Macquarie River Valley

IQQM Cap implementation summary report

Issue: 2

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Executive Summary

What has initiated the work?	The MDBMC Cap requires that NSW develop a suitable planning tool to enable review of water use and sharing arrangements in the Macquarie River Valley. The tool accepted as suitable for this purpose is a calibrated water balance model that includes all relevant important features on and in the system. The adopted model is called the integrated quantity/quality model (IQQM).
Scope of this report summarises the Macquarie IQQM status	This report summarises and documents the IQQM calibration, validation and model use for the Cap conditions scenario. Other related documents include: • IQQM - Macquarie R system calibration report [DLWC, 1995] • Streamflow synthesis for the Macquarie R catchment [DLWC, 1996[a]]
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 <u>all</u> of the important features in the system, and <u>closely</u> replicates records of flow and water 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 Macquarie Valley IQQM.
Calibration to 1985/86 – 1989/90 and validation to 1993/94 – 94/95 periods demonstrates model suitability	Chapter 3 and 4 present the model calibration and validation results . Comparison is made between time series observed data and time series model simulated data. Quality ratings were applied to the model calibration. The modelled water diversions show a generally "very high" quality calibration, with the end-of-system flow replication for the assembled model also being of "high" quality. Storage behaviour replication achieved a "very high" quality rating. Overall, the model achieved a "highXX" quality rating, demonstrating the model's suitability for the intended purposes.
Statement of model adequacy for comparing management options	The Macquarie River Valley IQQM can now be accepted as calibrated and validated to a satisfactory degree, and suitably robust for 100+ year scenario running and for comparison of the impacts of alternative management scenario options.
1993/94 Cap benchmark scenario	Chapter 5 describes 1993/94 conditions and the use of the Macquarie IQQM to simulate the 1993/94 Cap scenario. Results are presented for: a) the 112 year period from 1890 to 2001 inclusive, to estimate the long term Cap scenario average annual diversions;

b) the 1997/98 – 2000/01 period, to produce estimates of the Cap for auditing under the provisions of Schedule F of the Murray-Darling Basin Agreement.

Improvement suggestions

Chapter 6 lists a series of short and long term improvement plans, categorised as upgrades to flow, demand, storage behaviour and off-allocation calibrations and other general upgrades. These suggestions are not intended to reduce the credibility of the current model, but should be viewed as part of DNR's quality assurance process, which promotes continuous improvement to its 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 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.

Allocation Sub-system – Allocation sub-system is a number of river sections that represents a group of water users who are all treated the same in terms of determining allocation levels.

Allocation System – An allocation system is a group of allocation sub-systems that have the same announced allocation announcement. The allocation level for an allocation system is defined as the minimum of the allocation levels for all the allocation sub-systems under it. This applies when irrigator groups have access to only one dam's resources but their announced allocation level is determined by another dam's resource criteria.

Cap – The Murray Darling Basin Ministerial Council Cap on extractions for consumptive users at the level that would have occurred under 1993/94 development levels and management rules over a long term period of varying climatic conditions.

Cap Audit Scenario – An IQQM that has been configured for the simulation of 1993/94 development conditions and management rules, commencing in 1997/98, to provide annual estimates of the diversions that would have occurred under Cap conditions.

Cap Scenario – An IQQM that has been configured for the long-term simulation of 1993/94 development conditions and management rules.

Coefficient of Determination – Also see "r^2" for detail, but generally a statistical term that can be described as the degree of scatter between observed and simulated data points. Difference between the data is actually the difference between (linear) lines of best fit (ie $y = mx + b$) for each set of data.

DECCW – NSW Department Environment, Climate Change and Water

DIPNR – NSW Department of Infrastructure Planning and Natural Resources (former name of current NOW)

DLWC – NSW Department of Land and Water Conservation (former name of current NOW)

DNPWS – NSW Department of National Parks and Wildlife Services

DNR – NSW Department of Natural Resources (former name of current NOW)

DWE – NSW Department of Water and Energy

DWR – NSW Department of Water Resources (former name of current NOW)

d/s – Downstream.

ECA – environmental contingency allowance; a volume of water set aside in storage for environmental purposes.

Farmer's Risk – See irrigator behaviour.

FPH or Flood Plain Harvesting – Water obtained by pumping or direct inflows of water off the flood plain. This water has not been monitored to date, and is generally considered to be that water that fills spare capacity in an OFS, but not via ONA or OFA diversions. Conceptually flood plain harvested water includes water:

- Pumped from the floodplain to the OFS (ie during large floods), using secondary lift pumps
- Entering the OFS because flood levels spill directly into the OFS, and
- From local rainfall and runoff being sufficiently intense to cause significant OFS filling.

General Security Licences – The great majority of irrigation licences, in terms of both number and usage. In announcing allocation entitlements these licences are supplied with water after high security licence needs are fully satisfied.

High Security Licences – Licenses that provide the highest reliability of water supply. Generally these licences are for (relatively) small amounts of water for 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.

Hot-start – To configure the model with the correct boundary or initial conditions (ie, river flows, storage volumes, soil moisture levels and releases for water orders), it is started several weeks before the commencement of the analysis period. The purpose of this is to minimise the effect of initial assumptions on results produced by short term scenario runs.

Irrigator Behaviour (also called farmer's risk) – This relates to the irrigator's choice of the amount of area to plant and the main factors affecting this decision. For example, given a drought period with dry antecedent climatic conditions, low on farm storage, and low announced allocation, an irrigator who plants the same area as in wet years (ie years when storages are full) is taking a higher than previous risk. That is there is an increased likelihood that the irrigator will run out of supplies unless addition streamflows or rainfall occurs.

Licensed Entitlement Volume – The volume of water that a licence holder on a regulated stream/river can draw on during a 100% allocation announcement. The amount drawn may be subject to other licence conditions.

Link – The stretch of river in the model between two nodes. This may or may not represent a real length, noting that a link can be used to separate two processes at the same location.

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 – The units used to express rate of flow, in terms of megalitres (ie millions of litres) per day.

Node – A model node is used to represent a point on a river system where certain processes occur. The node type identifies the rules and parameters that are used by the model to simulate the relevant processes at a given location.

DWE – NSW Office of Water

OFA or Off-Allocation Extraction – Being the volume of water extracted by the irrigator 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 by a specified amount. The announcement of off-allocation periods may be subject to a number of other conditions such as equity, ease of access or 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, and is usually "billed" at a lesser cost.

OFS – On farm storage, usually referring to a large private storage constructed on an irrigator's property to store water.

ONA or On-Allocation Extraction – Meaning water diverted by the irrigator from regulated flows to satisfy the irrigator's crop needs or future management needs, debited against the announced allocation volume (ie allocation level times licensed volume entitlement) of the irrigator. The water supplied to the irrigator may be directly released from the dam release or by d/s tributaries, or by a combination of both.

Pump capacity – The maximum pump extraction rate for an irrigation node (ML/d).

r^2 – This is the symbol used in a statistical sense to express the degree of correlation between two sets of data (eg actual records versus model simulations), and is called the coefficient of determination. Its value is always expressed as a decimal less than 1.0, such that the closer its value is to 1.0, then the better the correlation.

Rainfall-runoff model - (see Sacramento model)

Reach – A number of model links connected together make up a river reach.

Regulated River – The section of river that is downstream of a major storage from which supply of water to irrigators or users can be regulated or controlled.

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.

Resource Assessment – The process of calculating announced allocation levels based on the current and predicted water resource availability and water requirements of all water users.

River Section – see river *Reach*.

Sacramento Model – The Sacramento rainfall-runoff model is used to estimate long term streamflows at gauging stations where there are short period of records or gaps in the flow data. The model tries to represent the physical processes that impact on runoff, it uses local rainfall and evaporation data as well as catchment details. The model is calibrated to reproduce the short term observed flow at the gauging station and then by inputting the long-term rainfall and evaporation, a long-term streamflow sequence can be estimated. The model was developed by Burnash et al (1973), in Sacramento California.

Storage Reserve – The amount of storage volume reserved for next year's supply reliability including high security demands. The storage reserve is taken into account when calculating this year's % allocation announcement.

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 can be used 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 (not necessarily January). In the Macquarie Valley the water year commences on the 1st July and concludes on the 30th June.

1. Introduction

## 1.1.	BACKGROUND TO IQQM

Prior to the early 1990's, monthly time step computer models had been configured, calibrated and implemented in most of the major river basins in NSW. These monthly models were only capable of long term water budget analysis and were suitable for investigating and developing the various water management and sharing policy initiatives at that time, e.g., establishing the security of water supply for consumers.

During the 1990's a large number of developments occurred in water management policies, including diversion limitations under the MDBMC cap, development of management rules and river flow objectives to achieve these limitations and water quality modelling requirements. These changes required a much greater level of model complexity, where representation of the short term variability in flows became increasingly more important.

In the late 1980's, prototypes of daily time step modelling software were being developed, with the WARAS model, developed by Lyall and Macoun (consultants) being one of the fore-runners. Building on many of the concepts within the WARAS model, the Department of Natural Resources (DNR) proceeded to develop a more generalised and complete river basin simulation computer program that can be used as a tool to investigate water resources management issues. This modelling tool is called the Integrated Quantity/Quality Model (IQQM).

IQQM operates at a maximum time step of one day, which allows a more realistic representation of hydrologic processes in both regulated and unregulated rivers. IQQM is also able to simulate in-stream water quality constituents, such as salinity and nutrients. A full description of IQQM, including details about model structure, algorithms, processes that can be modeled and assumptions are described in the IQQM Reference Manual [DLWC, 1995].

## 1.2.	AIM OF IMPLEMENTING IQQM IN THE MACQUARIE RIVER SYSTEM

The IQQM is being implemented for the Macquarie Valley from the headwaters of Windamere Dam to the outlet at Carinda just below the Macquarie Marshes.   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. A model such as this is required for the following purposes:
- Reproduction of river system behaviour over the calibration and validation periods;
- Reproduction of daily flows at key locations for assessment of environmental flow rules;
- Analysis of the impacts of alternative irrigation development scenarios over a long term (100+ years) simulation period;
- Development and analysis of impacts of environmental flow and river operation rules to meet specific river flow objectives; and
- Estimation of the long term average annual diversions for the Macquarie Valley under a 1993/94 Development Conditions scenario, ie *the Cap scenario*.

- Assessment of current irrigation diversions relative to those that would have occurred under 1993/94 development conditions with the current climatic inputs, ie *the Cap audit scenario*. This scenario is required for the MDBMC Cap auditing process.

1.3.   STATUS OF IQQM IMPLEMENTATION

The implementation plans for development and use of the Macquarie IQQM covered the following main steps:

1) Configure and calibrate the IQQM;

2) Validate the IQQM performance on more recent seasons;

3) Establish an agreed 1993/94 development conditions (MDBMC Cap);

4) Define and compare alternative future management options.

The model configuration, calibration and validation have now been completed. The long term simulation model has been prepared for the 1993/94 Cap conditions scenario and is documented in this report. There are some initial management scenarios also being configured including the natural conditions scenario and the 2000/01 conditions scenario. There are also a number of studies awaiting completion and sign-off of these initial scenarios, including a study of proposed Warren Weir upgrade options. Some work is under way in conjunction with CSIRO to analyse the effects of climate change scenarios on river flows and extractions.

1.4.   AIM AND OBJECTIVE OF THIS REPORT

The Macquarie Valley IQQM implementation report, referred to above, is of a highly technical nature and is intended to be used as a technical reference document. Stakeholders involved in the MDBMC Cap processes rarely require the level of detail documented in these technical reports. The aim of this summary report is to summarise the main findings and conclusions of the calibration, validation and 1993/94 Cap technical reports into a form that will be presented to the Murray-Darling Basin Commission as part of the Cap model approval process.

1.5.   SCOPE OF THIS REPORT

The scope of work covered in this report includes:

- Description of the Macquarie River Valley (Chapter 2);
- Configuring, calibrating and validating the Macquarie IQQM (Chapter 3 and 4);
- Establishing an agreed 1993/94 Cap scenario (Chapter 5);
- Outlining model improvement plans (Chapter 6);
- Details of the climatic and streamflow stations used (Appendix A);
- A summary of the model configuration (Appendix B);
- Some background to modelling the planting decision (Appendix C);
- A description of the quality assessment guidelines (Appendix D);
- Details of the 1993/94 Cap development conditions and management rules (Appendix E);
- Burrendong Dam flood mitigation zone release rules (Appendix F);
- Windamere Dam transfer constraints (to protect platypus habitat) (Appendix G).

- •   Historical irrigation diversions (Appendix H).

1.6.   QUALITY ASSESSMENT SYSTEM

A consistent set of quality assessment guidelines (Appendix A) has been used in this report to evaluate and report each main element of the model's calibration and validation performance. The general meanings attributed to the quality ratings are expressed in relation to the confidence that the model can replicate observed records of flows, diversions, storage behaviour and planted area as follows:

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

The quality of the observed data is also considered. The climatic representativeness of the data is assessed based on the period of calibration.

2. The Macquarie River Valley system

2.1. CATCHMENT DESCRIPTION

The headwaters of the Macquarie River Valley start at the Great Dividing Range (Figure 2.1). From Bathurst, the river system extends in a north-westerly direction for 560 km, with the catchment ending at the confluence with the Barwon River near Brewarrina. The total catchment area modelled by IQQM is approximately 29,900 sq. km.

Two major storages exist in the valley. Burrendong Dam with a conservation storage capacity of 1,188 GL and a further 489 GL of storage available for flood mitigation (using spillway gates) and a total catchment area of approximately 13,800 sq. km. U/s of Burrendong Dam, on the Cudgegong River, is Windamere Dam with a conservation storage capacity of 368 GL and a total catchment area of approximately 1,100 sq. km. Both storages are operated together to provide supplies to licensed irrigators in both the Cudgegong and Macquarie River (d/s of Burrendong Dam).

For the purposes of the flow and irrigation demand calibration of IQQM, the Macquarie River Valley was divided into three sections (Appendix B):

- Cudgegong River d/s of Windamere Dam (catchment area = 2,400 sq. km).
- Macquarie River to Dixons Long Point, u/s Burrendong Dam (catchment area = 7,000 sq. km).
- Macquarie River and associated effluents, d/s Burrendong Dam to Carinda (catchment area = 16,100 sq. km).

The annual average rainfall varies over the Macquarie Valley, from a maximum of 1200 mm over the high ground in the south-east to a minimum of less than 250 mm near the junction of Macquarie and Barwon Rivers in the north-west.

Evaporation potential, as measured in pans, substantially exceeds average rainfall throughout most of the catchment. It ranges from 1000 mm per annum in the south-east of the catchment, 1700 mm in the middle and up to 2000 mm per annum in the north-west.

2.1.1. The Cudgegong River downstream of Windamere Dam

The Cudgegong River d/s of Windamere Dam consists of the Cudgegong River, Lawsons and Wyaldra Creeks and numerous minor ungauged creeks. Mudgee and Gulgong are the major towns in this area. Between Windamere and Burrendong Dams, the topography is quite steep with the Cudgegong River having a well defined channel and only a limited flood plain.

2.1.2. Macquarie River Valley upstream of Burrendong Dam

The Macquarie River upstream of Burrendong Dam consists of the Macquarie, Campbells, Fish and Turon Rivers, Queen Charlottes and Lewis Ponds Creeks and the Winburndale Rivulet as well as minor ungauged creeks.

Four storages exist in this part of the valley:

- Ben Chifley Dam (16 GL)
- Suma Park Dam (18 GL)

- Oberon Dam. (45 GL)

- Winburndale Dam

These storages are primarily operated for the supply of town water to Bathurst (Ben Chifley Dam), Orange (Suma Park) and Lithgow (Oberon Dam).

Between Ben Chifley and Burrendong Dams, the topography is quite steep with the Macquarie River having a well defined channel and only a limited flood plain.
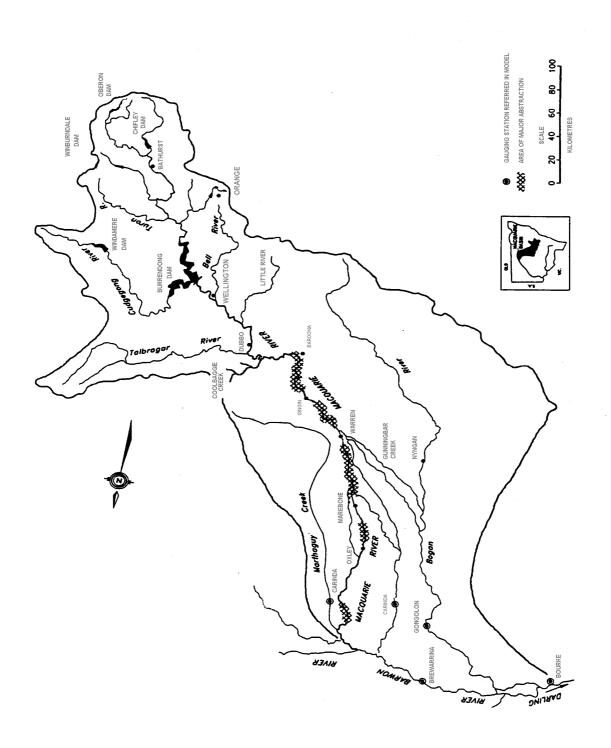
2.1.3.   Macquarie River Valley downstream of Burrendong Dam

The Macquarie River d/s of Burrendong Dam encompasses the majority of the Macquarie River catchment. It is characterised by a number of anabranches departing from the main river and either rejoining further d/s or discharging to join other river systems such as the unregulated Bogan River and Marthaguy Creek. Gunningbar Creek, Marra Creek, Reddenville Breakout and the Marebone Breakout are the major effluents d/s of Burrendong Dam. The city of Dubbo is also d/s of Burrendong Dam. The main unregulated tributaries contributing to the Macquarie River d/s of Burrendong Dam are the Bell, Little, Buckinbah and Talbragar Rivers and Coolbaggie Creek (Figure 2.1).

The Macquarie River Valley d/s of Burrendong Dam is also characterised by continually changing topography. From Burrendong Dam to Warren, the Macquarie River has a large natural channel capacity. From Warren to Marebone, the topography flattens and the natural channel capacity becomes insufficient to contain high flows within the banks. From Marebone to Carinda the catchment is characterised by a meandering network of effluent channels and anabranches, which make up part of the Macquarie Marshes.

The Macquarie Marsh Nature Reserve is 18,150 ha at the core of the marshes, however the size of wet area of the Marshes varies from 1,000 ha during dry periods to 300,000 ha during major floods. The Macquarie Marshes are listed under the Convention for Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention). They provide a home to some 60 species of waterbird, of which 42 breed in the Marshes.

Figure 2.1:   The Macquarie Valley catchment

2.2.   CLIMATIC DATA

2.2.1.   Rainfall

Rainfall data is required by IQQM to drive the soil moisture accounting in the irrigation module (Section 3.4), for computing the contributions to reservoir storage volumes (Section 3.5) and river reaches (Section 3.3) due to rainfall on the water surface and for generating catchment inflows using rainfall-runoff models (Section 5.3).

An extensive network of daily read rainfall gauges covers the Macquarie River catchment and selection of appropriate gauges for each of the above mentioned purposes in the Macquarie IQQM is discussed in Sections 3.4, 3.5 and 5.3 with a full listing of the gauges selected provided in Table A.1.

The location of some typical rainfall gauges is shown in Figure 2.2.

2.2.2.   Evaporation

Evaporation data is required by IQQM to drive the potential evapotranspiration from the crops in the irrigation module (Section 3.4), for computing evaporation losses from reservoirs (Section 3.5) and river reaches (Section 3.3) and for generating catchment inflows using rainfall-runoff models (Section 5.3).

A limited number of daily read evaporation gauges exist in the Macquarie River catchment and selection of appropriate gauges for each of the above mentioned purposes in the Macquarie IQQM is discussed in Sections 3.4, 3.5 and 5.3 with a full listing of the gauges selected provided in Table A.2. The location of some typical evaporation gauges is shown in Figure 2.2.

Figure 2.2:   Rainfall and evaporation station locations

2.3.   STREAMFLOW DATA

Streamflow data is used in two different ways in IQQM. Firstly, it is required for model calibration (Section 3.3) and secondly it is required for model simulations (Section 5.3).

2.3.1.   Cudgegong River downstream of Windamere Dam

There is a limited number of gauging stations on the main river, most of which have either been discontinued or have only limited data sets, including:

- D/S Windamere Dam (421079);
- Appletree Flat (421074);
- Rocky Water Hole (421149);
- Wilbertree Rd (421150);
- Guntawang (421013); and
- Yamble Bridge (421019).

There are two major tributaries entering the Cudgegong River, Lawsons and Wyaldra Creeks. Wyaldra Creek (421058) is the only gauged tributary, with a catchment area of 840 sq. km. There are also numerous minor ungauged creeks that enter the Cudgegong River, including Swan, Mullamuddy, Oaky, Pipeclay, MacDonalds, Rat Castle, Goodiman, Piambong, Goolma and Uamby Creeks. The total ungauged catchment area above Yamble Bridge is approximately 1,560 sq. km.

Selection of appropriate gauges to use in the Macquarie IQQM is discussed in Sections 3.3 and 5.3 with a full listing of the gauges selected provided in Table A.3. The location of some of these streamflow gauges is shown in Figure 2.3.

2.3.2.   Macquarie River upstream of Burrendong Dam

There are three gauging stations on the main river including:

- Bathurst (421007);
- Bruinbun (421025); and
- Dixons Long Point (421080).

There are a number of major tributaries entering the Macquarie River between Ben Chifley Dam and Burrendong Dam, including:

- Queen Charlottes Creek at Georges Plains (421053): 217 sq. km;
- Fish River at Tarana (421035): 593 sq. km;
- Winburndale Rivulet at Howards Bridge (421072): 720 sq. km;
- Turon River at Sofala (421026): 880 sq. km;
- Crudine Creek at u/s Turon Junction (421041): 349 sq. km;
- Lewis Ponds Creek at Ophir (421052): 618 sq. km.

In general, the gauging stations on these tributaries are located some distance from the confluence with the main river, producing large areas of ungauged catchment. There are also ungauged

contributions from smaller streams and local area runoff. The total ungauged catchment area above the Dixons Long Point gauge is approximately 2,700 sq. km.

Selection of appropriate gauges to use in the Macquarie IQQM is discussed in Sections 3.3 and 5.3 with a full listing of the gauges selected provided in Table A.3. The location of some of these streamflow gauges is shown in Figure 2.3.

2.3.3. Macquarie River downstream of Burrendong Dam

The total catchment area downstream of Burrendong Dam and upstream of the Carinda gauging station is approximately 16,100 sq. km. There are a number of gauging stations on the main river including:

- Wellington (421003);
- Dubbo (421001);
- Baroona (421127);
- Narromine (421006);
- Gin Gin (421031);
- Warren Weir (421004);
- Marebone Weir (421090);
- Oxley Station (421022); and
- Carinda (421012).

There are a number of major tributaries entering the Macquarie River below Burrendong Dam, including:

- Bell River at Newrea (421018): 1,629 sq. km;
- Buckinbah Creek at Yeoval (421059): 701 sq. km;
- Little River at Obley (421048): 612 sq. km;
- Talbragar River at Elong Elong (421042): 2963 sq. km;
- Coolbaggie Creek at Rawsonville (421055): 565 sq. km.

In general, the gauging stations on these tributaries are located some distance from the confluence with the main river, producing large areas of ungauged catchment. There are also ungauged contributions from smaller streams and local area runoff. The total ungauged catchment area is approximately 5,500 sq. km.
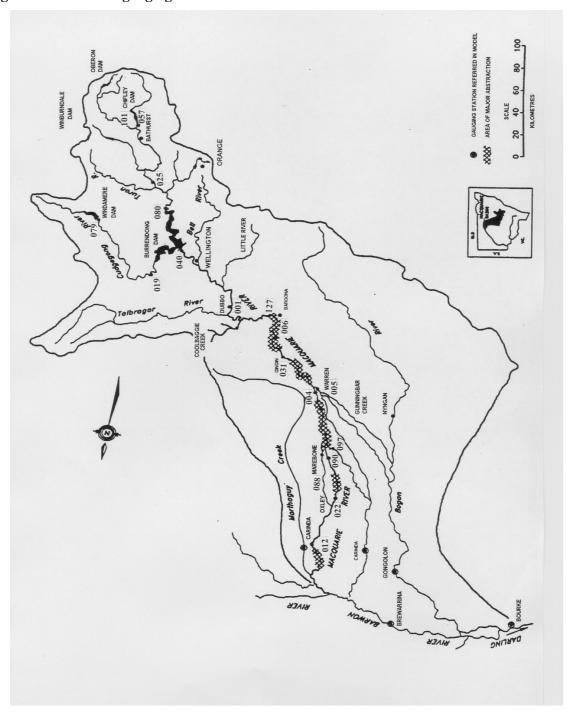
Selection of appropriate gauges to use in the Macquarie IQQM is discussed in Sections 3.3 and 5.3 with a full listing of the gauges selected provided in Table A.3. The location of some of these streamflow gauges is shown in Figure 2.3.

