI" quality of high to very high: can be used for detailed concept design new weirs or storage structures, or to design modifications to existing structures, or to determine CAP conformance for a particular year.
- "OI" quality of low to moderate: useful for comparing alternative improvement options or development scenario impacts, eg for Hydro-power feasibility studies, and for long term CAP determination.
- "OI" quality of very low indicates that the model requires further calibration before it can be relied upon.

Appendix E MDBMC Cap Development Conditions and Management Rules

Table E-1: Infrastructure & development parameters for the 1993/94 Cap scenario

ITEMS	DESCRIPTION	COMMENTS
GENERAL		
Simulation Period	01/10/1890 to 30/06/2006	
Water Year	01/07 to 30/06	
CATCHMENT INFORMATION		
Storages modelled ***Storage Volumes*** *(ML)*		As per Table 2-1
FLOW INFORMATION	*(Annual averages over simulation period)*	
Storage Inflows *(GL/yr)*	Burrinjuck 1,269 Blowering 1,696	
Tributary inflows *(GL/yr)*	Gauged 1,057 Ungauged [(1)] 730	
IRRIGATION INFORMATION		
General Security (GS) license volume *(ML)*		As per Table 2-2
High Security (HS) license volume *(ML)*		As per Table 2-2
Accounting system	Annual accounting Water use debiting	
Maximum irrigable area (summer) *(Ha)*	MI 108,988 CI 30,348 YCB river pumpers 10,797 Murrumbidgee river pumpers 43,478	
Maximum irrigable area (winter) *(Ha)*	MI 61,268 CI 28,564 YCB river pumpers 6,972 Murrumbidgee river pumpers 21,713	
Pump capacity *(ML/d)*	MI 8,500 CI 5,700 YCB river pumpers 10,715 Murrumbidgee river pumpers 36,819	

Maximum Allocation	Allowed up to 120% in any 1-year period	
Irrigator Carry-Over	None	
On-farm storage operation	None	
Active license factors *(%)*	100%	Weighted average
Average crop area *(Ha)*		See Table 2-5
OTHER EXTRACTIONS		
Town water supply *(ML/yr)*	Jugiong 4,461 Tumut 1,281 Gundagai 524 Wagga 2,955 Darlington Point 4 Carrathool 5 Hay 987 Balranald 802 Griffith 7,565 Morundah & Urana 766 Jerilderie 380	(3) Modelled as a fixed monthly pattern for each year of the simulation.
Stock & domestic *(ML/yr)*	Not modelled explicitly	
Industrial/mining/other *(ML/yr)*	Not modelled explicitly	
Groundwater access *(ML/yr)*	Not modelled explicitly	
RESOURCE ASSESSMENT		
Storage Reserve *(GL)*	None	
Total system supply requirements *(GL)*	(6)	(6) Varies with time of year, as per Table E-2
Minimum storage inflows *(GL/yr)*	1,367 (7)	(7) Varies with time of year
Minimum tributary inflows *(GLyr)*	331 (8)	(8) Varies with time of year
System development factor *(%)*	100%	Used in resource assessment
Maximum *Error! Reference source not found.* *(%)*	120%	

RIVER AND STORAGE OPERATING RULES			
Tributary recession factors *(%)*			As per Table B-3
Over order allowances *(%)*			
SURPLUS FLOW ACCESS			
Supplementary water cap *(GL/yr)*	No Cap		
Supplementary water thresholds	Fixed monthly thresholds		See Table B-5
RIVER FLOW REQUIREMENTS			
Minimum flow requirements *(ML/d)*			As per Table 4-2
Low Flow Protection	Protect d/s tributaries	No	
Error! Reference source not found. ***sharing***	Env. share above threshold	0%	

Notes: (1) Including Cocketgedong and estimated Nowranie inflows

Table E-2 Total system supply requirements (GL) under Cap conditions

AWD	0.00	0.25	0.50	0.75	1.00	1.25
Jul	695	825	910	1,020	1,110	1,260
Aug	686	814	898	1,006	1,095	1,243
Sep	668	792	873	978	1,064	1,207
Oct	635	752	828	927	1,008	1,143
Nov	550	659	713	796	864	978
Dec	477	566	613	683	740	835
Jan	399	465	508	563	608	684
Feb	307	352	382	420	451	503
Mar	223	250	267	290	309	340
Apr	160	173	182	193	202	217
May	130	137	141	147	151	159
Jun	110	112	113	115	117	119