There are also a number of effluent outflows from the main river, some of which return, including:

- Reddenville Break;
- Gunningbar Creek;
- Duck Creek;
- Crooked Creek;

- Marra Creek;
- Marebone Break (421088).

Figure 2.3:   Stream gauging station locations

2.4.   IRRIGATION INFORMATION

2.4.1.   Irrigation licences (regulated)

There are licences for regulated surface water extraction in the Macquarie River system, in the regulated sections below Windamere and Burrendong Dams.

The regulated licences were converted from area-based licences to volumetric licences in 1981. There has been an administrative embargo on the issuing of new licences (with the exception of stock, domestic, industrial and town water supplies) since 1979. This became a statutory embargo in 1982. The historic data on licensed irrigation volumes and licence types was analysed and separated into high security (HS) and general security (GS) licence portions.

In the regulated river reaches downstream of Windamere and Burrendong Dams there are approximately 920 water extraction licence holders. The total active GS licence entitlement in the valley is 631 GL (610 GL downstream of Burrendong Dam). The HS licences have a further 39 GL of entitlement, which includes town water supplies (19 GL) and high security irrigation (10 GL).

The major crops grown in the Cudgegong River in 1993/94 were lucerne and improved pasture. The major crops grown between Burrendong Dam and Baroona in 1993/94 were lucerne and cereal, with a variety of other crops grown to a lesser extent. The major crop grown downstream of Baroona was cotton.

The water year is July to June, with the major water demands being from November to March.

2.4.2.   Irrigator extraction and storage infrastructure

Regulated licences are generally issued with conditions relating to the maximum licensed extraction capacity, generally referred to as the authorised pump capacity. Installed pump capacities were also generally available from meter inspectors' records. Based on this data the total irrigator pump capacity was 13,446 ML/d for the system in the 1993/94 irrigation season.

On-farm storages have not been closely monitored and therefore there is no comprehensive database of historical capacities that have existed in the valley. The only information available is based on estimates made by regional representatives.

These estimates indicate that individual on-farm storages in the Macquarie River Valley range in capacity from 50 ML to 7,000 ML. The pump capacities are generally large enough to fill these storages in the first few days of an off-allocation event. The total volume of on-farm storage in the Macquarie River Valley downstream of Burrendong Dam in the regulated section of the river was estimated to be 32 GL in the 1988/89 irrigation season. This was estimated to have grown to 65 GL in the 1993/94 irrigation season and to 100 GL in 1999/00 (Figure 2.4). Some of this increase may be works for improved farm management rather than increased water availability and cropping. It is difficult to determine how significant the increase in on-farm storage capacity is in terms of increases in observed crop areas because over more recent seasons, the on-farm storages have been reasonably empty in October and the planted areas have been lower, as discussed below.

There is currently no significant on-farm storage development upstream of Burrendong Dam.
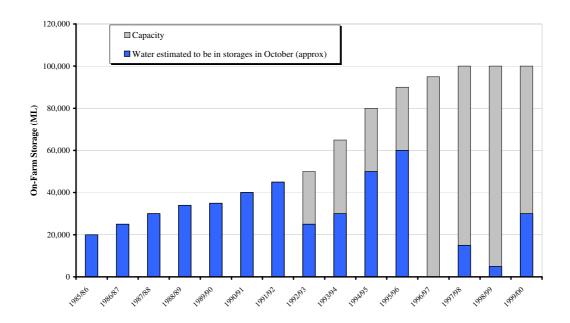
Figure 2.4:   Historical on-farm storage capacity and stored volume

2.4.3.   Irrigation extraction data

Individual meter readings were available on a quarterly basis for regulated licences. The recorded quarterly totals were disaggregated to daily totals based on the pattern of orders obtained from river operation records.

On the Macquarie River downstream of Burrrendong Dam, the general security licence holders have historically (since the late-70's) diverted an annual average of approximately 400 GL. Under 1993/94 conditions, the regulated licence holders on the Cudgegong River d/s of Windermere Dam divert approximately 4-5 GL annually.

The unregulated licence holders in the Valley had an estimated annual usage of 24 GL in the 1992/93 to 1994/95 period.

2.4.4.   Crop areas

Estimates of annual irrigated areas and types of crops were available since the mid-1980's for regulated licences.

There were a number of different sources for historical crop area information. The only source for crop areas based on individual crops and individual licences was taken from annual surveys conducted by DNR field staff that were entered into the DNR licence administration database.

There was information on cotton area planted in the valley in each year available from the Australian Cotton Foundation, Cotton Yearbooks, irrigator surveys and indicators (such as chemical and seed sales) gathered by industry representatives. This was used as a check on the crop area information obtained from estimates made by metering inspectors and regional representatives, with cross-checking based on volumes of water applied to the crops in each year.

Annual historical crop area information for the Macquarie Valley is presented in Figure 2.5.
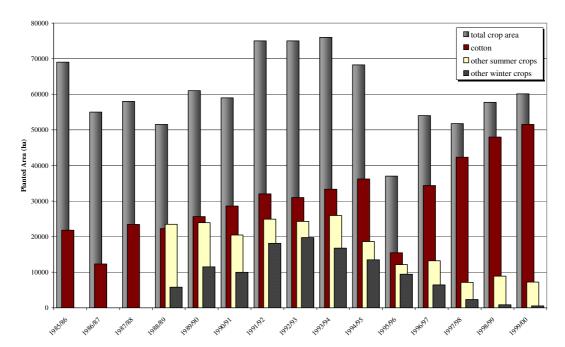
Figure 2.5:   Historical crop areas

Note: Crop areas (other than cotton) were estimated for 1994/95 based on the average of the preceding (1993/94) and following (1995/96) years.

2.4.4.1   Crop mix

Figure 2.5 indicates that the period 1991/92 to 1994/95 appears to be a relatively stable period, with the mix of crop types similar throughout. In 1993/94, cotton accounted for approximately 40 – 50% of the total crop mix, with a variety of other crops (mostly lucerne, summer and winter pastures and summer and winter cereals) making up the remaining portion. In the Cudgegong, the crop mix was predominantly lucerne (~55%) and improved pasture (~35%).
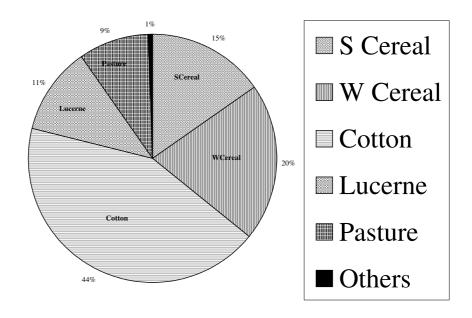
After 1995/96 the crop mix downstream of Burrendong Dam changed rapidly with increasing percentage of cotton. By 1999/00, cotton had increased to almost 90% of the total crop area in the Valley.

Upstream of Burrendong Dam, the crop mix has also changed in more recent years, with a large proportion of the crops now being grapes (~55%) and olives (~25%) and a much smaller proportion being lucerne (~5%) and improved pasture (~15%).

A break-down of the crop mix for the 1993/94 irrigation season is presented in Figure 2.6.

Figure 2.6:   Detailed crop mix for the 1993/94 irrigation season

MACQUARIE RIVER VALLEY
93/94 CROP MIX

2.4.4.2   *Application rates (irrigator's planting risk)*

The observed relationship between water availability and the total planted area (observed irrigators' planting decision) is illustrated in Figure 2.7. Water availability has been taken as the sum of the announced allocation, carryover of allocation from the previous year and the estimated volumes in on-farm storages at the start of the growing season (1st October).
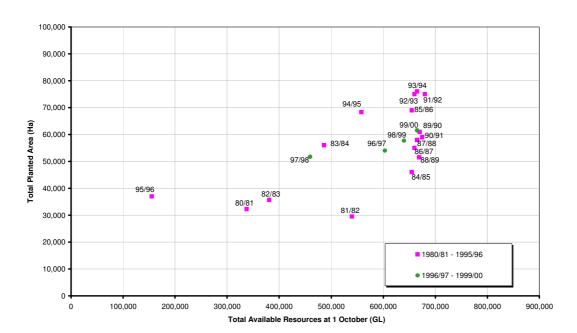
Figure 2.7:   Observed relationship between resource availability and planted area

Prior to the 1991/92 irrigation season (with the exception of the 1983/84 irrigation season) there were lower planted areas in the high resource availability years than in the later years. Information provided by regional representatives indicated that there was a steady increase in the volume of active licences over this earlier period. This would indicate that the lower planted areas are due to less licence activity as opposed to reduced irrigator's planting risk.

From the 1996/97 season onwards there was a significant shift towards lower planted areas. This period coincides with the introduction of the 1996 Water Management Plan (WMP) for the Macquarie Marshes and carryover accounting rules. Therefore the irrigator behaviour applicable to the 1986 Water Management Plan for the Macquarie Marshes (which was in place during the 1993/94 irrigation season) is unlikely to be consistent between the two periods. A major cause for this apparent conservative behaviour may be due to the introduction of carryover following severe resource constraint during the previous (1995/96) water year. This facility gives the irrigators the choice of minimising the number of resource constrained years by adopting conservative behaviour in resource abundant years.

For these reasons, the period of observed irrigators' planting risk that will be used to estimate the 1993/94 conditions planting risk was based on the 1991/92 to 1995/96 period (see Section 5.4.3.2 for further discussion). The individual irrigator's observed planting risk over this period appears to equate to an "average" valley risk of approximately 8 ML/ha (Figure 2.7).

2.4.4.3   *Maximum area*

The period 1991/92 to 1994/95 appears to be a relatively stable period, with the maximum observed area, during periods of high resource availability, similar throughout this period.   The maximum historical annual planted area for the Macquarie Valley was 76,000 ha in 1993/94.

2.4.4.4   *Minimum area*

The years of severe resource constraint during the mid-1990s would seem to indicate that, at extremely low resource availability, there is some minimum area that irrigators would plant, regardless of water availability, representing increased risk in those years.   The minimum historical annual planted area for the Macquarie Valley was 37,000 ha in 1995/96, which would appear to be due to resource constraint.

2.4.5.   End-of-year diversions

Observed diversion data indicated that irrigators were diverting unused allocation at the end of the irrigation season to fill their on-farm storages.   It is thought that this was due to some irrigators seeking to avoid socialisation of their unused allocation at the end of the water year.

2.4.6.   Transfer market

In the Macquarie Valley, the facility to transfer either licensed volume (permanently) or allocated water (annually) has been available since the introduction of volumetric licences in the early 1980s. Annual or temporary trade is generally less than 5% of the total entitlement and usually from the upper reaches to the lower, cotton growing areas.   Permanent trading is relatively infrequent and involves smaller volumes.

2.4.7.   High security irrigation

There is approximately 8.2 GL of high security irrigation entitlements downstream of Burrendong Dam. However, around 2 GL of the HS entitlement is the result of conversions from GS entitlement that have occurred after 1993/94.

2.4.8.   Unregulated use

Licences extracting water from streams outside the influence of regulated flows from Windamere or Burrendong Dams are known as unregulated or area-based licences.   There are approximately 1,150 of these licences and they are located mostly in the upper reaches of the catchment.   They operate on the basis of a maximum authorised irrigable area (which is approximately 26,000 Ha) and a lower flow limit for pumping (usually a visible flow at the nearest flow gauging station).   Operation of these licences has not been closely monitored to date, and there has generally been very little data collected regarding extractions and cropping by these licences.

2.5.   TOWN WATER SUPPLY

A number of major cities and towns receive their water supply from rivers in the Macquarie Valley.   These include Bathurst, Orange, Lithgow and Oberon in the section of the Macquarie River upstream of Burrendong Dam and Dubbo, Wellington, Nyngan and Cobar in the Macquarie River section downstream of Burrendong Dam.

The towns supplied from Burrendong and Windamere Dams, include Dubbo, Wellington, Nyngan and Cobar, and have a combined high security entitlement of 19 GL. They typically used all of their annual entitlement during the early 1990s.

Extractions for Bathurst are supplied from the Ben Chifley Dam and average around 8 GL annually. Extractions for Orange are supplied by Suma Park Dam and those for Lithgow and Oberon are supplied under the Fish River Scheme (supplied by Oberon Dam) and average around 12 GL annually. Supply to these towns is outside the current DNR licensing arrangements, and diversion totals for these towns are not currently collected as part of the regulated Macquarie–Cudgegong system.

2.6.   STOCK AND DOMESTIC REQUIREMENTS

Licensed volumes for stock watering and domestic supply purposes are high security entitlements, with around 3.7 GL licensed for these purposes in the Macquarie Valley. These entitlements are generally distributed as small amounts of additional entitlement with the general security irrigation licences and therefore, there is no information enabling usage for this purpose to be distinguished from general security irrigation. It has therefore been lumped together with the irrigation nodes in the model.

2.7.   INDUSTRIAL AND MINING EXTRACTIONS

Licensed volumes for industrial and mining purposes are high security entitlements, with around 6.4 GL licensed for these purposes in the Macquarie Valley, the majority of which is located in a single licence near Nyngan.

2.8.   GROUNDWATER ACCESS

Groundwater is used in the Macquarie River Valley for a variety of purposes, including irrigation, town water, stock and domestic purposes. Usage estimates of varying quality are available but are not comprehensive. There was also little information available indicating how extensively groundwater use is connected with surface water use.

2.9.   RESOURCE ASSESSMENT (ALLOCATIONS)

All regulated river valleys in NSW are managed under volumetric allocation schemes, where all licences are issued for a given volume (the licensed volume or entitlement). In any irrigation season, the amount of water made available to irrigation licences is quoted as an *allocation announcement*.

The allocation announcement is the result of a resource assessment process where the resource manager sums all available water resources at that time and all resources that are expected to become available for the remainder of the water year. Allowance is then made for essential requirements such as 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 licensed volume.

In all assessments of available resources it is assumed that drought conditions will ensue between the date of the assessment and the end of the water year. Consequently, all assessments of future inflows, losses and essential requirements are based on the driest recorded sequence in the historical

record. For inflows to the dam, and from downstream tributaries, the historical record currently extends over approximately 100 years.
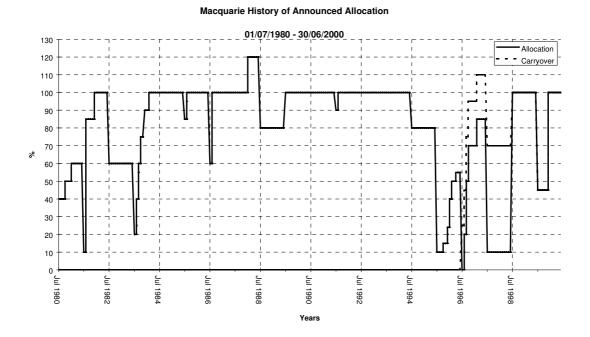
Many of the items used in the resource assessment are subject to change for a variety of reasons. From time to time transmission losses expected under drought conditions may be reviewed, or contingency reserves for supply or environmental purposes may be reassessed.

The allocation assessments are made at the beginning of the water year (1st July for Macquarie Valley), and then typically recomputed when there is a significant inflow to Burrendong or Windamere Dams.

The historical allocation announcements for the Macquarie Valley are presented Figure 2.8.

At the time of the Cap benchmark (1993/94), regional and river operational representatives indicated that there was also a commitment to ensure 20% allocation to irrigators located between Windamere and Burrendong Dams prior to allocating any water to the rest of the system.

Figure 2.8:   Historical announced allocations

2.10.   RIVER AND STORAGE OPERATION

The Macquarie River system is operated to ensure that maximum conservation of resource is achieved during regulated operation, and that flows in excess of the targets at the Macquarie Marshes (Section 5.12.3) are kept to a minimum. Flows in excess of requirements at the end of the regulated river system occur during normal regulated operations as a result of tributary inflows below the storage in excess of requirements, rainfall on crops reducing extraction of ordered water in transit, irrigator ordering accuracy and errors in forecasting system requirements.

2.10.1.   Tributary utilisation

When making releases from Burrendong Dam to satisfy consumptive requirements, the river operator forecasts what flow contributions they expect from downstream tributaries and adjusts the releases accordingly. In practice a range of factors influence the river operator's decision, including recent weather and the most recently observed inflows from the various downstream tributaries.

IQQM representation and calibration of tributary utilisation is discussed further in Section 3.5.1.

2.10.2.   Operational surplus

Operational surpluses result from errors in forecasting demands for irrigation and transmission losses, both of which can be quite variable. The variation in requirements is often manifested in higher releases from storage than orders plus average transmission losses would indicate.

In IQQM, these operational surpluses are represented as over-ordering. IQQM representation and calibration of over-ordering is discussed further in Section 3.5.2

2.10.3.   Flood mitigation releases

In addition to the 1,188 GL of storage up to the full supply volume, Burrendong Dam has approximately 500 GL of air space for flood mitigation, known as the Flood Mitigation Zone (FMZ), which is managed using seven radial gates, each 17 m wide and 6 m high.

Based on many years of experience, the DNR's river operations group developed a set of guidelines for releasing water from this flood mitigation zone. In general, water is not stored in the FMZ unless flooding occurs and inflows exceed the downstream channel capacity. When storage levels intrude into the FMZ, releases are generally made as soon as channel capacity is available to lower storage levels below the FMZ. A detailed description of the specific guidelines that were in place during the 1993/94 irrigation season is presented in Appendix F.

2.10.4.   Windamere to Burrendong transfers

In the early 1990's, the NPWS identified that there were a number of platypus breeding sites between Windamere and Burrendong Dams being adversely affected by:
• Flooding due to high release rates from Windamere Dam;
• River bank slumping due to rapid recessions when Windamere Dam releases was ceased.

To resolve this problem, the DNR and NPWS agreed on a set of release constraints on water being transferred from Windamere to Burrendong Dam. The constraints recognised that water needed to be transferred between the two storages, but also recognised that it would have less affect on the platypus habitat if the volume required was released over a more spread out pattern, with limits on:
• the peak flow rate;
• the rate of rise of the releases;
• the rate of fall and length of the recession of the releases.

Details of the transfer pattern and constraints are contained in Appendix G.

2.11.   SURPLUS FLOW ACCESS (OFF-ALLOCATION)

In the Macquarie River Valley downstream of Burrendong Dam, when flows are in excess of demands (surplus flows), off-allocation periods may be announced. Surplus flows may comprise of operational excess flows, tributary inflows and releases from Burrendong Dam flood mitigation storage (Appendix F). Surplus flows in the Macquarie River Valley can be extracted for irrigation as off-allocation supply, diverted into various effluent creeks to satisfy domestic requirements and mitigate downstream flooding or be allowed to pass downstream to the Macquarie Marshes.

Observed data provided by regional representatives indicated that typical targeted surplus flow thresholds at Warren under river operation policies in use during the 1993/94 irrigation season were approximately 500 to 1,000 ML/d. For surplus flows greater than this, off-allocation was announced. Off-allocation access (number of off-allocation days) for irrigators in all reaches was equalised as much as possible over each irrigation season, based on these access thresholds at Warren Weir.

The 1986 Water Management Plan for the Macquarie Marshes (Section 2.12.3) limits access to off-allocation water via an off-allocation cap. This cap is a function of flows that have occurred to the Marshes and Burrendong storage volume (Section 5.12.3).

2.12.   RIVER FLOW REQUIREMENTS

2.12.1.   Minimum flow

There is a fixed minimum release requirement from Windamere Dam on the Cudgegong River upstream of Burrendong Dam of 35 ML/day. There is also a fixed minimum release requirement from Ben Chifley Dam in the Macquarie River upstream of Burrendong Dam of 70 ML/day.

2.12.2.   Replenishments

Burrendong Dam provides replenishment flows for:
- Marra Creek; and
- Lower Bogan River

Marra Creek has a fixed annual requirement of up to a maximum of 15 GL, with the actual volume released being a function of antecedent conditions in these reaches at specified times of the year. Although there is some variation from year to year, typically the replenishment water is released in the period May to June. If the total volume of water that has flowed into Marra Creek over the preceding 2 months is less than 15 GL, then a replenishment release is made to make up the difference. The target flow rate for the replenishment is 250 ML/d.

The Lower Bogan River replenishment is similar to the Marra Creek replenishment. It also has a fixed annual requirement of up to a maximum of 15 GL, with the actual volume released being a function of antecedent conditions in these reaches at specified times of the year. Although there is some variation from year to year, typically the replenishment water is released in the period July to September. If the total volume of water that has flowed into the Lower Bogan River over the preceding 3 months is less than 15 GL, then a replenishment release is made to make up the difference. The target flow rate for the replenishment is 150 ML/d.

2.12.3.   Wetlands

In 1986, a management plan was jointly prepared by the DWR and the DNPWS to redress environmental degradation of the Macquarie Marshes, at the lower end of the Macquarie River.

Under the 1986 Water Management Plan (WMP), the Macquarie Marshes had a high security wildlife allocation of 50 GL [DWR and DNPWS, 1986]. This wildlife allocation was used in conjunction with surplus flows to maintain the extent, diversity and productivity of the wetland habitat. The wildlife allocation of 50 GL was assessed as the sum of flows in excess of other requirements at the gauging stations on the Macquarie River downstream of Marebone Weir, and on Marebone Break. Further details of the 1986 WMP are provided in Section 5.12.3.

In 1996, a new water management plan for the Macquarie Marshes was adopted [DLWC and DNPWS, 1996]. Amongst other major changes from the 1986 WMP, the 1996 WMP has a wild life allocation of 50 GL high security and an additional 75 GL general security entitlement. The following are the main features of those 1996 WMP rules:

  i.   125GL WLA (Wild Life Allocation) for the Marshes;
  ii.   The WLA was 40% (50 GL) HS and 60% (75 GL) GS;
  iii.   The HS WLA was not available if the GS irrigation allocation was < 10%;
  iv.   Releases were made based on "Translucent Dam Rules". These rules considered the flows that would naturally arrive at the Marshes based on Burrendong Dam inflows and only released flows that were considered useful to the Marsh;
  v.   This ensured that there would be more water made available for the Marshes, that the natural variability in Marsh events was preserved and that there were clear guidelines for releasing the WLA. However, the rules did not allow for any "Active Decisions";

The NSW Government developed the Water Management Act in 2000 and commenced the Macquarie and Cudgegong Regulated River Water Sharing Plan (WSP) in 2004. The following features of the WSP that effect the Marshes are:

  i.   160 GL WLA for the Marshes;
  ii.   The WLA is 100% GS (General Security);
  iii.   The GS WLA, by definition is available at all ranges of GS irrigation allocation;
  iv.   Releases are made based on a combination of "Translucent Dam Rules" (3/5 of available WLA) and "Active Decisions" (2/5 of available WLA);
  v.   This ensured that there would be the same amount of water available for the Marshes as the 1996 Plan, that natural variability in Marsh events was preserved with the Translucent component, but that there was also some flexibility for active decisions to be made.

2.12.4.   Other

There is a power station located downstream of Burrendong Dam that became operational in 1995. As the power station operates in an opportunistic fashion, there are no releases made specifically for it.

3. Model Calibration

3.1.   MODEL CONFIGURATION

The data available for the Macquarie Valley enabled the set-up of an IQQM to represent the water availability and sharing behaviour of the system. Details of the model set-up and presentation of the node-link diagram are contained in Appendices A and B. The number and types of nodes and links used in IQQM to represent the various complexities of any river system is dependent on the purpose for which the model is to be used. To achieve a model that meets the purposes outlined in Section 1.2, the Macquarie IQQM has been configured to include the major storages, stream gauging stations, system inflows and outflows, irrigation demand locations, town water supplies and various river and storage operation policies. In total, there are approximately 260 nodes configured in the Macquarie IQQM (Figure B.1 to B.3).

A number of processes were not configured as part of the model, or configured in a simplified form, as outlined below:

- Resource assessments (announced allocations) were set to observed values during the calibration process because there is often changes in policy and reassessment of estimated parameters, making it difficult to produce a generic resource assessment that reproduced announced allocations across the whole calibration period. The resource assessment parameters will be configured to suit particular scenarios during model simulation. Parameters for the Cap scenario are discussed in Section 5.9 and Appendix E;

- Unregulated licence cropping and usage have not been represented explicitly in the model because of their relatively small impact on river flows and a lack of suitable information to allow model calibration. The effects of unregulated licence activity will be present in the flow records used to produce inflows to the regulated system, especially in more recent years. No adjustment of inflows for unregulated licence activity has been made;

- Town water supplies were modelled using a fixed pattern of demand, representing the average monthly use over the chosen calibration period;

- Licensed volumes for stock and domestic purposes were not represented (due to insufficient data and their negligible effect on river flows);

- Groundwater use was not represented (due to insufficient data and the relatively small impact on river flows and diversions);

- Annual trade of allocated water and permanent trade of licensed entitlement was not represented.

3.2.   CALIBRATION OVERVIEW

Unlike physical scale models, computer models of river and irrigation systems cannot be seen physically or evaluated directly. Proof of their ability to mimic the real system's behaviour can only be given in mathematical and technical terms, relative to actual historic records of the system's behaviour. To achieve this, the parameters or variables in the model are adjusted until the model satisfactorily reproduces historical data over a selected period of time. This process is referred to as "calibration".

IQQM is a complex model and there are a number of different parameters that are used to represent the major river valley processes. For this reason, the calibration process has been developed to proceed sequentially, progressively eliminating unknowns. The sequential process adopted in the Macquarie Valley involves four (4) major steps, with the determination of specific parameters being the focus of each step, whilst setting all other as yet uncalibrated aspects to match the observed data. At the end of the four (4) stage process, all aspects are simulated by the model, based on the calibrated parameter values [DLWC, 1998[c]]. The four (4) 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 set to those observed historically. Routing parameters, transmission losses and ungauged inflows are calibrated.

- Irrigation diversion (demand) calibration - to reproduce observed irrigation extractions from the river, given observed crop areas and crop mix. Irrigation efficiency, soil moisture store, initial rainfall losses and crop factors are calibrated.

- Area planting decision - calibrates an irrigator's decision making process to reproduce observed planted crop areas. Maximum and minimum planted area, crop mix and farmer's planting decisions are calibrated.

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

The selection of the calibration and validation periods was constrained by the availability of data, especially for irrigation data such as diversions, areas and crop mixes. Within this constraint, the calibration period was chosen to be representative of as wide a range of climatic conditions as possible.

The periods chosen for the various stages of the calibration process were:

- Flow calibration: 01/07/1985 – 28/08/2000 (Cudgegong R. d/s of Windamere Dam)
- 01/01/1975 – 31/12/2003 (Macq. R. u/s of Burrendong Dam)
- 01/01/1985 – 31/12/1990 (Macq. R. d/s of Burrendong Dam)
- Demand calibration: 01/07/1985 – 30/06/1990
- Area calibration: 01/07/1985 – 30/06/1990
- Storage calibration: 01/09/1985 – 30/06/1990

Details of each of the individual stages of the calibration are presented in the full calibration and validation report [DLWC, 1995]. Presented here is the degree of replication achieved by the final model after the completion of the above mentioned calibration process.

3.3.   FLOW CALIBRATION

The objective of this step is to calibrate the river system flows module over the calibration period [DLWC, 1998[c]]. All known components of the mass balance within the river valley are set to the observed data. Known system inflows (gauged tributaries and reservoir inflows [DLWC, 1998[g]]) are used as inputs to the model. Irrigation demands are extracted from river reaches as per the observed data. Other demands (including town water supplies) are extracted from river reaches as per the patterns presented in Appendix B. The remaining unknowns (river routing [DLWC, 1998[k]], residual catchment inflows [DLWC, 1998[h]] and transmission losses [DLWC, 1998[e]]) are calibrated iteratively to achieve the best overall match to each main-stream gauge [DLWC, 1998[d]].

Streamflow data is required at all key main stream gauging stations (for deriving losses and flow routing parameters) and for all major tributaries (for mass balance) represented in the model over the calibration period.

An extensive network of streamflow gauging stations represents the main river flows in the Macquarie River catchment. The following criteria are used to select an appropriate sub-set to use in calibration of the main stream flows in the Macquarie IQQM:

- limit the length of river reaches;
- isolation of key features such as tributary inflows and effluent outflows;
- availability of good quality records to cover the intended calibration period, with a minimum number of missing periods.

After a review of the available main stream gauging stations and consideration of these criteria, there were twenty (20) gauging stations selected for use in the model (Table A.3).

There are also streamflow gauging stations located on most of the major tributary inflows in the Macquarie River catchment. The following criteria are used to select an appropriate sub-set to represent the tributary flow contributions in the Macquarie IQQM:

- significance of flow contribution;
- maximise gauged coverage of the contributing catchments;
- availability of good quality records to cover the intended calibration period and long term model simulation period;
- availability of nearby long term stream flow stations to be used to gap-fill and extend the stream flow data set;
- availability of nearby rainfall and evaporation stations that could be used to set-up rainfall-runoff models to gap-fill and extend the stream flow data set.

After a review of the available tributary gauging stations and consideration of these criteria, there were fourteen (14) gauging stations selected for use in the model (Table A.3).

Time series flow data was extracted from the Department's HYDSYS database for all of the key main river and tributary inflow gauging stations.

Streamflow data for gauging stations along the main river was used to compare the model results with the observed records, therefore, no processing was carried out for this data and any gaps due to missing data were left as such.   Table A.4 provides a summary of missing records during the calibration period for the main stream gauging stations used in the model.

Rainfall and evaporation onto the river surface were not modelled explicitly and have therefore been lumped into the losses.

Guidelines for assessing the quality of an IQQM flow calibration are listed in Appendix A.

3.3.1.   Cudgegong River downstream of Windamere Dam

There were short periods of available stream flow data that met the criteria listed in Section 3.2. This enabled this section of the model to be divided into four flow calibration reaches (see Table B.1).

Most of the inflow in the Cudgegong River is from ungauged catchments. Therefore, for each of the four reaches, both a loss node and a residual or ungauged contribution were required.

The main stream losses were first estimated using periods where there appeared to be no inflows from the ungauged catchments. Using these losses and periods when there were inflows from the ungauged catchments, the difference between the upstream and downstream gauges provided an estimate of the contribution from the ungauged tributaries in that reach. The daily correlation between this estimate and the time series of Wyaldra inflows (421058) and Windamere Dam inflows (back-calculated) was then calculated. The time series with the strongest correlation was selected as the site to use to estimate the time series of ungauged catchment contributions. This method of estimation is required because the ungauged contribution is needed both during flow calibration and for the 100+ year simulations.

The selected correlation site was initially factored based on an area ratio with the ungauged catchment for each reach. This initial estimate generally produced good results in terms of mass balance. This implies that the selected correlation catchment was probably close enough to the ungauged catchment to ensure there were no spatial average rainfall differences. Therefore no further factoring was applied.

To match the flow duration curve for the ungauged catchment with the unaccounted difference between the upstream and downstream gauge, an iterative process was then adopted. Typically, the ungauged catchment required a flow duration curve that was steeper and has more zero flow days than the correlation site. To achieve this, we factored up the ungauged catchment marginally to match the high flow end and then removed the excess flow at the low end with an adjustment loss node on the tributary. It is important to place these adjustment losses on the tributary and not on the main river to avoid them being added to main stream orders during periods of low flows.

The main stream loss is then fine-tuned to achieve the best possible match with the downstream gauge. The quality of the flow calibration for each reach is presented in Table 3.1.

Table 3.1:   Assessment of Flow Calibration: Cudgegong R. d/s of Windamere Dam

	SUBJECT			FLOW FREQUENCY				TIME SERIES	
Reach	Calibration Period	Aspect	Files	Whole Range (ML/d)	Low Range (ML/d)	Mid Range (ML/d)	High Range (ML/d)	Correlation (r^2 error)	CMAAD
00 Windamere to 421079	01/07/85 to 31/12/00 (cudg_00n.s6_)	Range:- Obs:- Sim:- Error:- Rating:-	- 421079.flo 421079n.flm - -	All flows 78.8 78.8 0.0% V. High	23 13.8 13.2 -4.2% High	104 48.0 48.3 +0.6% V. High	2889 459.9 460.2 +0.1% V. High	- - - 6% High	- - - 6% High
01 421079 to 421149	01/10/94 to 28/08/00 (cudg_m19.s6_)	Range:- Obs:- Sim:- Error:- Rating:-	- 421149.flo 421149m.flm - -	All flows 144.1 141.4 -1.8% V. High	41 23.4 24.7 +5.2% High	115 68.6 69.2 +0.9% V. High	2791 468.4 453.6 -3.2% V. High	- - - 10% High	- - - 12% Moderate
02 421149 to 421150	19/03/98 to 28/08/00 (cudg_o29.s6_)	Range:- Obs:- Sim:- Error:- Rating:-	- 421150x.mis 421150o.flm - -	All flows 306.0 305.2 -0.2% V. High	29 21.4 20.9 -2.3% V. High	1260 169.5 166.2 -2.0% V. High	17076 5100 5159 +1.1% V. High	- - - 43% V. Low	- - - 34% V. Low
03 421150 to 421019	14/08/97 to 21/06/00 (cudg_d39.s6_)	Range:- Obs:- Sim:- Error:- Rating:-	- 421019.mis 421019d.flm - -	All flows 649.6 650.9 +0.2% V. High	47 31.1 28.3 -9.1% Moderate	993 265.1 259.2 -2.3% High	40582 4810 4868 +1.2% V. High	- - - 36% Low	- - - 31% V. Low
03* Windamere to 421019	01/07/85 to 28/08/00 (cudg_al6..s6_)	Range:- Obs:- Sim:- Error:- Rating:-	- 421019b.flo 421019a6.flm - -	All flows 343.6 347.8 +1.2% V. High	28 20.4 22.9 +12.3% Moderate	668 126.3 129.2 +2.3% High	44191 2520 2537 +0.7% V. High	- - - 51% V. Low	- - - 27% V. Low

Notes: *   Results for the assembled flow calibration model.

In Reaches 00 and 01 a Very High quality calibration was achieved. In these reaches, the quality of the data was good and there were very little ungauged catchment contributions.

In Reaches 02 and 03 however, the amount of ungauged catchment was quite significant. The contribution from these catchments is estimated based on a correlation with either Windamere inflows or Wyaldra Creek flows. This method is quite satisfactory for achieving a good flow frequency match and mass balance, but typically has limitations with matching specific events. This is evident in the High to Very High matches in the flow duration curve and mass balance but the Low to Very Low quality rating in the correlation, which is weighted heavily by the high flow events.

A final test of the flow calibration for the individual reaches is performed by assembling all the reaches together and assessing the quality of the calibration at Yamble Bridge. This test uses observed inflows as input at the top of the system (Windamere outflows in this case) and compares the resulting flows at the intermediate main stream gauges and at the end-of-system gauge (Yamble Bridge). This comparison is performed to ensure that there are no cumulative errors in the individual reach calibrations that result in an unacceptable error at the bottom end of the system. Of particular significance is to achieve a Very High quality rating on the mass balance of flows at Yamble Bridge, thus ensuring that the inflows to Burrendong Dam are representative.

When calibrating Reach 03, there was only a relatively short period where data was available at both the upstream and downstream gauges and Wyaldra Creek. This introduces limitations in the climatic representativeness of the calibration period and therefore the robustness of the calibration. Therefore, we fine-tuned the losses in Reach 03 in the assembled model which has a much longer

simulation period, since it is governed by Windamere outflows. These fine-tuned losses were adopted for the long term simulation model.

The November/94 to January/95 period contained a transfer from Windamere to Burrendong Dam. During this period there was minimal contribution from the tributaries, thus providing an excellent opportunity to check the main stream losses. The flow hydrograph during this period matches at all the main stream gauges very well, indicating that the main stream losses are representative of the actual in-stream losses.

3.3.2. Macquarie River upstream of Burrendong Dam (Ben Chifley Section)

There were short periods of available stream flow data that met the criteria listed in Section 3.2. This enabled this section of the model to be divided into three flow calibration reaches (see Table B.1).

Estimates of the inflow contributing from the ungauged catchments were made using a correlation with streamflow gauging data for a nearby catchment, with catchment area ratios taken into consideration [DLWC, 1995]. The quality of the flow calibration in the upper Macquarie River reaches is presented in Table 3.2.

Table 3.2:   Assessment of Flow Calibration: Macquarie R. u/s of Burrendong Dam

	SUBJECT			FLOW FREQUENCY				TIME SERIES	
Reach	Calibration Period	Aspect	Files	Whole Range (ML/d)	Low Range (ML/d)	Mid Range (ML/d)	High Range (ML/d)	Correlation (r^2 error)	CMAAD
01 U/S Ben Chifley to 421007	01/01/66 to 31/12/78 (chifbat2.sqq)	Range:- Obs:- Sim:- Error:- Rating:-	- 421007c.flo 421007c.flm - -	All flows 952 958 +0.7% V. High	118 79 75 -5.0% High	3980 1107 1116 +0.8% V. High	33950 7457 7688 +3.1% V. High	- - - 15% Moderate	- - - 10% Moderate
02 421007 to 421025	01/01/47 to 31/12/83 (chifbru2.sqq)	Range:- Obs:- Sim:- Error:- Rating:-	- 421025.flo 421025c.flm - -	All flows 1389 1393 +0.3% V. High	90 41 43 +3.4% V. High	25000 1457 1460 +0.2% V. High	85000 40567 41009 +1.1% V. High	- - - 14% Moderate	- - - 10% High
03 421025 to 421080	01/01/71 to 31/12/78 (chifdix2.sqq)	Range:- Obs:- Sim:- Error:- Rating:-	- 421080.flo 421080c.flm - -	All flows 2822 2831 +0.3% V. High	150 78 85 +8.5% Moderate	17000 2125 2110 -0.7% V. High	135000 29866 30600 +2.0% V. High	- - - 4% V. High	- - - 6% High
Combined * U/S Ben Chifley to Bur'ndong Dam	01/01/1947 to 30/06/2003 (chifco46.sqq)	Range:- Obs:- Sim:- Error:- Rating:-	- bdngmerg.flo burr046.flm - -	All flows 3375 3574 +5.9% Moderate	190 75 100 +33.0% Low	35000 2575 2975 +7.1 Moderate	408000 75370 77900 +3.3% V. High	- - - 17% Moderate	- - - 14 High

Notes: *   Results for the assembled flow calibration model.

Reach 01 calibration was difficult because there was no data available for inflows to Ben Chifley Dam over the calibration period. Sacramento rainfall-runoff modelling was used to generate these inflows [DLWC, 1996[a]]. Also, there were no clearly defined release rules from the dam. The dam outflows were based on a combination of demands for Bathurst town water supply, a historical

minimum flow requirement of 35ML/d that was not strictly adhered to and dam spills. The two demands were incorporated into the model. However, because the storage is generally full, the spills are a much more significant factor in the total dam outflows. The spills are driven by the inflows and typically, rainfall-runoff models do not reproduce the timing of individual events. The distance of the rainfall stations from the stream flow station results in timing miss-match between the generated and observed flows. Therefore, the generated dam inflows would not match the timing of the historical dam inflows. This means that the simulated dam spills would also not correlate very well with the historical spills. The flow on effect is that the simulated flows at Bathurst have a Moderate (85%) correlation quality rating with the historical flows. Given this timing issue, the main aim was to achieve a good mass balance at Bathurst, which is demonstrated by the High quality rating for the full range of flows (Table 3.2).

In Reach 02 there is a significant ungauged catchment area. The contribution from the ungauged catchments was estimated by standard method being applied in other river systems. The approach used to account for this large ungauged catchment resulted in moderate to high correlation quality rating.

The length of recorded flows at Dixons Long Point is short and the quality was not very good. Therefore the loss function developed in Reach 03 was initially developed as part of the individual Reach 03 calibration. However, the calibration was checked and slightly modified in the final assembled model from Ben Chifley Dam to Burrendong Dam (as described in the next paragraph).

A final test of the flow calibration for the individual reaches is performed by assembling all the reaches together and assessing the quality of the calibration in terms of Burrendong Dam inflows. This test uses observed inflows at the top of the system (Ben Chifley Dam inflows in this case) and compares the resulting flows at the intermediate main stream gauges and at the end-of-system (i.e. Burrendong Dam). The pre-Burrendong Dam flows were merged with the post dam inflows to make a continuous longer time flow time series for calibration of Burrendong Dam inflows. The post-dam inflows were calculated by the standard back-calculation procedure. This comparison was performed to ensure that there are no cumulative errors in the individual reach calibrations that result in an unacceptable error at the bottom end of the system. The loss functions at Bathurst, Bruinbun and Dixons Long Point were slightly adjusted in combination with the recorded flows from the Cudgegong River (at 421019 Cudgegong River at Yamble Bridge) and a loss node to ensure that a mass balance on the Burrendong Dam inflows was achieved. It was observed that the model was underestimating the high flows. Therefore an additional residual for the high flow was also introduced to match Burrendong Dam inflow for the very wet years. The observed and modelled Burrendong Dam flows are plotted in Figures 3.1-3.3. The underestimation and mismatch of low and very high flows are evident from these plots.

The observed inflows to Burrendong Dam were estimated by a back-calculation technique (Section 3.5.1). This method generally underestimates low flows because of inaccurate observations and especially during summer when evaporation is significantly higher. When Burrendong Dam back-calculated inflows were compared to the nearby gauging records, it was found that flow duration curves at lower end were not consistent. Therefore to be consistent, the simulated flows from the combined reach were deliberately kept a bit higher than those from the back-calculated inflows.
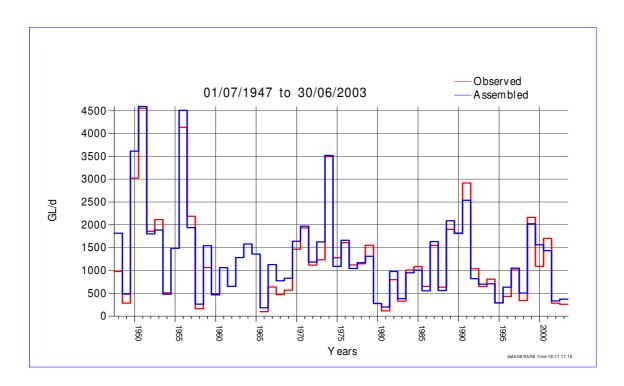
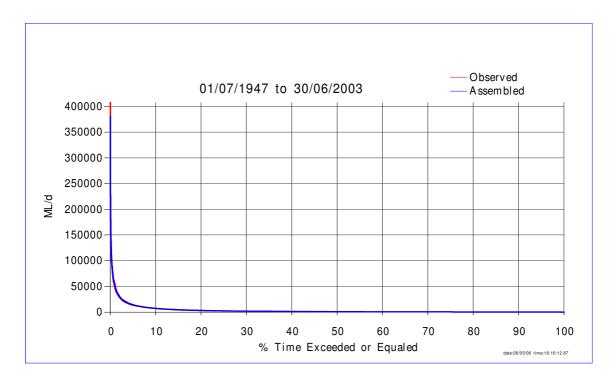**Figure 3.1: Burrendong Dam Inflows– Time series annual flows**

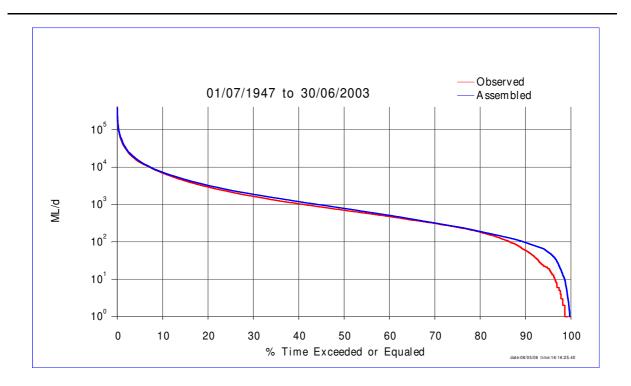**Figure 3.2: Burrendong Dam Inflow – Ranked daily flow**

Figure 3.3:   Burrendong Dam Inflows– Ranked daily flows – log scale

3.3.3.   Burrendong Dam Inflows based on combining of Cudgegong and Chifley Sections

During Cap auditing process of the past few years, it has been noticed that Burrendong Dam inflows could have been over-estimated by the model approach; therefore it was decided to re-visit and check the accuracy of those inflows. As already discussed above the Burrendong Dam inflows comprise flows from 2 sections; Cudgegong and Chifley systems. The Chifley system flows are modelled whereas Cudgegong system flows are largely recorded. Therefore it was decided to check the reliability of Chifley inflows. Since there is no stream gauging station at the end of the Chifley system a procedure has been developed to estimate Chifley system inflows from the back calculated Burrendong Dam inflows. The adopted procedure has been described in the following paragraphs.

The model setup for the inflows to Burrendong Dam was changed so that the adjusted net inflows for the sections Windamere Releases to Yamble Bridge and Yamble Bridge to Burrendong Inflows were both added as single blocks. The set up can be seen in the simplified schematic diagram in Figure 3.4.
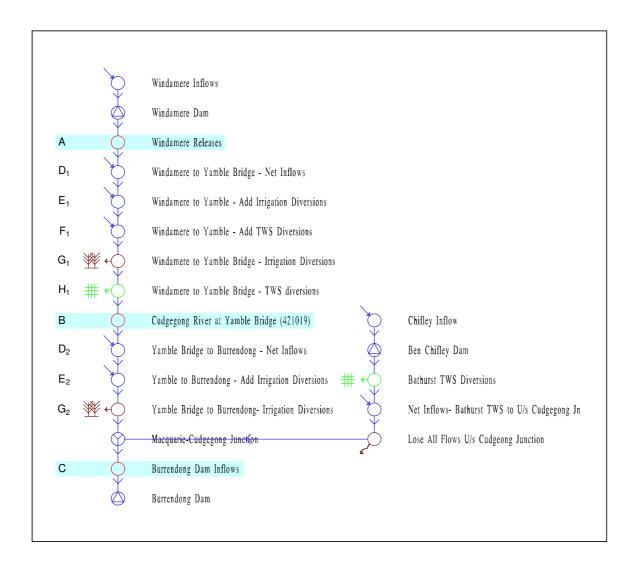
The schematic diagram shows the following labeled elements from top to bottom:

Label	Description
	Windamere Inflows
	Windamere Dam
A	Windamere Releases
D_1	Windamere to Yamble Bridge - Net Inflows
E_1	Windamere to Yamble - Add Irrigation Diversions
F_1	Windamere to Yamble - Add TWS Diversions
G_1	Windamere to Yamble Bridge - Irrigation Diversions
H_1	Windamere to Yamble Bridge - TWS diversions
B	Cudgegong River at Yamble Bridge (421019)
D_2	Yamble Bridge to Burrendong - Net Inflows
E_2	Yamble to Burrendong - Add Irrigation Diversions
G_2	Yamble Bridge to Burrendong- Irrigation Diversions
	Macquarie-Cudgegong Junction
C	Burrendong Dam Inflows
	Burrendong Dam

Right-hand branch:
Chifley Inflow; Ben Chifley Dam; Bathurst TWS Diversions; Net Inflows- Bathurst TWS to U/s Cudgegong Jn; Lose All Flows U/s Cudgeong Junction

Figure 3.4: Simplified schematic diagram of setup for Burrendong inflows in the new annual runs

The first step for developing the adjusted net inflows for the two sections was to derive the net inflows for these sections, which are shown as D_1 and D_2 in Figure 5.4. Both of these net inflows were derived by subtracting the flow at the upstream location from the flow at the downstream location for the period starting in January 1997. For Windamere a release, marked as "A" in Figure 3.4, the flow file for before a lag was done was "2007wind.sro". Before being used these flows were lagged by 1 day as explained below. For Yamble Bridge, marked "B" in the Figure 3.4, the flow used was as in "421019.flf" which was the gap-filled observed flow at the gauging station 421019. For Burrendong inflows, marked "C" in the Figure 5.4 the flow used was the back-calculated inflows from the file "bdnS2007.sio".

Before the upstream flows were subtracted from the downstream flows, lagging of the upstream and downstream flows for these flow sections was done where appropriate to try to get the timing of the inflows to Burrendong Dam about right. The lagging used was 1 day lag for Windamere releases, and no lag for the flows at Yamble Bridge or for Burrendong inflows. The flow file for Windamere releases or "A" with the lagging included was "2007wind_lag1.sro".

The computation of the net inflows for the two sections can be summarized by the following equations:

| Windamere to Yamble Bridge: | $D_1 = B - A$ |
| Yamble Bridge to Burrendong: | $D_2 = C - B$ |

D_2 effectively incorporates the net inflows for the following three sections in the model:

- Cudgegong River between Yamble Bridge and the Macquarie junction

- Macquarie River between Chifley inflows and Cudgegong junction

- Macquarie River between Cudgegong junction and Burrendong inflows

Because the two blocks of net inflows were to be added to the model, this meant that most of the other inflow and loss nodes for upstream of Burrendong Dam in the model could be switched off. As indicated in Figure 3.4, inflows and loss nodes for the Macquarie River upstream Cudgegong junction section were left on but a loss node just upstream of the Cudgegong junction removed all of the flows coming from this section. One advantage with this part of the setup is that Bathurst TWS diversions could still be modelled but would have no effect on Burrendong inflows. All of the irrigation diversions and town water supply (TWS) diversions nodes for the Cudgegong arm were also left on so that their diversions could be output. To compensate for this, simulated time-series of Cudgegong irrigation diversions and also the TWS diversions for the Cudgegong section where applicable were then added to the two net inflows files for the two annual runs. These simulated diversions were taken from the output for the annual run under corresponding conditions (Cap or Latest Conditions) but with Burrendong inflows forced to the back-calculated inflows. The simulated Cudgegong irrigation diversions for the top three Cudgegong reaches, shown as E_1 in Figure 3.4, were added to the net inflows for the Windamere to Yamble Bridge section (D_1). The simulated Cudgegong irrigation diversions for the bottom or fourth reach, E_2, were added to the net inflows for the Yamble Bridge to Burrendong section (D_2). The simulated Mudgee town water supply (TWS) diversions, F_1, which only applied to the Latest Conditions validation run, were also added to D_1 for this run. No lagging was done to any of these simulated time-series of irrigation and TWS diversions before adding them to the appropriate net inflows. The computation of the adjusted time-series of net inflows for the two sections for the Cap Audit annual run can be summarised as follows:

Adjusted net inflows for Windamere releases to Yamble Bridge $= D_1 + E_1$

$$= B - A + E_1$$

Adjusted net inflows for Yamble Bridge to Burrendong inflows $= D_2 + E_2$

$$= C - B + E_2$$

The overall water balance for the net inflows for the two sections for the Cap Audit annual run is as follows:

Adjusted net inflows for Windamere releases to Yamble Bridge $\approx D_1 + E_1 - G_1$

Adjusted net inflows for Yamble Bridge to Burrendong inflows $\approx D_2 + E_2 - G_2$

In these equations G_1, as also seen in Figure 3.4, is the modelled diversions for irrigator nodes in the section Windamere releases to Yamble Bridge in the models for the two new annual runs. G_2 is the modelled diversions for irrigator nodes in the section Yamble Bridge to Burrendong inflows in the models for the two new annual runs.

Another consideration when setting up these new run was that the file with the adjusted net inflows in each of the new annual runs contained some negative values. When these time-series were used in the IQQM simulations, the negative values were changed to zero by IQQM. This was affecting the overall volumes of water entering the system for these blocks of inflows. To fix this problem each of the files with the adjusted net inflows were multiplied by a factor which would bring the average when the negatives are replaced with zeroes to be approximately equal to the average for the adjusted net inflows which contained the negative values. The inflows generated based on this new procedure will be referred as "**Pseudo Observed flows**".

The procedure of calculating of Burrendong inflows to be used in the long-term model is described earlier in this section. Based on that procedure the net inflows from the Chifley section of Macquarie River to Burrendong dam were also estimated and will be referred as "**Modelled flows**" from here on.

Table 3.3 compares the new derived **Pseudo Observed Chifley** flows into the Burrendong Dam and the **Modelled Chifley flows**. Its's clear from Table 3.4 and Figure 3.5, in the extremely dry years (similar to last few years) these Modelled Chifley inflows based on Section 3.3.2 procedure are significantly higher and for the extremely dry years they are quite low. For Schedule F such anomalies, especially for the past few extremely dry years, can create wrong impressions for the year to year audits. Therefore, it was decided to use only the **Pseudo Observed inflows** from the Chifley system for the Schedule F audits.

Since Pseudo Observed Chifley flows are not available for the long-term. Therefore for the long-term Cap estimate purposes, the **Pseudo Observed inflows** are used where available and the remainder of the inflow sequence comprises **Modelled Chifley flows**. Over a longer period, the under and over-estimations during extreme dry and extreme wet years would cancel out each other and should not significantly change the reliability of results.

Table 3.3:   Pseudo Observed and Modelled Chifley Inflows

Water Year	Pseudo Observed (ML)	Modelled (ML)	Difference (ML)
1969	1033400	1163200	-129800
1970	1404000	1391800	12200
1971	1000300	1067000	-66700
1972	950870	1268300	-317430
1973	2523400	2509500	13900
1974	1136100	977560	158540
1975	1404600	1398000	6600
1976	988420	908900	79520
1977	942580	950910	-8330
1978	1210300	920170	290130
1979	174820	145460	29360
1980	84103	159910	-75807
1981	553620	683030	-129410
1982	225590	253430	-27840
1983	808860	737950	70910
1984	883670	794320	89350
1985	530920	432430	98490
1986	1442200	1513600	-71400
1987	553560	473700	79860
1988	1521700	1669200	-147500
1989	1497700	1409500	88200
1990	2448300	2028200	420100
1991	909900	672890	237010
1992	566080	621820	-55740
1993	704330	601030	103300
1994	186250	184940	1310
1995	275360	437360	-162000
1996	750610	784480	-33870
1997	226190	440230	-214040
1998	1630800	1618200	12600
1999	651120	1035500	-384380
2000	1199900	1142200	57700
2001	244130	265090	-20960
2002	78343	93632	-15289
2003	211460	406390	-194930
2004	172530	412540	-240010
2005	381260	946860	-565600
2006	81127	195573	-114446
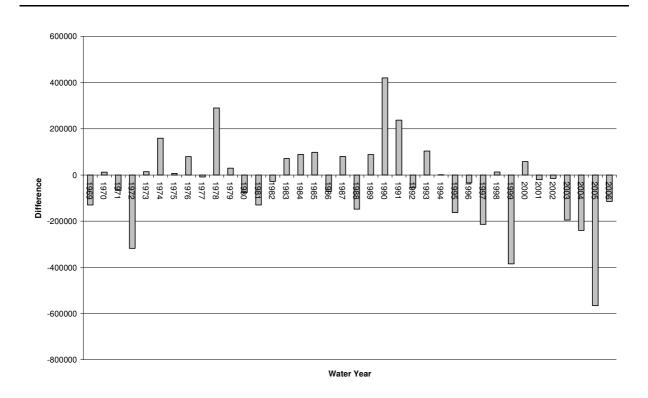
Figure 3.5:   Difference between Pseudo observed and modelled inflows from the Chifley Section

3.3.4.   Macquarie River downstream of Burrendong Dam

There were a number of periods of observed stream flow data that met the criteria listed in Section 3.2. This enabled this section of the model to be disaggregated into seven flow calibration reaches (see Table B.1).

The calibration period for this section of the Valley is from 1st July 1985 to 31st December 1990 for all reaches apart from reaches 2 and 5 that were missing a large proportion of data in the 1985/86 water year. The calibration period for these two reaches is 1st July 1986 – 31st December 1990.

For consistency with diversion and area calibration the CMAAD was calculated on water years (July-June), except for the final year, which only used data from 1st July 1990 to 31st December 1990 due to a lack of data in 1991. The July to December period in 1990 was considered important to include in the calibration because of the large flood that occurred in August 1990, thus allowing higher flows to be calibrated.

Estimates of the inflow contributing from the ungauged catchments were made using a correlation with streamflow gauging data for a nearby catchment, with catchment area ratios and spatial average rainfall differences taken into consideration [DLWC, 1995].

The quality of the flow calibration in each of the seven reaches is presented in Table 3.4.

Table 3.4:   Assessment of Flow Calibration: Macquarie River d/s of Burrendong Dam

	SUBJECT			FLOW FREQUENCY				TIME SERIES	
Reach	**Calibration Period**	**Aspect**	**Files**	**Whole Range (ML/d)**	**Low Range (ML/d)**	**Mid Range (ML/d)**	**High Range (ML/d)**	**Correlation (r^2 error)**	**CMAAD**
01 Burrendng to 421001	01/07/85 to 31/12/90 (rch1b.s6n)	Range:- Obs:- Sim:- Error:- Rating:-	- 421001.flo ch1b.iqn - -	All flows 5296 5354 +1.1% V.High	- - - +3.8% High	- - - +0.5% V. High	- - - +1.1% V. High	- - - 4% V. High	- - - 3% V. High
02 421001 to 421127	01/07/86 to 31/12/90 (rch2b.s69)	Range:- Obs:- Sim:- Error:- Rating:-	- 421127.flo ch2b.iqn - -	All flows 6007 5952 -0.9% V. High	- - - -6.4% High	- - - 0.5% V. High	- - - -0.9% V. High	- - - 2% V. High	- - - 2% V. High
03 421127 to 421031	01/07/85 to 31/12/90 (rch3_1.s6n)	Range:- Obs:- Sim:- Error:- Rating:-	- 421031tt.flo h3_1.iqn - -	All flows 4730 4787 +1.2% V. High	- - - +0.9% V. High	- - - +4.0% High	- - - +0.6% V. high	- - - 4% V. High	- - - 3% V. High
04 421031 to 421004	01/07/85 to 31/12/90 (rch4.s6n)	Range:- Obs:- Sim:- Error:- Rating:-	- 421004.flo rch4.iqn - -	All flows 2690 2664 -1.0% V. High	- - - -3.0% V. High	- - - -0.1% V. High	- - - -1.1% V. High	- - - 3% V. High	- - - 3% V. High
05 421004 to 421090	01/07/86 to 31/12/90 (rch5_2.s6n)	Range:- Obs:- Sim:- Error:- Rating:-	- 421090.flo h5_2.iqn - -	All flows 1388 1399 +0.8% V. High	- - - +14.4% Moderate	- - - +0.4% V. High	- - - +0.3% V. High	- - - 6% High	- - - 2% V. High
06 421090 to 421022	01/07/85 to 31/12/90 (rch6a.s6n)	Range:- Obs:- Sim:- Error:- Rating:-	- 421022.flo ch6a.iqn - -	All flows 892 885 -0.8% V. High	- - - -6.3% High	- - - -4.0% High	- - - +0.9% V. High	- - - 4% V. High	- - - 3% V. High
07 421022 to 421012	01/07/85 to 31/12/90 (rch7a2.s6n)	Range:- Obs:- Sim:- Error:- Rating:-	- 421012.flo h7a2.iqn - -	All flows 629 634 +0.9% V. High	- - - +8.6% Moderate	- - - +2.3% High	- - - +0.5% V. High	- - - 5% High	- - - 3% V. High
Combined* Burrendng to 421012	01/07/85 to 31/12/90 (rchalz1.s6n)	Range:- Obs:- Sim:- Error:- Rating:-	- 421012.flo alz1.iqn - -	All flows 629 616 -2.0% High	- - - 42.9% V. Low	- - - 17.7% Low	- - - -5.3% High	- - - 6% High	- - - 6% V. High

Notes: *   Results for the assembled flow calibration model.

The quality rating for the individual reach flow calibrations is generally Very High.

Reach 4 has a moderate quality rating in the low range because the model does not reproduce the historic operation of Marebone Weir. The model uses a fixed relationship of flow in the main river upstream of Marebone Weir versus release rate down Marebone Break. Historically, decisions to make releases down Marebone Break are made for a variety of reasons and are not governed by flows in the river.

In general, for the lower reaches, the regulated effluents and small weirs made the flow calibration quite difficult. The main aim in all of these reaches was to achieve an overall quality rating of Very High.

The quality rating for Reach 7 is Very High overall, but not as good in each of the flow ranges. This reach incorporates the majority of the Macquarie Marshes. The Marshes were modelled as a single storage node, with a large amount of routing in the reach upstream (to reproduce the flow attenuation that occurs within the Marshes) and a calibrated outflow function. This simplified modelling of the Marshes results in smoothing of the variations in simulated flows at Carinda when compared to the observed flows.

There was some difficulty in calibrating the outflow function from the Marshes to match the observed data. There appeared to be an increase in losses in the Marsh for increasing inflows (measured at upstream Marebone Break) up to a certain threshold. Beyond this threshold, the losses decreased with increasing inflow. This may be due to both rating inaccuracies at high flows and the large volume of overland and effluent flow that returns to the Marshes below the Marebone Weir gauge. A normal loss node is unable to model decreasing losses therefore an outflow function was calibrated based on the inflow (after routing) to the marsh storage node. The inundation area produced by the storage node was calibrated to several large historical floods in the Macquarie Marshes. This gives the Macquarie IQQM the ability to provide an estimate of the daily time series of inundation areas in the Marshes during simulations. When more detailed information on water movement within the Marshes becomes available, this calibration can either be improved or modelled using alternate methods.

A final test of the flow calibration for the individual reaches is performed by assembling all the reaches together and assessing the quality of the calibration at Carinda. This test uses observed inflows as input at the top of the system (Burrendong outflows in this case) and compares the resulting flows at the intermediate main stream gauges and at the end-of-system gauge (Carinda). This comparison is performed to ensure that there are no cumulative errors in the individual reach calibrations that result in an unacceptable error at the bottom end of the system. The final row in Table 3.3 shows the results for the assembled model. These indicate that the match in the low flows at Carinda is of Low quality. This is primarily due to the simplified Macquarie Marshes modelling causing smoothing of the flows and shifting water from the event peaks into the recessions.

Graphical comparisons in the form of annual time series graphs (Figures 3.6 to 3.7) and flow frequency curves (Figures 3.9 to 3.11) for reaches 1, 5 and 7, which correspond to gauges at Dubbo, Marebone Weir and Carinda, respectively, are shown below. These graphs are for the assembled model. Dubbo is above the major irrigators, whereas Marebone is below most of the irrigation but still above the Marshes. Carinda is below the Marshes and is considered to be the end-of-system for the Macquarie IQQM.

Figure 3.7 demonstrates that much of the volume in the large event of late 1990 bypassed the gauge at Marebone Weir via Marebone Break and the other effluent channels further upstream. However, Figure 3.8 clearly shows that this large event has re-appeared at the Carinda gauge, downstream of the Marshes.
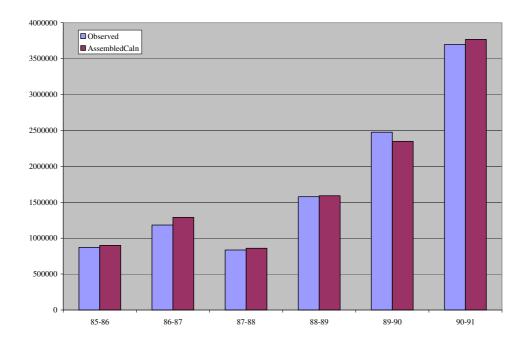
Figure 3.6:   Macquarie River at Dubbo – Annual flow volume comparison

NOTES: 1) The 90/91 figure is the total up to 31/12/1990 only. This part-year was included to cover the large event in late 1990.
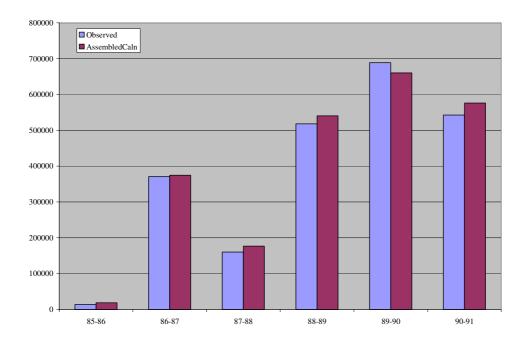
Figure 3.7:   Macquarie River at Marebone – Annual flow volume comparison

NOTES: 1) The 85/86 figure is the total from April to June only. Prior to this, the observed data is missing.

2) The 90/91 figure is the total up to 31/12/1990 only. This part-year was included to cover the large event in late 1990.
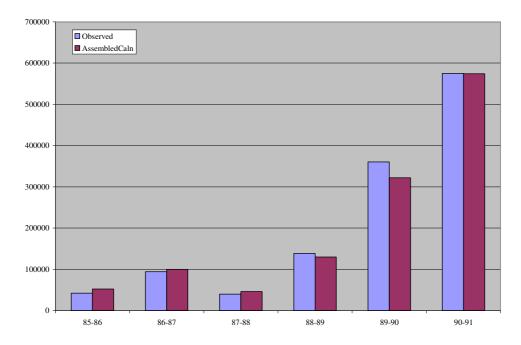
Figure 3.8:   Macquarie River at Carinda – Annual flow volume comparison

NOTES: 1) The 90/91 figure is the total up to 31/12/1990 only. This part-year was included to cover the large event in late 1990.

Daily time series plots for the driest and wettest years of the calibration period are presented in Figures 3.12 and 3.13 respectively. These graphs are for the assembled model. The intention of presenting these results is to indicate that, although IQQM uses an average loss for a given flow rate, the error introduced in years where the losses would be most different to the average is small.

Figure 3.9:   Flow Calibration: Results for Reach 1

Figure 3.10:   Flow Calibration: Results for Reach 5
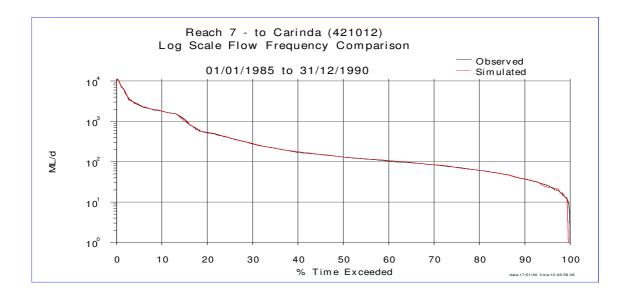
Figure 3.11:   Flow Calibration: Results for Reach 7
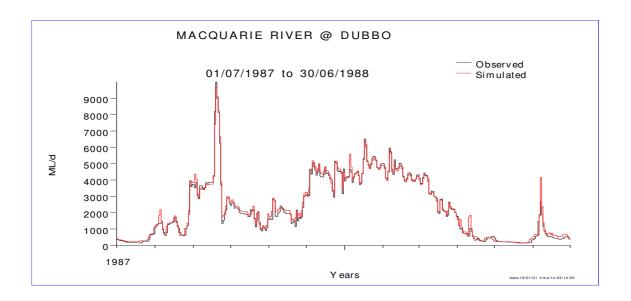
Figure 3.12:   Macquarie River at Dubbo – Driest year in period
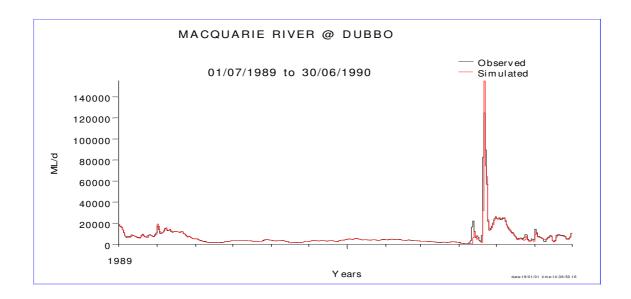
Figure 3.13:   Macquarie River at Dubbo – Wettest year in period

3.4.   DIVERSION VOLUME REPLICATION

3.4.1.   Background and methodology

Irrigation licences were grouped into 33 nodes in the Macquarie IQQM (Table B.2), generally based on river reaches between flow gauges and tributary confluences/effluent offtakes.

IQQM uses a soil moisture accounting model and crop evapotranspiration to generate irrigation demands. The model takes into account crop areas and different crop types, crop factors, rainfall, evaporation, irrigation efficiency and active licence factors [DLWC, 1998[b]].

The objective of this step is to calibrate the crop demand module over the calibration period [DLWC, 1998[c]]. The parameters calibrated during flow calibration (routing, losses and residuals) are used, crop areas and types and off-allocation extractions are set to the observed data. Appropriate rainfall and evaporation data is selected to drive the crop demand module, which is then calibrated to replicate the observed demands based on the observed areas. The IQQM uses theoretical crop factors [Allen, et. al., 1998], with the unknowns being the size of the average "effective" soil moisture store, rainfall interception loss for each irrigator group and the crop watering efficiency for each crop type. Values for these parameters are adjusted until the simulated crop water demands best match the observed data [DLWC, 1998[d]].

Of the available rainfall stations in the Valley, the following criteria are used to select an appropriate sub-set to use in the Macquarie 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 modelling period; and
- continuity and quality of data;
- availability of nearby gauging 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 nine (9) long term rainfall stations (Table A.1) selected to drive the crop demand module in the model.

Of the available evaporation stations, the following criteria are used to select an appropriate sub-set to use in the Macquarie IQQM:

- adequate representation of spatial variability of the evaporation;
- continuity and quality of data;
- availability of records longer than 15 years to allow generation of evaporation sequences [DLWC, 1998[l]] to cover the intended long term modelling period; and
- availability of nearby rainfall stations that cover the intended long term modelling period. These will be used to generate long term evaporation sequences [DLWC, 1998[l]].

After a review of the available evaporation stations and consideration of these criteria, there were three (3) long term evaporation stations (Table A.2) selected to drive the crop demand module in the

model. Every effort was made to collate the best available rainfall and evaporation data for these stations from the Bureau of Meteorology.

The long term daily evaporation estimates used in the Macquarie IQQM upstream of Burrendong Dam are based on observed evaporation that has been extended using a simple evaporation generation module [DLWC, 1998[1]].

The long term daily evaporation estimates used in the Macquarie IQQM downstream of Burrendong Dam were developed prior to the invention of the evaporation generation module, therefore the long term monthly average evaporation rates, disaggregated to a daily time step, are used [DLWC, 1995].

Crop factors for grapes, orchards, cotton, lucerne, pastures and cereals were estimated from guidelines published by the United Nations Food and Agriculture Organisation [Allen, et. al., 1998]. Some changes were then made to these crop factors within allowable limits (±10%) to fine tune the calibration. The crop factors used for different crops and irrigation efficiency factors are presented in Table B.1.

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. These estimated installed pump capacities were also compared for consistency with the maximum observed order placed for each irrigation licence.

As part of the calibration process an active licence volume was determined for each irrigation node, representing the degree of licence utilisation during the calibration period. This was the volume adopted for calibration, but was then modified for the validation (Chapter 4) and simulation model (Chapter 5) based on the active licence data for the period 1992/93 to 1995/96.

3.4.2.   Results

3.4.2.1   Overall

The quality of the total diversion calibration is presented in Table 3.5.

Table 3.5:   Diversion calibration quality achieved for the Macquarie Valley

SUBJECT		ANNUAL DIVERSION TIME SERIES MATCH				QUALITY RATING
Irrigator Group	Quality Indicator	Observed GL	Simulated GL	Indicator Value	Apparent Error	
1985/86	Volume ratio[1]	377	385	102%	2%	V. High
1986/87	Volume ratio[1]	347	380	109%	9%	Moderate
1987/88	Volume ratio[1]	431	465	108%	8%	Moderate
1988/89	Volume ratio[1]	329	340	103%	3%	High
1989/90	Volume ratio[1]	427	340	80%	-20%	Low
Whole period[3]	Volume ratio[1]	1911	1910	100%	0%	V. High
	CMAAD[2]	-	-	-	9.6%	V. High

(1) – representing mass balance replication

(2) – representing temporal variability of annual diversion volume matches

(3) – for the calibration period from July 1985 to June 1990

The comparison between simulated and observed ONA diversion volumes has a very high quality rating. However, Figure 3.14 does show variations on a monthly basis. Any inaccuracies in the diversion calibration may be caused by a number of reasons including:

1) Anomalies in the observed irrigation area data. The simulated areas are set to these values and then the crop demand module is calibrated such that this area generates the observed irrigation demand. Therefore any errors in the area data will result in errors in the crop demand calibration. Checks on the application rates (ML/ha) that the crop is generating are used as a guide to indicate problems of this nature.

2) Anomalies in the observed irrigation diversion data makes it difficult to match the observed and simulated diversions based on the observed areas. As mentioned above, checks on the application rates that the crop is generating is used as a guide to indicate problems of this nature.

3) Model simplifications, such as the spatial representation of rainfall and evaporation (ie. it is considered to be uniformly distributed based on the nearest rain/evaporation gauge) and the simplified representation of the soil moisture store and its effect on irrigation ordering [DLWC, 1998[b]].

4) The observed diversions include small amounts of usage by stock and domestic licences and mining and industrial licences. The Macquarie IQQM has not been configured to represent these entitlements as their usage was small and (in the case of stock and domestic entitlements) difficult to discern from irrigation usage.
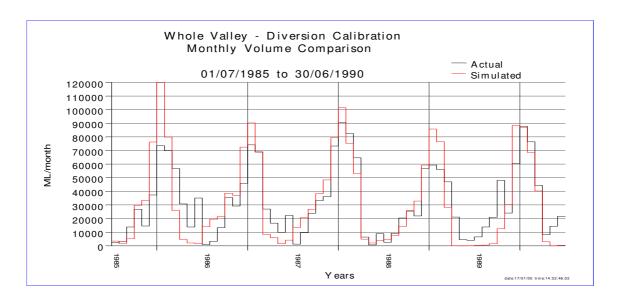
Figure 3.14: Monthly Diversion Calibration: Results
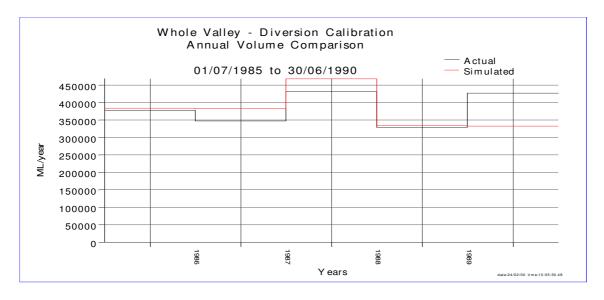
Figure 3.15: Annual Diversion Calibration: Results

3.4.2.2   Cudgegong

The Cudgegong system irrigators were calibrated to match the observed annual diversion estimates provided by the regional representatives (Section 2.4.3) for the early 1990's to present.

3.5.   STORAGE BEHAVIOUR REPLICATION

Storage behaviour replication by the model is the best numerical proof that the model as a whole is performing within reasonable tolerances as all elements of the system contribute to the pattern of draw-downs and releases. Additionally, any systematic or cumulative errors are quite evident because the simulated and observed storage behaviour will diverge.

A number of model parameters are calibrated in the storage calibration process [DLWC, 1998[c]], with a brief summary presented here. To calibrate these parameters, the calibrated parameters from flow and demand calibration are used, with the crop areas and off-allocation extractions still set to the observed data.

3.5.1.   Inflow into dams using back calculation

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 OIC sheets [DLWC, 1985-1996[a]]. The back-calculation technique is based on a mass balance of dam inputs and outputs as follows:

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

Daily Burrendong and Windamere Dam OIC sheets were obtained for the period 1985 to 1995 and were used to estimate dam inflows. These inflows were used for calibrating the storage behaviour.

After a review of the available rainfall and evaporation stations and consideration of the criteria outlined in Section 3.4.1, the rainfall (Table A.1) and evaporation (Table A.2) stations were selected to drive the storage behaviour in the model. Every effort was made to collate the best available rainfall and evaporation data for these stations from the Bureau of Meteorology.

(Section 3.5.2 & 3.5.3 moved to section 3.3?)

3.5.2.   Windamere Dam inflows

The Windamere Dam Sacramento model was calibrated to its back-calculated inflows, for the period 1985 to 1999. The results of that calibration have been described in Table 3.6. Long term Windamere Dam inflows were then generated by using the Sacramento model of for the full 112 year simulation period and merging this data with the available observed inflows prior to dam construction and back-calculated inflows post-dam construction. The mass balance for the Sacramento Model calibration is very high, however the apparent error indicates that the time series match is of quite low quality and the CMAAD is also quite low. This is due to the inherent problems associated with Sacramento model calibrations, these include trying to match high flows and low flows, as well as getting good correlations in wet years and dry years.

Table 3.6   Assessment of storage inflows for Windamere Dam

SUBJECT			FLOW FREQUENCY				TIME SERIES	
Storage	Period used in comparison	Aspect Reported	Whole Range (ML/d)	Low Range (ML/d)	Mid Range (ML/d)	High Range (ML/d)	Correlation (r² error)	CMAAD
Windamere	01/01/1985-31/12/1999	Observed:-	126	-	-	-	-	-
		Simulated:-	125	-	-	-	-	-
		Appar't Error:-	-0.9%	-12.2%	-3.4%	1.0%	27.7%	28.4%
		Rating:-	V. High	Moderate	High	V. High	Low	V. Low

3.5.3.   Burrendong Dam inflows

Inflows to Burrendong Dam were discussed in detail in Section 3.3.2 and 3.3.3. The 1985 to 2003 period was the primary period for model calibration and the previous statistics on flow calibration addressed the full period of record. The statistics for the dam inflows over this period are shown in Table 3.7. The recorded flows for Cudgegong River at Yamble Bridge (421019) were subtracted from the back-calculated dam inflows (observed) to generate the contributing flows from rest of the system.

Table 3.7   Assessment of storage inflows to Burrendong Dam

SUBJECT			FLOW FREQUENCY				TIME SERIES	
Storage	Period used in comparison	Aspect Reported	Whole Range (ML/d)	Low Range (ML/d)	Mid Range (ML/d)	High Range (ML/d)	Correlation (r² error)	CMAAD
Burrendong	01/07/1985-31/12/2003 (macqc006.sqq) (netchifc.obs) (netchifc.co6)	Observed:-	2590	-	-	-	-	-
		Simulated:-	2625	-	-	-	-	-
		Appar't Error:-	-0.3%	-30.0%	-2.0%	+2.0%	19.0%	14.0%
		Rating:-	V. High	Low	V. High	V. High	Moderate	High

3.5.4.   Tributary utilisation

There is no specific information describing this process in reality, and a simplified approach is used within IQQM that is then calibrated. Typically, the forecast flow in a tributary on a future day, is based on a fixed fraction of the current flow in the tributary (i.e. a fixed ratio recession on the tributary flow over the time it takes water to travel from the head-water storage to the location of the tributary). This is the method that has been adopted within IQQM.

Tributary utilisation is generally quoted in terms of the river operator's adopted *tributary recession factor*. The number of days in the future for which the prediction is required is equal to the travel time from the storage (where the release is being computed for the current day) to the tributary. Releases from the storage to meet downstream demands are reduced to allow for this predicted tributary inflow.

Typically, the tributary recession factors reduce progressively down the main river because of the increasing uncertainty as the prediction is required further into the future. Factors for all ungauged tributaries are set to zero. In reality, the factors are not fixed, but they also vary with time and antecedent climatic conditions.

The fixed tributary utilisation factors that produce the best calibration of storage behaviour over the calibration period are presented in Table E.1.

3.5.5.   Operational surplus

There is no specific information describing this process in practice, and a simplified approach is used within IQQM that is then calibrated. Generally, the releases from the head-water storage are greater than the addition of the summed orders and the accumulated transmission losses. The amount the releases are greater by is called the operational surplus. This surplus is designed to allow for any uncertainty in the transmission losses, travel times and attenuation of flows.

IQQM represents this by applying a fixed *over-order factor* to the orders placed by each of the irrigation groups prior to the order being passed up to the storage(s) for release.

Typically, the over-order factors increase progressively down the main river because of the increasing uncertainty in transmission losses and greater flow attenuation with increased travel distance.

During the calibration process, it was found that over-order factors were not required to produce the best calibration of storage behaviour over the calibration period, ie the factor = 0%.

3.5.6.   Results

The quality indicator for storage calibration (CMASDD) indicates an apparent error of less than 2%, and is associated with a very high confidence. Figure 3.16 shows that there is a good match between observed and simulated draw-down rates due to irrigation demands. The matching draw-down rates indicate that the observed and simulated total annual demands and their temporal distribution are similar. The outflow from Burrendong Dam was 98.2% of observed data and as shown in Figure 3.17 the flow frequency comparison is good for all ranges of flows.
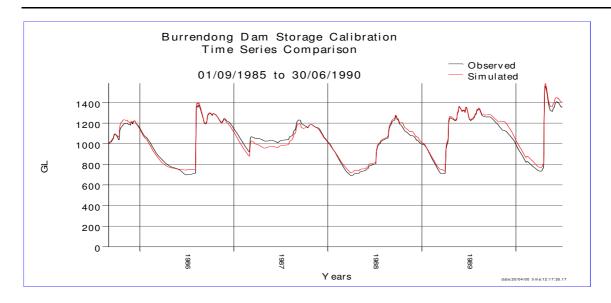
Figure 3.16:   Storage Calibration: Results – Storage Behaviour
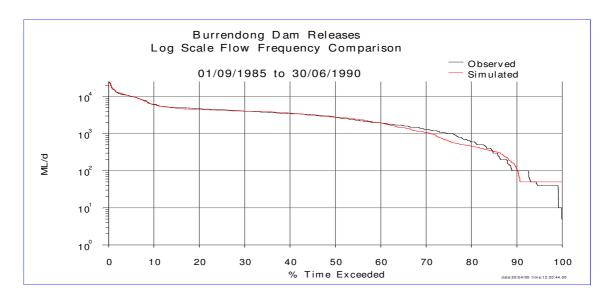
Figure 3.17:   Storage Calibration: Results – Storage Outflows

3.6.   PLANTED AREA REPLICATION

It has been recognised that the planting decision derived during the calibration process (1985/86 – 1989/90 for the Macquarie Valley) is unlikely to be appropriate for use in the Cap scenario. Consequently, a discussion of the planting decision process in IQQM, and its calibration, are presented in Appendix C. The derivation of a planting decision for the Cap scenario is discussed in detail in Section 5.4.3 and Appendix C.

3.7.   SURPLUS FLOW REPLICATION

There was a lack of detailed data for off-allocation diversions during the calibration period and the surplus flow announcements were made on an event by event basis. There was a large degree of variation in the factors used to decide on access to surplus flows from event to event. However, there was a general practice of announcing off-allocation to equalise the access to surplus flow for all the irrigators as much as possible, usually by making the number of off-allocation days roughly the same for all irrigators.

Efforts to match the off-allocation announcements in Macquarie during the calibration period proved very difficult and it was decided that the off-allocation access would remain set to observed data for the purposes of calibrating the other processes in the model. An appropriate set of off-allocation thresholds were derived for the 100 year scenario runs as discussed in Section 5.11.

3.8.   OVERALL MODEL CALIBRATION

The overall model calibration quality has been assessed using a combination of selected key indicators (Appendix D). The results of applying this evaluation process are summarised in Table 3.9, and maintains the apparent overall (average) index (AI%) to the overall index (OI%) quality rating of high.

Table 3.8:   Macquarie Valley IQQM overall quality rating

Replicated Item	Key Indicator	Indicator value % "I" (see note 1)	Associated Quality Rating	Standardised Lower range limit "SL"	Standardised Upper range limit "SU"	Lower Limit of "I" range: "UL"	Upper Limit of "I" range: "UL"	Standardised Indicator "SI"
Total Diversions	Volume Ratio	0.0	Very High	0	5	0	2	0.0
	CMAAD	9.6	Very High	0	5	0	10	4.8
EOS@ Carinda	Volume Ratio	2.0	Very High	0	5	0	2	4.6
	CMAAD	5.8	Very High	0	5	0	10	2.9
Storage Volume	CMASDD	1.8	Very High	0	5	0	2	4.5
Mid-system flow@Dubbo	Mid-flow Range VR	1.1	Very High	0	5	0	2	2.8

Note 1: Negative values converted to absolute values

Table 3.9:   Macquarie Valley IQQM overall quality indicators

Overall Quality Indicator Outcome		
Aspect or Item	**Indicator**	**Quality**
AI%	3.2	Very High
Calibration period length =	4.5 years	
OI%	3.6	Very High

A good way of presenting on overall calibration summary is to look at the main components of the mass balance in the system (Figure 3.18).
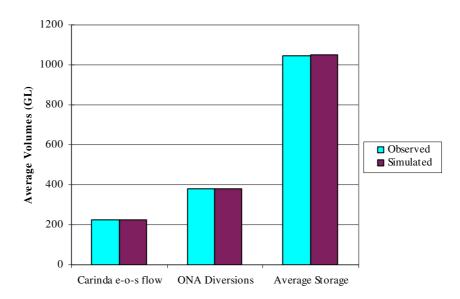
Figure 3.18: Average Annual Mass Balance in Macquarie System

Figure 3.18 clearly demonstrates that the model reproduces each of the major components of the mass balance extremely well. Based on the overall quality rating system and the mass balance study, the final model calibration can be accepted as suitable for strategic planning purposes in general, for the Cap scenario and for the Cap audit scenario.

4. Model Validation

4.1.   BACKGROUND

The validation of the calibrated model was done in two stages. The first stage was simply validating the flow to ensure that the flow calibration was robust outside the calibration period and during a period of small irrigation development. The second stage was a full simulation of the model from July 1993 to June 1995 to ensure that the diversion, area and storage calibrations are robust outside the calibration period.

4.2.   FLOW VALIDATION

The flow validation was carried out in periods prior to significant amounts of development (ie. before 1965) to avoid the need for irrigation diversion data. The validation periods for the flow calibration reaches are shown in Table 4.1. Reach 03 was not validated as there appears to be an effluent present in the reach prior to 1972, which causes the simulation to overestimate flows at Gin Gin. Reach 05 was not validated because there was no pre-development flow data at Marebone Weir (421090).

All irrigator and TWS diversions were removed for the flow validation process. In Reach 06, Oxley Break was removed since the flow data and rating curve at Oxley station indicates that it was only formed during the floods in the 1970s.

The quality assessment parameters for flow validation are the same as those used for flow calibration. The values achieved in the flow validation are presented in Table 4.1.

Table 4.1:   **Assessment of Flow Validation**

SUBJECT			FLOW FREQUENCY				TIME SERIES	
Reach	Validation Period	Aspect	Whole Range (ML/d)	Low Range (ML/d)	Mid Range (ML/d)	High Range (ML/d)	Correlation (r^2 error)	CMAAD
01	01/07/50- 30/06/65	Observed:-	5686	-	-	-	-	-
		Simulated:-	5367	-	-	-	-	-
		Appar't Error:-	-5.6%	-12.8%	-9.2%	-5.1%	11.7%	6.4%
		Rating:-	Moderate	Moderate	Moderate	High	Moderate	High
02	01/07/51- 30/06/65	Observed:-	5274	-	-	-	-	-
		Simulated:-	5466	-	-	-	-	-
		Appar't Error:-	3.6%	-4.3%	-3.8%	4.7%	8.2%	6.6%
		Rating	High	High	High	High	High	High
04	01/07/52- 30/06/65	Observed:-	2878	-	-	-	-	-
		Simulated:-	2801	-	-	-	-	-
		Appar't Error:-	-2.7%	1.5%	-0.04%	-3.4%	7.3%	6.4%
		Rating	High	V. High	V. High	V. High	High	High
06	01/07/56- 30/06/65	Observed:-	1235	-	-	-	-	-
		Simulated:-	1273	-	-	-	-	-
		Appar't Error:-	3.1%	19.2%	-12.2%	9.8%	5.5%	3.8%
		Rating	High	Moderate	Moderate	High	High	V. High
07	01/07/58- 30/06/65	Observed:-	494	-	-	-	-	-
		Simulated:-	417	-	-	-	-	-
		Appar't Error:-	-15.5%	72.6%	-14.5%	18.0%	25.3%	15.5%
		Rating	Low	V. Low	Moderate	Moderate	Low	Moderate

As expected, these results are not as good as those achieved in flow calibration because there is no direct fine tuning of the calibration parameters to improve the match. Most results are quite good, with a CMAAD of high to very high. The poorer validation in reach 7 may be due to a combination of poor quality flow data in the validation period at Carinda (421012) as well as the constantly changing flow regime of the Marshes, which causes the inflow/outflow relationship within the Marshes to change over time. In general, the flow validation results are satisfactory and indicate that the routing, ungauged catchment estimates and losses are robust when tested outside the calibration period.

4.3. DIVERSIONS, AREA AND STORAGE BEHAVIOUR

To validate the other components of the calibrated model, the model was simulated for the 1993/94 and 1994/95 water years and the results were compared with observed data. The level of development in the model was set at those present during the 1993/94 irrigation season for both years, with the assumption that levels of development did not change significantly for 1994/95. There was only a limited amount of observed data available at the time of the validation including:

- total annual planted areas for the valley;

- annual total on-allocation and off-allocation diversions for the valley;

- diversions at the end of the water year (which reflected the irrigator behaviour at the time – Section 2.4.5);

- daily storage behaviour for Burrendong Dam;

- annual flow totals at downstream Burrendong Dam and upstream Marebone Weir;

- observed allocation announcements.

The following modifications to the calibrated model were required to perform the validation:

1) estimation of the development in these years, based on a knowledge of development in the 1992/93 and 1995/96 seasons. This estimate was required for on-farm storage volumes and active licence factors, with the adopted interpolation set at 2/3 of the way between the known values. All other parameters were set to the levels observed during 1993/94;

2) the inflows to Burrendong Dam were set to the observed data, so that differences in the storage behaviour would only be due to errors in the model calibration downstream of Burrendong Dam;

3) for the period 8th October to the 7th November 1993 the historical releases from the flood mitigation zone were not made according to the simplified rules specified in the model. These releases had a significant impact on the Burrendong storage volume that the simplified rules could not reproduce. Therefore, the releases in the model were set to match the historical releases during this period.

4) releases made for Marsh replenishment were set to the observed releases for the 1993/94 and the 1994/95 water years since these occurred in August and September, which is outside of the conventional time for releases;

5) the announced allocation at the start of 1994/95 was 80%. Subsequent inflows provided water for a possible increase in this announcement but no increase was made due to other external factors.. To replicate this, the model was set to not increase the allocation after January;

6) Warren Weir, with re-regulation capabilities and a storage volume of 1000 ML, was added to the model during the validation period to help replicate the operational efficiency of the system in these years. Whilst in reality Warren Weir does not as yet have the capacity to re-regulate flow, the river operators decrease releases to meet irrigator orders if they are expecting rainfall in an

attempt to minimise rain rejections from irrigators. IQQM does not currently have the facility to decrease releases based on rainfall forecasting, but by giving Warren Weir re-regulation capabilities, the rain rejection flows can be captured by Warren Weir and then redistributed to downstream irrigators. Although the modelled mechanism is not strictly representative of the situation in reality, the end result of improved system efficiency is achieved.

The area validation was performed by comparing the simulated and observed planted areas for each of the years (Table 4.2). The area planted for 1993/94 was the same as the observed area. In the 1994/95 season the simulated area is slightly less than observed, which is probably the result of the adopted system development being as per the 1993/94 irrigation season.

To validate the diversions, the simulated and observed annual total diversion volumes and the simulated and observed release patterns from Burrendong Dam releases (Figure 4.1) were compared. Comparison of the release patterns from Burrendong Dam indicates that the daily pattern of irrigation demands is correct for most of the validation period. However in March and April the simulated demand is higher than observed and from August to October the simulated demand is lower than observed. The reason for this observed shifting in the irrigation demand pattern is possibly due to changes in crop mix towards cotton. The overall drawdown of Burrendong Dam at the end of the season is close to observed. The results of the diversion validation are shown in Table 4.2.

Table 4.2:   1993/94 and 1994/95 Validation Summary Results

Parameter	1993/94		1994/95	
	Observed	Simulated	Observed	Simulated
Announced Allocation	100	100	80	77
Planted areas	76000 Ha	76269 Ha	68000 Ha	66304 Ha
Burrendong Releases	944	978	720	677
On-allocation diversions Total May-June	453 80 – 100	455 92	508 40 – 50	429 41
Off-allocation diversions	90	103	14	48
Total diversions	543	558	522	477
Marebone Surplus	450	398	143	147

Table 4.3:   Quality of Burrendong releases validation

SUBJECT			FLOW FREQUENCY				TIME SERIES	
Gauge	Validation Peroid	Aspect	Whole Range (ML/d)	Low Range (ML/d)	Mid Range (ML/d)	High Range (ML/d)	Correlation (r^2 error)	CMAAD
Burrendong Releases	01/07/93 - 30/06/95	Observed:- Simulated:- Appar't Error:- Rating:-	1663 1655 -0.5% V. High	62 46 -25.8 % Low	1332 1363 2.3% High	283 269 -4.9% V. High	- - 27.3% Low	- - 4.6% Very High

Table 4.4:   Quality of diversion and area validation

SUBJECT		ANNUAL DIVERSION TIME SERIES MATCH				QUALITY RATING
Irrigator Group	Quality Indicator	Observed GL	Simulated GL	Indicator Value	Apparent Error	
Whole system ONA diversions	Volume ratio[1]	961	884	92.0%	-8.0	Moderate
	CMAAD[2]	-	-	-	8.4	Very High
Whole system OFA diversions	Volume ratio[1]	104	151	145.2%	45.2	Very Low
	CMAAD[2]	-	-	-	45.2	Very Low
Whole system total diversions	Volume ratio[1]	1065	1035	97.2%	-2.8	High
	CMAAD[2]	-	-	-	5.6	Very High
Whole system area planted	Volume ratio[1]	144000	143078	99.4%	-0.6	Very High
	CMAAD[2]	-	-	-	1.7	Very High

(1) – representing mass balance replication

(2) – representing temporal variability of annual diversion volume matches

In the 1993/94 irrigation season the area planted and the overall diversion match is very close. However the split between simulated on-allocation and off-allocation is different from the observed data. This is because in reality the level of surplus flow required for an off-allocation event to be announced (surplus threshold), varies with time for each off-allocation reach, however in IQQM the surplus threshold for each reach is stationary over time. This makes it impossible to accurately simulate each observed off-allocation event.

There is a slight underestimation in the total 1994/95 diversions (Table 4.2) partially due to the fact that the adopted system development was as per the 1993/94 irrigation season and partially due to the slight underestimation in the simulated available resources. Another point to note is that whilst the simulated Burrendong Dam releases are more than observed releases, the simulated Marebone surplus is greater than the observed Marebone surplus. This is due to over-estimating tributary inflows by 28 GL, underestimating diversions by 38 GL and potentially underestimating the losses in dry years such as the 1994/95 year, since IQQM's loss nodes are derived to represent average losses. Also in reality, releases from Burrendong may be withheld if rainfall is expected (rainfall forecasting) and surplus flows can be accessed as OFA and stored in OFS, to be used by crops at a later date. IQQM is unable to perform these functions, which can cause Burrendong Dam to release slightly too much water when compared to observed data in wet periods.

To validate the storage, the simulated and observed storage behaviour for the two-year period was compared (Figure 4.1). For periods when the dam is not in the flood mitigation zone, the simulated storage behaviour is fair to good, with the start and end of year volumes being roughly the same. However there does appear to be an overestimation of the drawdown in March and April in both irrigation seasons and an underestimate of drawdown from August to October in 1994, as discussed above. The rest of the months have a drawdown approximately parallel to the observed drawdown.

The flood mitigation zone release rules that have been set up in the model (see Appendix D) were also tested by comparing the observed and simulated drawdown of Burrendong Dam (Figure 4.1) and Burrendong releases (Figure 4.2). During the second half of November and all of December, where the releases were simulated, the simulated drawdown is almost parallel to the observed drawdown.

The resource assessment module that has been set up in the model was also tested during the validation phase. The simulated and observed announced allocations compared well (Table 4.2).
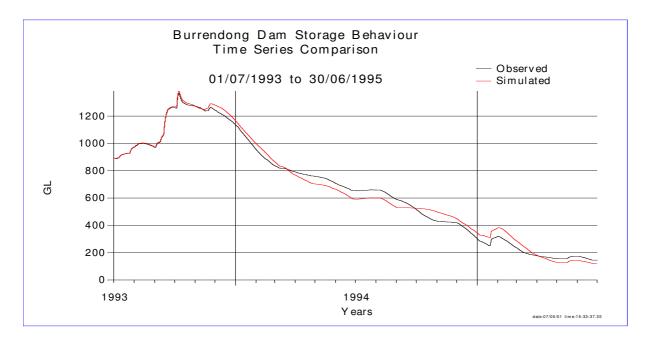
Figure 4.1:   Validation: Storage Behaviour
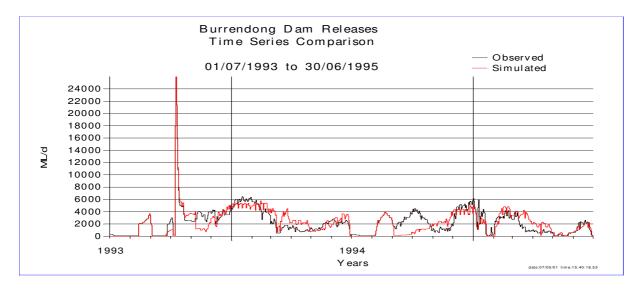
Figure 4.2:   Validation: Storage Releases

5. 1993/94 development conditions (Cap) scenario

The Macquarie River valley is a designated river valley under Schedule F of the Murray-Darling Basin Agreement [MDBMC, 1996], 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 stipulated MDBMC Cap. DNR will use the Macquarie 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, calibrated and validated for the Macquarie Valley. This chapter outlines how the Macquarie IQQM has been configured to perform Cap simulations. The simulation discussed here is based on long term climatic data and fixed 1993/94 levels of infrastructure development, irrigator behaviour and management rules and is therefore called the *Cap scenario*. This scenario will be used to establish a long term average annual Cap diversion. This chapter also describes how this scenario has been used for annual Cap auditing (i.e. the *Cap audit scenario)*.

5.1.   CAP IN BRIEF

The Macquarie River IQQM has been used to run the Cap scenario for a 112 year simulation period from 1890 to 2001. It has also been used to run the Cap audit scenario for the 1997/98, 1998/99, 1999/00, 2000/01 and 2001/02 water years for Schedule F accounting requirements. The following assumptions were used to represent Cap conditions:

- Burrendong and Windamere Dams at 1993/94 capacities and operating rules;
- Pump capacity as installed in the 1993/94 irrigation season;
- On-farm storage capacity as estimated for the 1993/94 irrigation season;
- The mix of crop types as observed during the 1992/93 irrigation season;
- Irrigation efficiencies calibrated based on the observed diversion data up to 1994;
- Maximum planted areas based on observed data up to the 1993/94 irrigation season;
- Management rules applicable for the 1993/94 irrigation season.

5.2.   CLIMATIC DATA

5.2.1.   Rainfall

For the long term simulations, the rainfall stations selected based on the criteria outlined in Section 3.4.1 are extended and gap-filled to cover the intended simulation period. The long term rainfall data was obtained from Bureau of Meteorology.

5.2.2.   Evaporation

For the long term simulations, the evaporation data is usually generated, where required, based on a relationship between monthly evaporation totals and number of rain days in the month [DLWC, 1998[1]]. In the Cudgegong section of the model, this technique was used. However, downstream of

Burrendong Dam, the long term monthly average evaporation is used throughout the simulation period.

5.3.   FLOW DATA

5.3.1.   Streamflows

In model simulation, streamflow data is required for all major tributaries to be represented in the model over a 110+ year period. The long term streamflows at the key main stream gauging stations are not required.

The observed data for the tributary gauging stations selected for use in the model (Table A.3) was collated, gap-filled and extended using Sacramento rainfall-runoff models [DLWC, 1996[a]] such that they covered the intended simulation period.

The ungauged catchment contributions were then derived based on applying the methodology outlined in Section 3.3 to the long term gauged tributary inflows.

5.3.2.   Inflows into the dams

The procedure for Windamere and Burrendong Dam inflows has already been described in Section 3.3. The inflows derived using these techniques were use in the Cap model.

5.4.   IRRIGATION INFORMATION

Observed data was used to configure the model, such as estimates of physical infrastructure including pump capacities and on-farm storages (Section 2.4). Parameters such as crop irrigation efficiencies have been determined during the calibration period with further adjustment made during the validation process [DLWC, 1995]. A full listing of parameters describing the Macquarie IQQM Cap scenario is included in Appendix E.

5.4.1.   Irrigation licences (regulated)

The total regulated entitlement and regulated licence distribution is as per those described by the observed data for the 1993/94 irrigation season (Section 2.4.1 and Table E.3).

5.4.2.   Irrigation extraction and storage infrastructure

The regulated pump capacities and on-farm storages are configured as per the observed data for the 1993/94 irrigation season (Section 2.4.2 and Table E.1).

5.4.3.   Crop areas (planting decision determination)

In the Macquarie IQQM, decisions on how much area to plant are based on the amount of available resource. For each irrigation group, a relationship between planted area and available resource (ie, an application rate or *irrigator's planting risk*) was derived, with the relationship bounded by a maximum and minimum area to plant at the extremes of water availability. Details on modelling the planting decision are provided in Appendix C, and the adopted planting decision is shown in Figure 5.2.

5.4.3.1   *Crop mix*

Limited data was available on individual crop mix on a licence by licence basis. Data was available for the 1992/93 irrigation season downstream of Burrendong Dam on an individual by individual licence basis. Total crop mixes (Figure 2.5) indicate that figures for 1993/94 are reasonably similar to those for 1992/93.

Therefore the 1992/93 crop mix for each individual irrigation node downstream of Burrendong Dam was adopted for the Cap simulation scenario crop mix. For the Cudgegong, the overall crop mix in the 1993/94 scenario was estimated as described in Section 2.4.4.

The adopted 1993/94 crop mix for each irrigation node is stationary during the simulation. The adopted 1993/94 crop mix can be broken up into three distinct sections: the Cudgegong and up and downstream of Narromine. In the Cudgegong, lucerne makes up approximately 57% of the crop mix, with improved pasture making up 37%. The remainder consists of vegetables and grapes. Upstream of Narromine, lucerne was typically the largest single crop type (40-50%) followed by cereals (40%), with the remaining portion cotton and others. Downstream of Narromine, which accounts for approximately 90% of the area planted in the Macquarie Valley, the dominant crop was cotton (50%).

The comparison of summer and winter crop areas (Figure 2.5) indicates that, whilst the winter crop areas make up half of the crops other than cotton, this is a very small portion of the total cropped area. In addition, an examination of the potential water requirements for winter crops indicated that they were even less significant to the total diversions. The analysis of summer and winter crop areas indicates that the winter planting decision is of minimal consequence to irrigation usage and, consequently, a single crop planting decision in early October based on water availability at that time for both summer and winter crops has been adopted.

5.4.3.2   *Application rates (irrigator's planting risk)*

For each irrigation group downstream of Burrendong Dam, a separate relationship between planted area and available resource (ie, an application rate or *irrigator's planting risk*) was derived. Although data was available for the late 1980's, the evidence of growth in active licences prior to the 1991/92 irrigation season made it difficult to use this data for estimating the irrigators' planting risk. Alternatively, an appropriate risk function for each irrigation group was derived based on the 1991/92 to 1995/96 period.

This period was considered to be reasonably stable and representative of the risk that would occur in the Cap scenario because:

1) Most of the growth in active licences had occurred prior to this;

2) The 1996 Water Management Plan for the Macquarie Marshes had not yet been implemented;

3) It covered a broad range of climate variability, from resource constrained (1995/96) to resource abundant (1991/92 to 1993/94) years.

For each irrigation group in the Cudgegong, the maximum area is planted every year. The final adopted application rates (irrigator's planting risk) for each irrigation group are presented in Table E.4, with the simulated data points representing the Valley's behaviour as a whole presented in Figure 5.2.

5.4.3.3 Maximum area

The observed data was analysed for all years up to and including the 1993/94 irrigation season and the total maximum planted area for the Valley was estimated based on the maximum observed area in any one of these years.

Based on this analysis, the total maximum planted area adopted for the Macquarie IQQM Cap scenario is 78,679 ha. Use of this figure reproduces the 76,000 Ha planted in the 1993/94 irrigation season, since not all the irrigators are planting their maximum area in this season.

The total valley maximum planted area was disaggregated to the irrigation groups based on their individual maximum observed planted area up to the 1993/94 irrigation season (Table E.5). A cross-check was also made based on the maximum area that each could plant given their licence and on-farm storage volumes and an approximate application rate. The maximum planted area adopted for the Cudgegong irrigators in the Cap scenario is 1,002 Ha.

5.4.3.4 Minimum area

The observed data was analysed for all years up to and including the 1998/99 irrigation season and, in conjunction with discussions with regional representatives, used to estimate the total minimum area that would be planted in the Valley for the Cap scenario in resource constrained years.

After this analysis, it was decided that the total area planted in the 1995/96 irrigation season was a reasonably good indication of the total minimum area that would be planted. However, it was noted that in this season, there were some resources available (Figure 2.7) and therefore an extrapolation was made from this point to estimate the value that would occur if there were no resources available.

Therefore, the total minimum planted area adopted for the Macquarie IQQM Cap scenario is approximately 34,373 ha. To disaggregate this estimated total minimum area on an individual irrigation group basis, it was distributed to the irrigation groups that have access to on-farm storages and was disaggregated based on the ratio of their licence volumes (Table E.5).

5.4.4. End-of-year diversions

The available observed data (1985/86 – 1990/91 and 1993/94 – 1994/95) was analysed and, although the extent of ordering unused allocation to fill on-farm storages at the end-of-year varied from season to season, it was decided to adopt the average behaviour.

The volumes of extracted water relative to the respective licence volumes of each irrigation group represented in the model were averaged over these periods, with particular emphasis given to the behaviour exhibited in the 1993/94 – 1994/95 period. The irrigation groups were configured to extract this average volume at the end of every season, subject to their volume of remaining allocation and on-farm storage capacity constraints.

5.4.5. Transfer market

The small amount of trade indicated by the observed data was considered too small to warrant adjustment of entitlements for the various irrigation groups. Much of this trade only occurs between the irrigators that are represented within the same irrigation groups represented in the model. In fact,

no manual adjustment of licence volumes/entitlements to represent temporary trade was required to achieve satisfactory model validation for the 1993/94 and 1994/95 irrigation seasons (Chapter 4).

5.4.6.   High security irrigation

The high security irrigation entitlements downstream of Burrendong Dam have been represented in the model by a single irrigation group located in the Narromine to Gin Gin reach, with a licence volume of 4.2 GL.

The commitment to supply 20% allocation to irrigators located between Windamere and Burrendong Dams (Section 2.4.7) has been modelled in the Cap scenario by partitioning 20% of the active irrigation licence volume located upstream of Burrendong Dam as a high security irrigation group. Therefore, there are four high security irrigation nodes (one in each irrigation reach) in the Cudgegong River section, with a total licence volume of 1,100 ML.

5.4.7.   Unregulated use

The unregulated licences have not been included explicitly in the Macquarie 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 Macquarie 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 Macquarie system, this effect has been deemed to be negligible.

It is intended that, if sufficient information should become available, the model would be expanded to represent unregulated licences explicitly, as discussed in Chapter 6.

5.5.   TOWN WATER SUPPLY

Of the town water supplies in the Macquarie Valley (Section 2.5), four have been represented in the model: Bathurst (8,000 ML), Wellington (2,155 ML), Dubbo (8,755 ML) and Nyngan/Cobar (8,090 ML which includes 4,150 ML of industrial/mining). The total entitlement is 26.7 GL, including Bathurst which receives its supply from Ben Chifley Dam. Records obtained from the relevant Shire Councils indicate that these TWS generally use close to their full entitlement each year. Town water supply extractions have been modelled using a fixed daily pattern of demand based on available monthly figures. In the Macquarie IQQM, the average annual extraction for all of these TWS (including the industrial/mining component) is 25.2 GL. The fixed monthly pattern of daily demands for each of these TWS is presented in Table B.2. Bathurst TWS was modelled to ensure that Burrendong inflows were correct. However, since its water is supplied by Ben Chifley Dam, these extractions have not been included in the Cap targets. The annual extraction figure adopted in the Cap targets is therefore 18.6 GL.

All other TWS in the Macquarie Valley, including Oberon, Lithgow and Orange have been implicitly incorporated into the model by calibrating system inflows using gauging stations located below these towns.

5.6.   STOCK AND DOMESTIC REQUIREMENTS

There was not enough information to separate the extractions for stock and domestic purposes in the regulated sections of the Macquarie River, and they have been incorporated implicitly as irrigation use (for licences with a dual purpose) or as part of transmission losses where it occurs.

5.7.   INDUSTRIAL AND MINING EXTRACTIONS

The majority of the entitlement in this category is held in one licence of 4 GL at Nyngan. There was not enough information to model this licence separately in the model. Therefore, the 4,150 ML has been lumped together with the 3,940 ML town water supply licence for Nyngan/Cobar. No other entitlements of this type have been modelled.

5.8.   GROUNDWATER ACCESS

No groundwater access has been represented explicitly in the Macquarie IQQM Cap scenario. Consideration of this issue will be part of future model improvements (Section 6.5).

5.9.   RESOURCE ASSESSMENT

The typical information required to make resource assessments for the Macquarie 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:

- Burrendong and Windamere storages are operated as a combined system to maximise resource, with transfers constraints detailed in Section 2.10.4 and Appendix G;
- Maximum allocation of 100%;
- No carryover of unused allocation;
- No borrow from the following year's allocation;
- Storage reserve is a function of total storage and time of year, with a volume of 169 GL in Burrendong storage and 9 GL in Windamere storage in October.

In recognition of the under-utilisation of licensed entitlement, additional water was made available when announcing allocations up to the mid 1990s. In the Macquarie valley this was done by way of a "system utilisation factor". A full listing of parameters used can be found in Appendix E.

5.10.   RIVER AND STORAGE OPERATION

5.10.1.   Tributary utilisation

Appropriate tributary utilisation factors were determined during the calibration period (1985 – 1990) [DLWC, 1995], with further adjustment made during the validation process to represent more recent river operation practises. The adopted factors for the Cap scenario are listed in Table E.1.

5.10.2.   Operational surplus

Appropriate operational surplus factors were determined during the calibration period (1985 – 1990) [DLWC, 1995], with further adjustment made during the validation process to represent more recent river operation practises. The factors required to achieve storage calibration and validation were found to be zero and therefore this was adopted for the Cap scenario.

5.10.3.   Flood mitigation release

The flood mitigation release rules described in Appendix F have been incorporated into the Cap scenario.

5.11.   SURPLUS FLOW ACCESS (OFF-ALLOCATION)

As discussed in Section 3.7, attempts to match off-allocation announcements during the calibration period proved extremely difficult. Therefore, it was decided that an appropriate set of off-allocation thresholds for the 110+ year scenario runs would be derived based on a combination of matching river operation practices over the calibration period and meeting long term off-allocation access policies.

An appropriate threshold was chosen within the range of 500 to 1,000 ML/d (as indicated by the observed data – Section 2.11), such that the observed off-allocation announcements at Warren were matched as closely as possible. The threshold adopted was 730 ML/d.

The Valley was then divided into twelve off-allocation reaches, based on key points of flow contributions or reductions (Table 5.2). The adopted threshold at Warren was used as a starting point for calculating appropriate thresholds in the other reaches. Thresholds in the other reaches were derived iteratively such that the long term access to surplus flow was equalised for all the irrigation nodes as much as possible during the 110+ year simulation period (Table 5.2). Equal access was defined to have been achieved when the number of off-allocation days was the same for all irrigation nodes.

Table 5.1:   Adopted off-allocation thresholds for the Cap scenario

Off-allocation Reach		Off-allocation Threshold
From	**To**	**(ML/d)**
Burrendong Dam	Bell R Junction	2
Bell R Junction	Little R Junction	245
Little R Junction	Dubbo	260
Dubbo	Talbragar R Junction	240
Talbragar R Junction	Coolbaggie Ck Junction	285
Coolbaggie Ck Junction	Baroona	320
Baroona	Gin Gin	300
Gin Gin	Gunningbar Ck Offtake	320
Gunningbar Ck Offtake	Warren Weir	400
Warren Weir	Reddenville Return	730
Reddenville Return	Marebone Weir	800
Marebone Weir	Oxley	750
Bulgeraga Ck		175
Gunningbar Ck		2

There is also an off-allocation diversion limit of 50 GL per water year (Section 5.12.3).

5.12.   RIVER FLOW REQUIREMENTS

5.12.1.   Minimum flows

Fixed minimum release requirements downstream of Windamere and Ben Chifley Dams have been configured in the model as defined in Section 2.12.1.

5.12.2.   Replenishments

Although in reality, there is variation on the exact timing of the replenishments made for Marra Creek and the Lower Bogan River, these two replenishments are represented in the model as fixed antecedent conditions based replenishments in May to June and July to September, respectively. Both are configured as defined in Section 2.12.2.

5.12.3.   Wetlands

The 1986 Water Management Plan for the Macquarie Marshes [DWR & NPWS, 1986] was in place during the 1993/94 irrigation season. A summary of this plan is presented in this section.

There was a 50 GL high security wildlife allocation that was managed by the National Parks and Wildlife Service to prolong required water levels in the Macquarie Marshes once a bird breeding event had commenced. Therefore, this volume was triggered based on events entering the Macquarie Marshes. The wildlife allocation water was not available when the announced allocation for irrigation was less than or equal to 25%, unless a wildlife allocation release had not been made for the previous 3 years. An overdraw of up to 25 GL was permitted, if it was available in the storage, to allow for the satisfactory completion of waterbird breeding. The amount overdrawn was debited against the allocation in the next year except when the conservation storage of the dam filled before the next wildlife allocation.

There was also a 50 GL cap on off-allocation access for irrigators, which was reset if:
1. 300 GL had flowed to the marshes since the start of the water year or;

2. The off-allocation diversions were made from Burrendong Dam flood mitigation zone releases.

3. The off-allocation threshold were set arbitrarily somewhere between the range of 700-800 ML/d at Warren

In addition to the off-allocation cap, the plan indicated that there should be no off-allocation declarations between 01/08 to 31/12 unless:

1. 20 GL had flowed to the marshes in 60 consecutive days starting 01/06. Note: this particular rule was not included in the model;

2. A wildlife allocation release had already been made;

3. Flood mitigation zone releases were being made.

These rules have been configured in the Cap scenario.

The off allocation sharing rules were significantly changed in 1996. The following are the major changes:

1. The off-allocation cap would not re-set.
2. The off-allocation threshold set to 5000 ML/d at Warren.

The WSP has same off allocation sharing rules as of 1996.

5.12.4.   Other

Even though the power station located downstream of Burrendong Dam operates in an opportunistic fashion, it did not become operational until 1995 and it therefore has not been configured in the Cap scenario.

5.13.   COMPARISON WITH 1992-1995 PERIOD

To assess the robustness of the Cap scenario, a simulation was performed over the period where irrigation development was closest to Cap conditions, with the 1992/93, 1993/94 and 1994/95 seasons considered most appropriate. For this analysis, following are assumed:

1. Inflows to Burrendong Dam were forced to be recorded.
2. Forced recorded releases when the dam was operating within the flood mitigation zone.
3. Forced releases in August/September 1993 for the Macquarie marshes.
4. Forced releases in August 1994 for the wildlife.
5. Since 1992 was quite wet year therefore all On Farm Storages (OFS) were assumed be full at the start of simulation on 1 July 1992.
6. Burrendong storage level was set to the recorded at start of the simulation on 1 July 1992.

The observed and simulated results were compared for a number of processes including: allocation, planted areas, diversions, storage behaviour and end-of-system flows. The results are presented in Table 5.3. The combined Windamere and Burrendong storage behaviour for the 1992-95 period is shown in Figure 5.1.

Table 5.2:   Key observed vs modelled parameters for 1992/93 – 1994/95

Parameter		*1992/93*	*1993/94*	*1994/95*
Announced Allocation (%)				
October	Modelled	100	100	71
	Observed	100	100	80
	Difference	0%	0%	-9%
Areas (Ha)				
	Modelled	76,779	76,779	61,393
	Observed	75,000	76,000	68,279
	Difference	+2%	+1%	-10%
Diversions (GL/YEAR)				
	Modelled	520	532	440
	Observed	460	543	522
	Difference	60	-11	-82
		+13%	-2%	-16%
Application rate	Modelled	6.8	6.9	7.2
(ML/Ha)	Observed	6.1	7.1	7.6
Flows (GL/YEAR)				
Burrendong Releases	Modelled	733	899	617
	Observed	622	944	719
Tributary contribution		151	253	63
	Difference	111	-45	-102
		+14%	-4%	-13%
End-of-system:	Modelled	393	573	273
(Marebone)	Observed	256	544	263
	Difference	37	29	10
		14%	5%	4%
End-of-system:	Modelled	33	67	17
(Carinda)	Observed	22	65	17
	Difference	11	2	0
		50%	3%	0%
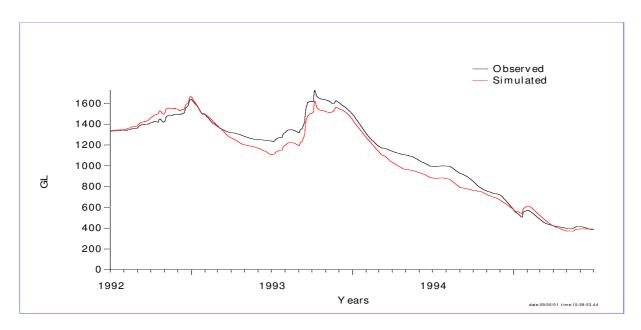
Figure 5.1:   Observed verses simulated combined Windamere and Burrendong Storage behaviour for 1992/93 – 1994/95

5.13.1.   Allocations

The observed and modelled announced allocations are the same for the 1992/93 and 1993/94 irrigation seasons. The 9% under-estimate in the 1994/95 irrigation season is due to the modelled storage volume being 109 GL lower than the observed storage volume at the start of this water year.

5.13.2.   Areas

When comparing the observed and modelled planted areas over the 1992-95 validation period, there are three major factors that need to be considered:

1. the differences between observed and modelled allocation announcements will produce an expected difference in the planted areas;
2. the irrigator's risk function in the model;
3. the adopted maximum area in the model.

A comparison of the observed and modelled areas indicates that the model plants 2% more area than observed in 1992/93, 1% more in 1993/94 and 10% less in 1994/95. The reduction in planted area in 1994/95 is consistent with the 9% under-estimate in the modelled allocation, therefore this difference in the planted areas is considered acceptable.

5.13.3.   Diversions

When comparing the observed and modelled diversions over the 1992-95 validation period, there are two major factors that need to be considered:

1) the differences between observed and modelled planted areas will produce an expected difference in the diversions;
2) the differences between observed and modelled diversions produced during the calibration of the model (Section 3.4) will also produce an expected difference between the observed and modelled diversions during the validation period;

A comparison between simulated and observed total diversions, shows that the model diverts 13% more water in 1992/93, 2% less in 1993/94 and 16% less in 1994/95.

During the periods of high rainfall from November 1992 to January 1993, the observed application rate (6.1 ML/Ha) is much lower than the simulated application rate (6.8 ML/Ha). The cause of this difference is unclear, but may be due to either run-off harvesting in reality or non-representative rainfall in the model. Excess run-off can be harvested by irrigators and pumped into their on-farm storages to be used later as required. There is no data available to calibrate this component of the model and it has therefore not been included in the Macquarie IQQM. If the rainfall in the model is non-representative, this should not result in a systematic error, but rather a random error, ie in some years the rainfall will be over-estimated and in others it will be under. This type of error is normally encountered in hydrologic modelling.

The reduction in diversions in 1994/95 is consistent with the 10% under-estimate in the modelled planted area, therefore this difference in the diversions is considered acceptable. The average application rate over the 3 years is 7.0 ML/Ha for both the simulation and the observed data, which tends to indicate that the year to year variations in application rates are in fact due to non-representative rainfall in the model over the 1992 to 1995 period.

The inclusion of the run-off harvesting behaviour of the Macquarie irrigators into the Macquarie IQQM has been added to the list of future improvements, Section 6.2.11.

5.13.4.   Storage behaviour and end-of-system flows

When comparing the observed and modelled storage behaviour over the 1992-95 validation period, it is necessary to consider the differences between observed and modelled regulated demands. These differences will produce both an expected difference in the storage releases and an expected difference in the end-of-system flows.

Flood mitigation and environmental flow releases were set to the observed releases, where the actual releases made were different to those that would have occurred according to the rules described in Appendix F.

For the 1992/93 season, the modelled storage releases were 111 GL higher than observed, which is considered to be consistent with meeting the 89 GL over-estimate in the modelled diversions.

For the 1993/94 season, the modelled storage releases were 45 GL lower than observed, which, when considered with the lower end-of-system flows, is considered to be consistent with meeting the 11 GL under-estimate in the modelled diversions.

For the 1994/95 season, the modelled storage releases were 102 GL lower than observed, which is considered to be consistent with meeting the 82 GL under-estimate in the modelled diversions.

Carinda can be considered as the end of system of Macquarie System. However, as described in Section 3.3.3, the Macquarie marshes are modelled as a single storage node, with a large amount of routing in the reach upstream and a calibrated outflow function. This simplified modelling of the

Marshes results in smoothing of the variations in simulated flows at Carinda when compared to the observed flows. Therefore, in addition to Carinda, the modelled flows are also compared at Marebone. There appears to be overestimation of flows at Marebone for all of the years. However, the differences are not very significant and are acceptable. In spite of modelling deficiency of marshes, the model and observed flows at Carinda are matching very well.

5.14.   RESULTS

5.14.1.   The Cap scenario (long term simulation)

A comparison of the long-term simulated (based on the Cap scenario) and estimated 1993/94 irrigators' planting decision curve (based on the observed total area planted for the Macquarie Valley over the 1991/92 – 1995/96 period) is presented in Figure 5.2.
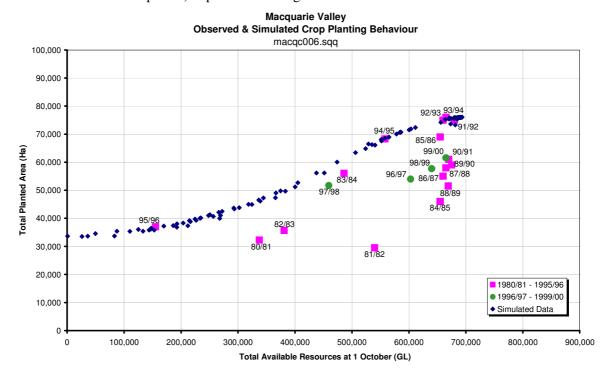
Figure 5.2:   **Simulated relationship between resource availability and planted area**

The observed data pre-1991/92 and post-1995/96 irrigation season is considered to be misrepresentative of the irrigator's behaviour during the 1993/94 irrigation season (Sections 2.4.4.2 and 5.4.3.2).

A good overall match between the simulated and observed planted areas is achieved for the period from 1991/92 to 1995/96 (Figure 5.2), which is considered to best represent Cap behaviour across a variety of resource availability levels (Sections 5.4.3.2).

The summary results for the long-term IQQM Cap simulation are presented in Table 5.3.

Table 5.3:   Summary of the Cap scenario results (as set up in *macqc013.sqq*)

Summary Aspect	*Sub-aspect*			*Average (GL/year)*
Water usage	General Security			346
	Supplementary			71
	High Security			5
	Town Water Supply			25
	Total Cap Diversions			**447**
Crop model	Average planted area (Ha)			60,240
	Maximum planted area (Ha)			76,840
River flows	Macquarie at Dubbo			1189
	Marebone Break + Macquarie at Marebone Weir			413
	Macquarie at Carinda			101
Supply Reliability on 01/01	100%	80%	20%	0%
(% of years that achieved ≥ stated % allocation)	52	63	92	100

Note: results from macqc013.sqq

Figure 5.3:   Cap scenario simulated total annual diversions

5.14.2.   Cap audit scenario (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 Macquarie Valley, the Cap simulation is commenced at the start of the 1997/98 water year (July), with storage levels initialised at observed values.   The IQQM 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, the Macquarie IQQM is started in January, 1997 to allow for the environmental replenishment triggers (Section 2.12.2) to be initialised, to allow for the river system to fill with water and to provide the correct starting soil moisture levels. Storage levels are set such that, at the commencement of the 1997/98 water year, they are equivalent to observed levels. This is known as *hot-starting* the model for the 1997/98 water year.

At the commencement of the simulation, IQQM will plant an area based on the resources available at that time. For Macquarie Valley, the water year commences in July, allowing for the possibility of inappropriately simulated winter planted areas carried over from the end of the previous (1996/97) water year.

To avoid this problem, the initial crop areas in the first season of the Cap audit scenario are as close as possible to the estimated observed winter crop areas planted in March, 1997. Ideally they should be the areas that would have been planted under Cap conditions, but it is not possible to estimate what these would have been. The diversions and areas in the first three months of the Cap audit scenario are less than 5 GL, compared with approximately 24 GL in the observed data, thus introducing a maximum under-estimation of 20 GL for the Cap figure for the 1997/98 water year.

The annual Cap simulation results for the 1997/98 – 2007/08 irrigation seasons are presented in Table 5.4, with a comparison to the observed data.

Table 5.4:   Annual Cap simulation compared to observed data

| Water Year | On-Allocation Diversions | | Off-Allocation Diversions | | Total Planted Areal | | Announced Allocation + Carryover | | | |
| | | | | | | | 01/Oct | | 01/Feb | |
	Obs (GL)	Sim (GL)	Obs (GL)	Sim (GL)	Obs (Ha)	Sim (Ha)	Obs (%)	Sim (%)	Obs (%)	Sim (%)
1997/98	396	280	8	37	58,074	47,345	70	44	70	46
1998/99	288	402	48	113	55,207	76,840	100	100	100	100
1999/00	374	243	11	87	62,697	59,563	100	64	100	100
2000/01	436	323	28	171	66,193	76,695	174	100	198	100
2001/02	546	474	0	39	79,472	76,668	119	100	131	100
2002/03	376	199	0	7	52,616	38,882	59	25	59	25
2003/04	161	155	13	43	25,938	37,121	13	21	23	21
2004/05	64	85	0	13		34,387	5	0	8	11
2005/06	171	279	8	42		34,732	8	2	43	51
2006/07	197	18	5	41		34,704	28	2	28	2
2007/08	30	127	1	25		34,675		2		16

Note results from ma08c102.sqq

Table 5.4 was developed to compare Schedule F modelling under 1993/94 development with observed behaviour over the 1997-2008 period. The table also highlights the impact of changed operating rules, on-farm development and farmer's behaviour over the years. As discussed in Section 2.12.3, there were 3 significant changes to the river operating rules over this simulation period. The 1986 environmental flow rules were operative up until 1996, from 1997-98 till 2003 the Macquarie system was run under 1996 environmental flow rules and the WSP rules are in operation since 2004.

Table 5.4 illustrates the apparent change in behaviour that has occurred since the implementation of the 1996 Water Management Plan. The observed data for years post 1997/98 demonstrate an apparent conservative behaviour by irrigators relative to previous years and relative to the simulated Cap behaviour. In 1997/98, the first of the listed comparison years in Table 5.4, there was less resource available and the model subsequently plants slightly less area than the historical figure. The historical conservative behaviour again shows up in the 1998/99 irrigation season where the model plants a much higher area than the historical figure. This higher area also results in much higher diversions. The 1999/00 year is again comparable due to less resource being available and the 2000/01 year shows the conservative behaviour again. It is not clear whether this conservative behaviour is a long term behavioural change, but it has certainly been one of the reasons for the Macquarie Valley being so far below the Cap to-date (Table 5.5).

The off allocation sharing rules have been described in Section 5.12.3. In 1993/94, the 1986 rules were in place. The observed off allocations for 1998-99 to 2001-02 are significantly lower than those

predicted by the model. This is largely due to the fact that the model has 1986 rules that although have a cap of 50 GLs still have a re-setting clause. Because the 1996 rules (which were in place during the 1998-2002 period) do not have re-setting clause and also have higher off allocation thresholds (5000 ML/d at Warren), therefore observed off allocation diversions are significantly lower than those predicted by the model (1993/94 conditions having 1986 rules).

The cumulative difference between observed diversions and the estimate of diversions as they would have been under Cap conditions (provided by the Macquarie Valley IQQM) commencing from 1997/98 is detailed in Table 5.5.

Table 5.5:   Annual Cap accounting under Schedule F

Water year	Observed			Modelled with IQQM				
	On allocation diversions *	Off allocation diversions	Total diversions	On allocation	Off allocation	TWS & S&D	Total diversions	Difference between observed & modelled
1997/98	396	8	404	280	37	25	343	-61
1998/99	288	48	338	402	113	25	540	201
1999/00	374	11	386	243	87	25	356	-30
2000/01	436	28	465	323	171	25	520	55
2001/02	546	0	546	474	39	25	538	-9
2002/03	376	0	376	199	7	24	230	-146
2003/04	161	13	175	155	43	25	223	49
2004/05	64	0	64	85	13	25	123	59
2005/06	171	8	180	279	42	25	346	166
2006/07	197	5	201	18	41	25	83	-118
2007/08	29	1	30	127	25	25	176	145
Cumulative total			**3136**				**3477**	**311**
Long-term average Cap estimate*:								447
20% of Long-term average Cap estimate:								**89**
Cumulative Cap performance:								Below Cap

• Includes extractions for irrigation and TWS.

• Note: results from ma08c102.sqq

6. Improvement Plans

Models are like any other "man-made" item – once they have been built they require maintenance to stay relevant. This maintenance is a dynamic process and covers updating the model to account for:

- New model capabilities
- Improvements to existing model capabilities
- Further information becoming available to facilitate improved calibration
- More time and resources to refine calibration

In the development of the IQQM software, every effort has been made to ensure that all aspects of the software are operating as intended. However, should it become apparent that any part of the software is not operating appropriately, and resolution of the problem causes any change to the results of Cap simulations, the MDBC will be informed of the changes to the results, and the reason why the changes occurred.

6.1.   UPGRADES TO THE FLOW CALIBRATION

6.1.1.   Extended streamflow records

Since the outset of implementing the Macquarie IQQM, it has been intended that the flow calibration of the individual reaches would be reviewed based on the availability of more recent and better quality streamflow data. It is envisaged that this upgrading process would occur on approximately a five (5) year cycle.

6.1.2.   Additional tributary gauges

There are some additional tributaries for which gauged information is now available. Currently, these are lumped into the estimate of the contribution from residual catchments. A careful review of the available data is required before deciding to include these separately, because they will require the use of Sacramento models for gap filling and data extension.

6.1.3.   Routing of tributary inflows

For most tributaries, the gauging station is located some distance from the junction with the main river. The inflow contribution for each tributary is typically based on the streamflow data recorded at the relevant gauging station, with the catchment area downstream of the gauging station lumped into the residual catchment estimation for the reach. This could be improved by routing the tributary estimates from the gauging station down to their junction with the mainstream and rederive the estimated contribution from their associated residual catchments.

6.1.4.   Antecedent conditions based losses

Incorporation of antecedent streamflow conditions on loss estimates, ie losses at low flows are higher if there has been a prior long period of drought relative to being on the recession of a flood.

6.1.5.   Variable river surface area based on streamflow

This will provide a facility for better representation of varying evaporation from the water surface based on streamflow and therefore better representation of the source of losses and gains in a river reach. This will become more critical for salinity modelling.

6.2. UPGRADES TO THE DEMAND AND AREA CALIBRATION

6.2.1. Extended irrigation demand data

As for the flow calibration, it is also intended that the demand calibration would be reviewed based on the availability of more recent and better quality crop area and irrigation extraction data. The DNR is currently reviewing collected area data with a view to centralising the databases and analysing the quality of the data. It is also possible that remote sensing capabilities may improve in the short to medium term, providing better estimates of cropped areas. This improved data may allow for recalibration of the IQQM in the future. It is envisaged that this upgrading process would occur on approximately a five (5) year cycle.

6.2.2. Crop modelling using crop model 3

This improved crop module will incorporate varying 'windows of opportunity' for planting, crop growth based on degree-days and determine the effect on crop yield due to water shortage. The new module will also simulate farmer behavioural practices, such as changing crop areas and mix in response to past and present resource availability.

6.2.3. Improved modelling of planting decisions

At present there is only limited information available on the planting decision processes. Once more detailed information becomes available, it is envisaged that the planting decision module will also be improved to better represent the variability and complexity that occurs in reality.

6.2.4. Representation of transfer market

At present there is no way of dynamically representing the transfer market within the model. The transfers are either assumed to be insignificant or a simplified approach is used to represent this mechanism.

6.2.5. Better spatial representation of rainfall used to generate crop demands

Currently in the Macquarie IQQM, 9 rainfall stations are used to cover the major demand centres in the Macquarie Valley. This results in smoothing of orders placed by the irrigation groups, since their demands are all being generated based on the same or similar rainfall data, whereas in reality, there is a large degree of spatial variability in the rainfall.

6.2.6. Better temporal representation of evaporation used to generate crop demands

Currently in the Macquarie IQQM downstream of Burrendong Dam, the evaporation data used to drive crop demands and storage losses are based on long term average monthly values, disaggregated to a daily time-step. This results in under-estimation of crop requirements in dry years and over-estimation in wet years.

6.2.7. Improved representation of on-farm storage usage

On-farm storage operation in the model is currently based on reported irrigator behaviour and to achieve the best possible diversion calibration. However, as more information becomes available, it may be possible to represent explicitly on-farm activities such as rainfall harvesting, reuse of irrigation tailwater and division of on-farm storages into cells to reduce evaporation.

6.2.8.   Explicit representation of unregulated users

Inclusion of irrigation nodes to represent the unregulated water users on tributaries. This may also require a review of inflow contributions from these tributaries.

6.2.9.   Improved representation of floodplain/overland flow harvesting

At present there is very little information upon which to calibrate flow harvesting activities. As further information becomes available, refinements of existing modelling and improvements to the model representation may be possible.

6.2.10.   Town water supply modelling

Replace the fixed monthly pattern modelling approach with a demand calibrated to climate (rainfall and evaporation) and population.

6.2.11.   Detailed modelling of development in the upper Macquarie River

Currently Oberon Dam (Lithgow and Oberon TWS) and Suma Park Dam (Orange TWS) are not represented explicitly in the model. These are not seen as significant issues, as their extractions are implicitly incorporated in the inflow data sets for the Macquarie River upstream of Burrendong Dam.

6.2.12.   Include run-off harvesting behaviour by irrigators

At present, the run-off harvesting module for irrigators has not been activated and incorporated into the model calibration. This can cause higher modelled application rates in wet years than those that would be observed in reality.

6.3.   UPGRADES TO THE STORAGE BEHAVIOUR MODELLING

6.3.1.   Variable tributary utilisation

IQQM currently uses a fixed factor to represent recessions on current flows when estimating the flow that will be contribute to meeting order requirements. In reality, this prediction is a function of many factors including the preceding flows (ie rising or falling) and the time of year.

6.3.2.   Variable operational surplus

IQQM currently uses a fixed over-order factor to represent long-term operational surplus. In reality, this factor is a function of many factors including the magnitude of the orders, antecedent conditions and time of year.

6.3.3.   Gated storage modelling

At present, the flood mitigation zone release rules are modelled using a simplified approach. It is envisaged that the full gated storage operation module, with the appropriate release rules, will be incorporated into the model in the future.

6.4.   UPGRADES TO OFF-ALLOCATION MODELLING

6.4.1.   Improved off-allocation modelling

At present, off-allocation is modelled in each reach based on a single threshold that is applied for all months of the year. In reality, announcing off-allocation is a much more complex and variable

process. The minimum amount of work required in this improvement would include using a threshold that is variable depending on month of the year.

6.5.   GENERAL UPGRADES

6.5.1.   Separation of consumptive users from environmental requirements

Currently in the model, there are a number of replenishment flows that are non-consumptive. In reality, these are provided for a combination of consumptive users, such as stock and domestic supply, and non-consumptive users, such as minimum flows for instream habitat. This improvement will require an assessment of current replenishment flow volumes and their intended purposes.

6.5.2.   Incorporate the significance of access to groundwater resources

This would require an investigation of the extent of groundwater use and a relationship with surface water access and crop water requirements.

6.5.3.   Improved modelling of Macquarie Marshes

At present the Macquarie Marshes are represented as a single lumped storage, with routing and an estimate of losses. A hydraulic module was investigated as an alternative, but this proved to be unsuccessful, probably due to a lack of data. If the appropriate data was available, this approach could be re-examined and may produce better results than the current simplified modelling.

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A. Climatic and Streamflow Stations

Table A.1:   Rainfall stations used for model configuration

Location	Station No
CROP DEMANDS	
Mudgee P.O.	062021
Wellington P.O.	065034
Dubbo	065012
Narromine P.O.	051037
Nevertire	051038
Warren P.O.	051054
Mumblebone	051034
Miowera	051031
Quambone (Carwell)	051072
STORAGE BEHAVIOUR	
Burrendong Dam	062003
Mumblebone	051034

Table A.2:   Evaporation stations used for model configuration

Location	Station No
CROP DEMANDS	
Mudgee P.O.	062021
Wellington P.O.	065034
Trangie	051049
STORAGE BEHAVIOUR	
Burrendong Dam	062003
Trangie	051049

Table A.3:   Stream gauging stations used for model configuration

STATION NAME	RIVER/CREEK	NUMBER
MACQUARIE R. U/S BURRENDONG DAM		
MAIN RIVER (for Flow Calibration only)		
U/S Ben Chifley Dam	Campbells River	421101
Apsley	Campbells River	421057
Bruinbun	Macquarie River	421025
Dixons Long Point	Macquarie River	421080
TRIBUTARY INFLOWS		
Tarana	Fish River	421035
Georges Plains	Queen Charlottes Ck	421053
Howards Bridge	Winburndale Rivulet	421072
Sofala	Turon River	421026
U/S Turon River Junction	Crudine Creek	421041
Ophir	Lewis Ponds Creek	421052
Hill End	Pyramul Creek	421067
Hill End	Green Valley Creek	421066
CUDGEGONG R. D/S WINDAMERE DAM		
MAIN RIVER (for Flow Calibration only)		
D/S Windamere Dam	Cudgegong River	421079
Rocky Water Hole	Cudgegong River	421149
Wilbertree Rd	Cudgegong River	421150
Yamble Bridge	Cudgegong River	421019
TRIBUTARY INFLOWS		
Gulgong	Wyaldra Creek	421058

Table A.3: **Stream gauging stations used for model configuration (cont'd)**

MACQUARIE R. D/S BURRENDONG DAM		
MAIN RIVER (for Flow Calibration only)		
D/S Burrendong Dam	Macquarie River	421040
Dubbo	Macquarie River	421001
Baroona	Macquarie River	421127
Narromine	Macquarie River	421006
Gin Gin	Macquarie River	421031
Warren Weir	Macquarie River	421004
Marebone Weir	Macquarie River	421090
Oxley	Macquarie River	421022
Carinda	Macquarie River	421012
Gunningbar Creek Below Regulator	Gunningbar Creek	421005
Marebone Break	Marebone Break	421088
Carinda Road	Marra Creek	421097
TRIBUTARY INFLOWS		
Newrea	Bell River	421018
Yeoval	Buckinbah Creek	421059
Obley	Little River	421048
Elong Elong	Talbragar River	421042
Rawsonville	Coolbaggie Creek	421055

Table A.4:   Missing data on main stream gauging stations (over calibration period)

Model	Station	No.	Missing Periods
Cudgegong River Downstream of Windamere Dam	D/S Windamere Dam	421079	07/08/85-03/09/85; 15/10/85-31/10/85; 06/03/91-22/03/91; 29/01/93-14/02/93; 06/09/99-09/09/99
	Rocky Water Hole	421149	01/07/85-29/10/94; 18/11/96-17/02/97; 12/05/97-13/09/97; 15/03/98-18/03/98; 24/10/98-20/11/98; 13/01/00-23/02/00;
	Wilbertree Rd	421150	01/07/85-13/08/97; 20/07/99-07/09/99; 22/06/00-28/08/00
	Yamble Bridge	421019	25/09/99-27/09/99; 10/10/99-13/10-99;
Macquarie River Upstream of Burrendong Dam	Bathurst	421007	No missing data
	Bruinbun	421025	24/11/76-06/01/77
	Dixons Long Point	421080	01/07/78-30/8/78; 11/10/78-31/12/78
Macquarie River Downstream of Burrendong Dam	Dubbo	421001	05/07/85-26/07/85
	Baroona	421127	01/01/85-11/06/85; 16/12/87-18/02/88; 01/09/89-07/09/89
	Gin Gin	421031	01/01/85-07/01/85; 08/05/86-14/05/86
	Warren Weir	421004	01/01/85-07/01/85
	Marebone Weir	421090	01/01/85-07/01/85; 04/07/85-03/10/85
	Oxley	421022	02/01/85-05/01/85; 08/02/85-11/02/85; 22/03/85-25/03/85; 04/04/85-07/04/85; 08/06/85-11/06/85; 15/06/85-17/06/85; 21/06/85-24/06/85; 21/07/85-29/07/85; 17/08/85-20/08/85; 24/08/85-26/08/85; 29/09/85-05/10/85; 11/12/85-14/12/85; 22/12/85-30/12/85; 18/01/86-21/01/86; 31/01/86-02/02/86; 06/02/86-08/02/86; 01/03/86-10/03/86; 04/04/86-06/04/86; 08/05/86-12/05/86; 18/05/86-20/05/86; 06/06/86-16/06/86; 23/06/86-25/06/86; 09/07/86-21/07/86; 19/09/86-22/09/86; 01/11/86-05/11/86; 27/11/86-30/11/86; 22/12/86-28/12/86; 30/01/87-02/02/87; 25/02/87-27/02/87; 27/03/87-29/03/87; 03/04/87-05/04/87; 18/04/87-21/04/87; 02/05/87-04/05/87; 09/06/87-12/06/87; 19/06/87-22/06/87; 24/07/87-26/07/87; 31/07/87-02/08/87; 26/08/87-31/08/87; 15/10/87-25/10/87; 30/10/87-01/11/87; 05/11/87-10/11/87; 13/11/87-15/11/87; 20/11/87-23/11/87; 27/11/87-30/11/87; 19/12/87-21/12/87; 19/12/87-21/12/87; 24/12/87-31/12/87; 27/02/88-03/03/88; 09/03/88-14/03/88; 30/04/88-02/05/88; 02/06/88-09/06/88; 30/06/88-10/07/88; 16/07/88-19/07/88; 23/09/88-26/09/88; 30/09/88-03/10/88; 28/10/88-31/10/88; 18/11/88-20/11/88; 24/11/88-03/01/89; 20/01/89-10/02/89; 17/02/89-19/02/89; 24/02/89-27/02/89; 03/03/89-14/03/89; 03/03/89-14/03/89; 23/03/89-25/03/89; 11/03/89-22/03/89
	Carinda	421012	21/12/86-31/12/86
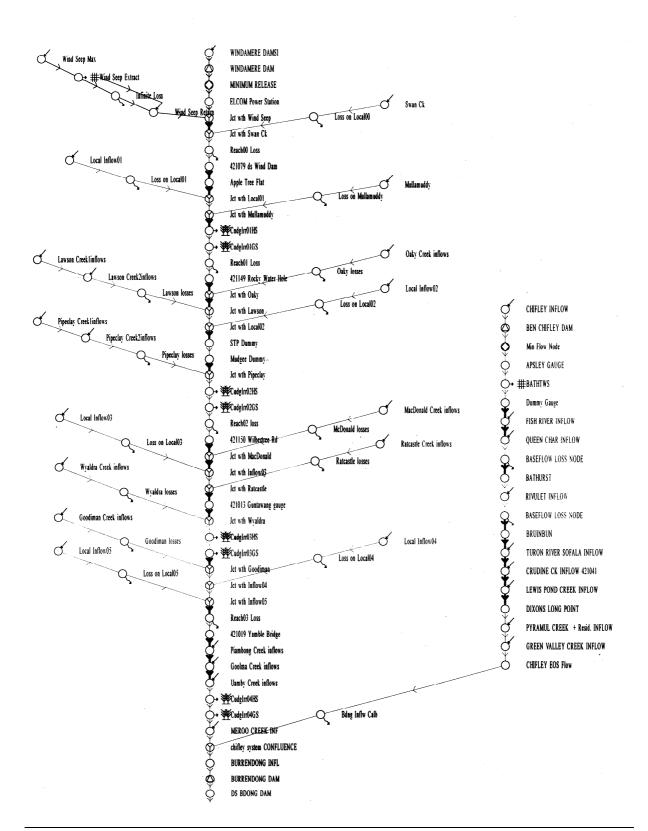
B. Model Configuration

The Macquarie IQQM covers the Macquarie River system draining to the Barwon River near Brewarrina (Figure 2.1). The main features represented in the model are:

• 4 on-river storages: Windamere, Ben Chifley, Burrendong and Warren Weir

• 14 stream gauging stations on the Cudgegong and Macquarie Rivers, used for measuring streamflow

• 27 system inflow locations representing both gauged and ungauged inflows

• 12 effluent channels leaving the main stream and their return locations (where applicable)

• 32 irrigation demand locations, of which 8 are on the Cudgegong River and the remainder are on the Macquarie River downstream of Burrendong Dam

• 4 town water supplies: Bathurst, Wellington, Dubbo and the Gunningbar Diversion for Nyngan

• 2 flow control locations: Windamere and Ben Chifley minimum releases

• 8 off-allocation announcement reaches

• 2 replenishments: Marra Creek and Lower Bogan

• Environmental release requirements for the Macquarie Marshes

• Burrendong Dam flood mitigation zone release rules (Appendix F)

• Water order management rules to control the releases from Windamere Dam subject to platypus habitat requirements (Appendix G)

The Valley was schematised in IQQM using three sub-models, i.e. the Cudgegong River downstream of Windamere Dam (Figure B.1), the Macquarie River upstream of Burrendong Dam (Figure B.2) and the Macquarie River downstream of Burrendong Dam (Figure B.3). These sub-models have been assembled into one model for the Macquarie River Valley.

Figure B.1:   Macquarie River U/S Burrendong Dam Node-Link Diagram

Figure B.2:   Macquarie River Burrendong Dam to Reddenville Bk Node-Link Diagram
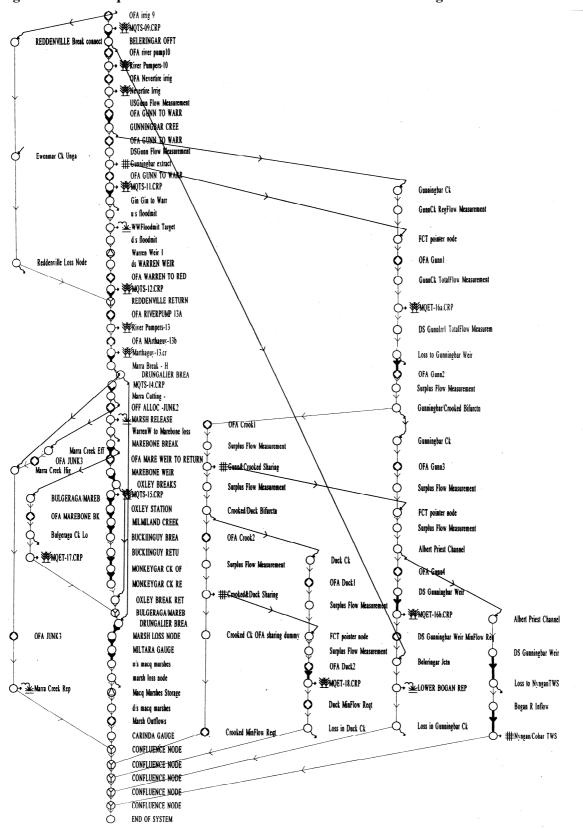
Figure B.3: Macquarie River D/S Reddenville Break Node-Link Diagram

The flow calibration reaches that were used in the Macquarie IQQM are listed in Table B.1.

Table B.1:   Flow calibration reaches in Macquarie IQQM

Valley Section	Upstream Site (Station No.)	Downstream Site (Station No.)
Cudgegong R. d/s of Windamere Dam *Reach 0*	Windamere Releases (OIC Sheets)	D/S Windamere Dam (421079)
Reach 1	D/S Windamere Dam (421079)	Rocky Water Hole (421149)
Reach 2	Rocky Water Hole (421149)	Wilbertree Rd (421150)
Reach 3	Wilbertree Rd (421150)	Yamble Bridge (421019)
Reach 4	Yamble Bridge (421019)	Back-calculated Burrendong Dam Inflows
Macquarie R. u/s of Burrendong Dam *Reach 1*	Apsley 421057	Bathurst (421007)
Reach 2	Bathurst (421007)	Bruinbun (421025)
Reach 3	Bruinbun (421025)	Dixons Long Point (421080)
Inflows to Burrendong Dam	Yamble Bridge (421019) Dixons Long Point (421080)	Back-calculated Burrendong Dam Inflows
Macquarie River d/s Burrendong Dam *Reach 1*	Downstream Burrendong Dam	Dubbo (421001)
Reach 2	Dubbo (421001)	Baroona (421127)
Reach 3	Baroona (421127)	Gin Gin (421031)
Reach 4	Gin Gin (421031)	Warren Weir (421004)
Reach 5	Warren Weir (421004)	Marebone Weir (421090)
Reach 6	Marebone Weir (421090)	Oxley (421022)
Reach 7	Oxley (421022)	Carinda (421012)

Table B.2:   Macquarie IQQM 1993/94 Irrigation Group Information

Node No	Irrigation Group	
	From	**To**
209	HSec: D/S Windamere Dam	Rocky Water Hole (421149)
210	GSec: D/S Windamere Dam	Rocky Water Hole (421149)
222	HSec: Rocky Water Hole (421149)	Wilbertree Rd (421150)
223	GSec: Rocky Water Hole (421149)	Wilbertree Rd (421150)
233	HSec: Wilbertree Rd (421150)	Yamble Bridge (421019)
234	GSec: Wilbertree Rd (421150)	Yamble Bridge (421019)
245	HSec: Yamble Bridge (421019)	Burrendong Dam
246	GSec: Yamble Bridge (421019)	Burrendong Dam
34	Burrendong Dam	Bell R Junction
36	Bell R Junction	Little R Junction
40	Little R Junction	Dubbo (421001)
44	Dubbo (421001)	Talbragar R Junction
46	Talbragar R Junction	Coolbaggie Ck Junction
49	Coolbaggie Ck Junction	Narromine (421006)
52	GSec: Narromine (421006)	Gin Gin (421031)**
53	Narromine-Trangie Irrigation Scheme	
54	Buddah Lakes Irrigation Scheme	
55	Tenandra Irrigation Scheme	
56	Trangie-Nevertire Irrigation Scheme	
57	HSec: Narromine (421006)	Gin Gin (421031)
61	Gin Gin (421031)	Reddenville Break Junction
64	Reddenville Break Junction	Beleringar Ck Junction
66	Beleringar Ck Junction	Gunningbar Ck Junction**
67	Nevertire Irrigation Scheme	
69	Gunningbar Ck Offtake	Warren Weir (421001)
73	Warren Weir (421001)	Ewenmar Ck Junction
77	Ewenmar Ck Junction	D/S Marebone Weir (421090)**
78	Marthaguy Irrigation Scheme	
87	D/S Marebone Weir (421090)	Oxley Station (421022)
136	Gunningbar Ck U/S Gunningbar Weir	
119	Gunningbar Ck D/S Gunningbar Weir	
108	Marebone Break and Bulgeraga Ck	
120	Duck Ck	

Note: ** This node includes irrigators pumping directly from the river only.

Table B.3:   Monthly pattern of daily TWS demands

Month	Bathurst (ML/d)	Wellington (ML/d)	Dubbo (ML/d)	Nyngan (ML/d)
January	28.0	8.4	32.5	46.4
February	26.0	8.4	26.5	48.0
March	23.0	7.1	24.0	36.0
April	18.0	5.7	24.0	16.8
May	14.0	4.2	23.1	4.0
June	13.0	4.2	20.5	3.2
July	12.0	2.7	21.4	2.4
August	12.0	2.7	21.4	7.2
September	14.0	4.2	20.5	16.8
October	16.0	5.7	21.4	20.0
November	19.0	7.1	20.5	18.4
December	24.0	8.4	24.0	44.8
Annual Total	6654 ML	2091 ML	8514 ML	7997 ML

C. Modelling the Planting Decision

6.6.   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.

6.7.   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 set to observed data. The main objective of this calibration stage is to generate the observed planted areas [DLWC, 1999[f]] 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.

6.8.   MAXIMUM AREA

The specified maximum planted area 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 allow for this variation, the maximum observed planted area for the entire valley over the calibration period was 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. A sanity check based on the maximum area that each could plant given their licence and on-farm storage volumes and approximate application rates was also performed.

6.9.   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, a minimum area based on the observed behaviour 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.

6.10.   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.

6.11.   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.

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.

6.12.   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
```

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 achieve 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.

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* $\sum$ Absolute value(Simulated annual – Observed annual) / $\sum$ (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).

6.13.   DIVERSION CALIBRATION QUALITY INDICATORS AND RATINGS

Table D.2:   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* $\sum$Absolute value(Simulated annual – Observed annual) / $\sum$ (Observed annual values)

6.14.   STORAGE CALIBRATION QUALITY INDICATORS AND RATINGS

Table D.3:   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 c	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* $\sum$Absolute value(SMDS – OMDS) / (Observed maximum drawdown*Number of months)

6.15. 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 = $100* \sum$ Absolute value(Simulated annual – Observed annual) $/ \sum$ (Observed annual values)

6.16. 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.

6.17. 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:
1) Total diversion for the valley (Volume ratio and CMAAD)

2)   End of system flows (Volume ratio and CMAAD)

3)   Combined storage behaviour (CMASDD)

4)   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:

1)   Very High   0%<=x<=5%

2)   High   5%<x<= 10%

3)   Moderate   10%<x<=15%

4)   Low   15%<x<=20%

5)   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, $AI = \sum SI,s / 8$. 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
```

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

```
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.

E. MDBMC Cap Development Conditions and Management Rules

Table E.1:   1993/94 Infrastructure & Development Parameters

ITEMS	DESCRIPTION		COMMENTS
GENERAL			
Simulation Period	01 Jul 1890 to 30 Jun 2000		
CATCHMENT INFORMATION			
Storages modelled	Windamere and Burrendong Dams		
Storage Volumes (ML)	Capacity	Dead Storage	
Windamere	368,000	7,000	
Ben Chifley	15,500	200	
Burrendong	1188,000	33,730	
FLOW INFORMATION			
Storage Inflows (GL/yr)	Windamere: 59 Burrendong: 1065		Avg over 1890 to 2001
Tributary inflows (GL/yr)	Cudgegong system: 127 Macquarie R u/s Burrendong: 879 Macquarie R d/s Burrendong: 487		Avg over 1890 to 2001 Includes ungauged inflows

Table E.1:   1993/94 Infrastructure & Development Parameters (cont'd)

IRRIGATION INFORMATION		
General Security (GS) licence volume (ML)	Irrigation: 620,552	
High Security (HS) licence volume (ML)	5,300	
Maximum irrigable area (Ha)	76,000	
On-farm storage capacity (GL)	65	
Pump capacity (ML/d)	13,446	
Active licence factor (%)	97	
Irrigators' carry over (%)	Nil	
On-farm storage operation	Flood plain harvesting Nil End-of-year diversions Yes	Evidence of end-of-year diversions was found.
Average crop mix (%)	Summer Cereal: 16 Winter Cereal: 19 Cotton: 41 Lucerne: 14 Pasture: 10 Other: 1	Details in Section 2.4.4.1
OTHER EXTRACTIONS		
Town water supply (ML/yr)	Bathurst 8,000 Wellington 2,155 Dubbo 8,755 Nyngan + Cobar 8,090 **TOTAL 27,000**	Modelled as fixed pattern of monthly usage each year
Stock & domestic (ML/yr)	Not modelled explicitly	Incorporated into GS irrigation nodes
Industrial / mining (ML/yr)	Not modelled explicitly	Incorporated into Nyngan + Cobar TWS extraction
Groundwater access (ML/yr)	Not modelled	

Table E.1:   1993/94 Infrastructure & Development Parameters (cont'd)

RESOURCE ASSESSMENT			
Storage Reserve *(GL)*	Windamere:	9	Max. @ start of water year
	Ben Chifley	0	
	Burrendong:	169	
Transmission / operation loss *(GL)*	Windamere:	Nil	To provide 100% allocation
	Ben Chifley	Nil	
	Burrendong:	180	
	TOTAL	**180**	
Minimum storage inflows *(ML)*	Windamere:	Nil	Max. @ start of water year
	Ben Chifley	Nil	
	Burrendong:	77,000	
Minimum tributary inflows *(ML)*	D/S Burrendong Dam:	8,000	Max. @ start of water year
System development factor *(%)*		97	
Maximum allocation *(%)*		100	
RIVER AND STORAGE OPERATING RULES			
Transfer rules	Transfers between Windamere and Burrendong Dam are constrained to a fixed pattern to protect platypus habitat in the Cudgegong River		Details in Appendix G
Tributary recession factors *(%)*	Burrendong orders: Bell R 100		
	Little R 100		
	Buckinbah Ck 100		
	Talbragar R 100		
	Coolbaggie Ck 5		
	Ewenmar Ck 0		
Over-order allowance *(%)*	All reaches	0	
Off-allocation Cap *(GL/yr)*		50	Details in Section 5.12.3

Table E.1:   1993/94 Infrastructure & Development Parameters (cont'd)

SURPLUS FLOW ACCESS		
Off-allcation thresholds	Based on 730ML/d at Warren Weir	Details in Section 5.11
RIVER FLOW REQUIRMENTS		
Minimum flow requirements		
Windamere releases (ML/d)	35	
Ben Chifley releases (ML/d)	70	
Replenishments		
Marra Ck (GL/yr)	Annual requirement up to 15 GL; releases May to June (depending on antecedent conditions); target flow rate = 250 ML/d.	
Lower Bogan R (GL/yr)	Annual requirement up to 15 GL; releases July to September (depending on antecedent conditions); target flow rate = 150 ML/d.	
Wetlands		
Macquarie Marshes	The 1986 Water Management Plan for the Macquarie Marshes has been implemented into the Macquarie IQQM	Details in Section 5.12.3

Table E.2:   Adopted Crop Factors and Irrigation Efficiency

Crop →	Cotton	Lucerne	Summer Cereals	Winter Cereals	Pasture	Olives	Grapes	Vegetables	Orchard
Irrigation Efficiency	0.70	0.70	0.70	0.65	0.80	0.90	0.90	0.75	0.90
Jan	0.85	0.60	0.76	0	0.60	0.7	0.7	1.15	0.90
Feb	0.82	0.59	0.60	0	0.59	0.7	0.61	1.09	0.90
Mar	0.56	0.56	0.60	0	0.58	0.61	0.42	0.38	0.83
Apr	0	0.53	0.53	0.73	0.56	0	0.28	0	0.66
May	0	0	0.34	0.73	0.54	0	0.28	0	0
Jun	0	0	0	0.73	0.52	0	0.28	0	0
Jul	0	0	0	0.71	0.46	0.65	0.28	0	0
Aug	0	0	0	0.71	0.50	0.66	0.28	0	0
Sep	0.60	0	0.15	0.64	0.54	0.68	0.52	0	0.57
Oct	0.72	0.47	0.32	0	0.58	0.69	0.70	0	0.69
Nov	0.85	0.55	0.57	0	0.59	0.70	0.70	0.43	0.84
Dec	0.88	0.60	0.77	0	0.60	0.70	0.70	0.87	0.90

Note: These are the average of the irrigation groups' efficiencies. There are actually differences in efficiency between different irrigation groups along the river.

Table E.3:   Macquarie IQQM 1993/94 Irrigation Group Information

Node No	Irrigation Group From	To	Licence Volume (ML)
209	HSec: D/S Windamere Dam	Rocky Water Hole (421149)	84
210	GSec: D/S Windamere Dam	Rocky Water Hole (421149)	338
222	HSec: Rocky Water Hole (421149)	Wilbertree Rd (421150)	394
223	GSec: Rocky Water Hole (421149)	Wilbertree Rd (421150)	1578
233	HSec: Wilbertree Rd (421150)	Yamble Bridge (421019)	453
234	GSec: Wilbertree Rd (421150)	Yamble Bridge (421019)	1811
245	HSec: Yamble Bridge (421019)	Burrendong Dam	181
246	GSec: Yamble Bridge (421019)	Burrendong Dam	724
34	Burrendong Dam	Bell R Junction	4767
36	Bell R Junction	Little R Junction	17824
40	Little R Junction	Dubbo (421001)	14319
44	Dubbo (421001)	Talbragar R Junction	3992
46	Talbragar R Junction	Coolbaggie Ck Junction	20522
49	Coolbaggie Ck Junction	Narromine (421006)	9458
52	GSec: Narromine (421006)	Gin Gin (421031)**	88874
53	Narromine-Trangie Irrigation Scheme		59706
54	Buddah Lakes Irrigation Scheme		32500
55	Tenandra Irrigation Scheme		33431
56	Trangie-Nevertire Irrigation Scheme		63511
57	HSec: Narromine (421006)	Gin Gin (421031)	4172
61	Gin Gin (421031)	Reddenville Break Junction	65673
64	Reddenville Break Junction	Beleringar Ck Junction	22537
66	Beleringar Ck Junction	Gunningbar Ck Junction**	11365
67	Nevertire Irrigation Scheme		33024
69	Gunningbar Ck Offtake	Warren Weir (421001)	1528
73	Warren Weir (421001)	Ewenmar Ck Junction	1340
77	Ewenmar Ck Junction	D/S Marebone Weir (421090)**	19621
78	Marthaguy Irrigation Scheme		13989
87	D/S Marebone Weir (421090)	Oxley Station (421022)	50169
136	Gunningbar Ck U/S Gunningbar Weir		4415
119	Gunningbar Ck D/S Gunningbar Weir		8831
108	Marebone Break and Bulgeraga Ck		32315
120	Duck Ck		2390
	TOTAL		**625836**

Note: ** This node includes irrigators pumping directly from the river only.

Table E.4:   Application rates (irrigator's planting risk) for each irrigation group

| Node No.	Irrigator	Application Rate at Max. Area (ML/Ha)
209, 210	Cudg01	5.3*
222, 223	Cudg02	5.8*
233, 234	Cudg03	5.5*
245, 246	Cudg04	5.4*
34	MQTS-01	8.3
36	MQTS-02	6.9
40	MQTS-03	8.3
44	MQTS-04	8.0
46	MQTS-05	5.7
49	MQTS-06	8.0
52	River pumpers -07	6.4
53	Narromine-Trangie-07	8.9
54	Buddah Lakes-07	9.1
55	Tenandra-07	9.5
56	Trangie-Nevertire-07	9.1
57	HSec -07	6.9
61	MQTS-08	8.8
64	MQTS-09	7.4
66	River pumpers-10	5.9
67	Nevertire-10	5.9
69	MQTS-11	7.0
73	MQTS-12	7.7
77	River pumpers-13	8.3
78	Marthaguy-13	8.3
87	MQTS-15	5.6
136	MQET-16a	7.4
119	MQET-16b	7.4
108	MQET-17	6.1
120	MQET-18	8.3
	TOTAL (Weighted Average)	**8.0**
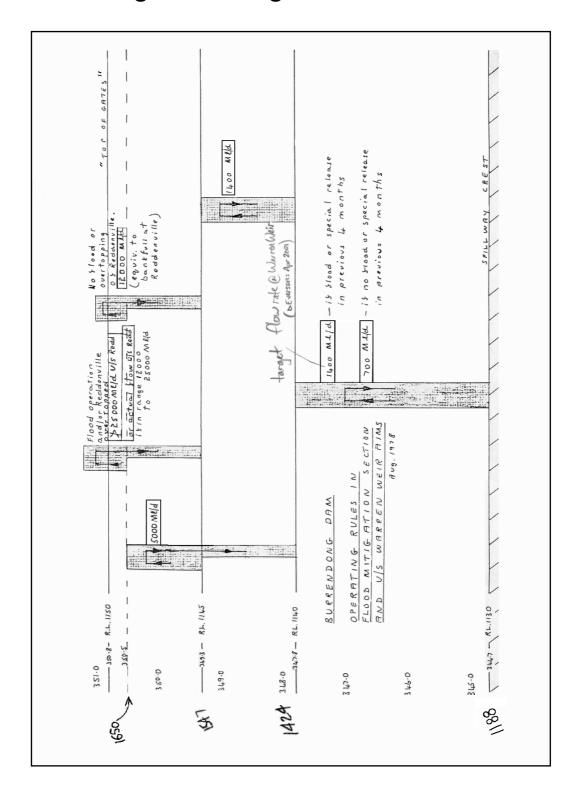
Note: *   The Cudgegong irrigators plant their maximum area each year.

Table E.5:   Maximum and minimum areas for each irrigation group

Irrigator	Irrigator	Minimum Area Planted (Ha)	Maximum Area Planted (Ha)
209	Cudg-01HS	16	16
210	Cudg-01GS	64	64
222	Cudg-02HS	68	68
223	Cudg-02GS	273	273
233	Cudg-03HS	83	83
234	Cudg-03GS	330	330
245	Cudg-04HS	34	34
246	Cudg-04GS	134	134
34	MQTS-01	0	195
36	MQTS-02	528	1,077
40	MQTS-03	0	1,264
44	MQTS-04	0	325
46	MQTS-05	0	2,822
49	MQTS-06	0	1387
52	River pumpers -07	7,714	15,738
53	Narromine-Trangie-07	3,274	6,680
54	Buddah Lakes-07	1,777	3,625
55	Tenandra-07	1,720	3,510
56	Trangie-Neverti-07	3,425	6,988
57	HSec -07	602	602
61	MQTS-08	3,637	7,420
64	MQTS-09	2,071	4,226
66	River pumpers-10	1,044	2,131
67	Nevertire-10	2,696	5,500
69	MQTS-11	0	152
73	MQTS-12	0	78
77	River pumpers-13	0	2,095
78	Marthaguy-13	732	1,494
87	MQTS-15	2,653	5,413
136	MQET-16a	0	556
119	MQET-16b	0	1,113
108	MQET-17	1,479	3,018
120	MQET-18	0	268
	TOTAL	**34,622**	**78,679***

Note: *   The maximum simulated area is 76,269 Ha because the irrigators do not all plant their maximum area in the same year.

F. Burrendong Flood Mitigation Zone Release Rules

G. Windamere Dam Transfer Constraints

This Appendix contains details of the constraints on transfers between Windamere and Burrendong Dams (see Section 2.10.4 for background information).

Table G.1 presents the final agreed hydrograph shape used to constrain transfers between Windamere and Burrendong Dams.

If more than 13.3 GL (the volume in one transfer pattern) is required to be transferred, then successive transfer patterns are required.

Table G.1:   Windamere Dam Release Constraints for Platypus Habitat

Day Number	Release Rate (ML/d)
1	700
2	1,400
3	1,400
4	1,400
5	1,400
6	1,400
7	1,133
8	867
9	600
10	600
11	600
12	600
13	600
14	600
TOTAL	13,300

H. Historical Irrigation Diversions

The DNR have used a number of database systems over the years to manage irrigation diversion data and there are a number of sets of historical diversion data in existence for certain periods. When the Macquarie model was calibrated a review was undertaken and what was believed to be the final set of diversion data obtained. Since that time a number of data review processes have been undertaken to better identify the data. The following table details the water diversion data used in the model calibration and the latest available from the database.

Table H.1:   Changes in Irrigation Diversion Data

Year	Irrigation diversion data used in calibration (GL)	Irrigation diversion data currently on the database (GL)	Difference (GL)
1983/84	-	189.9	-
1984/85	-	339.3	-
1985/86	377.1	370.0	7.1
1986/87	347.2	350.6	-3.4
1987/88	430.9	442.7	-11.8
1988/89	328.8	372.0	-43.2
1989/90	427.0	428.5	-1.5
1990/91	-	473.5	-
1991/92	-	547.9	-
1992/93	460	460.0	0.0
1993/94	543	543.1	-0.1
1994/95	522	514.7	7.3
1995/96	-	199.7	-
1996/97	-	346.7	-
1997/98	-	404.0	-
1998/99	-	338.5	-
1999/00	-	386.1	-
2000/01	-	465.2	-
2001/02	-	546.4	-
2002/03	-	375.9	-
2003/04	-	174.2	-
Average[#]	**429.5**	**435.2** (All years = 394)	**±9.3 (2%)**

[#]   based on common data only

The model was calibrated over the 1985/86 to 1989/90 period and validated over the 1993/94 to 1994/95 period. The average variation between the observed and simulated annual diversion totals over the calibration period was approximately $\pm 9\%$ (Table 3.4). The discrepancies indicated above have an average variation of only $\pm 2\%$. Therefore, it is considered that the differences outlined in the above table would have little to no impact on the model calibration.