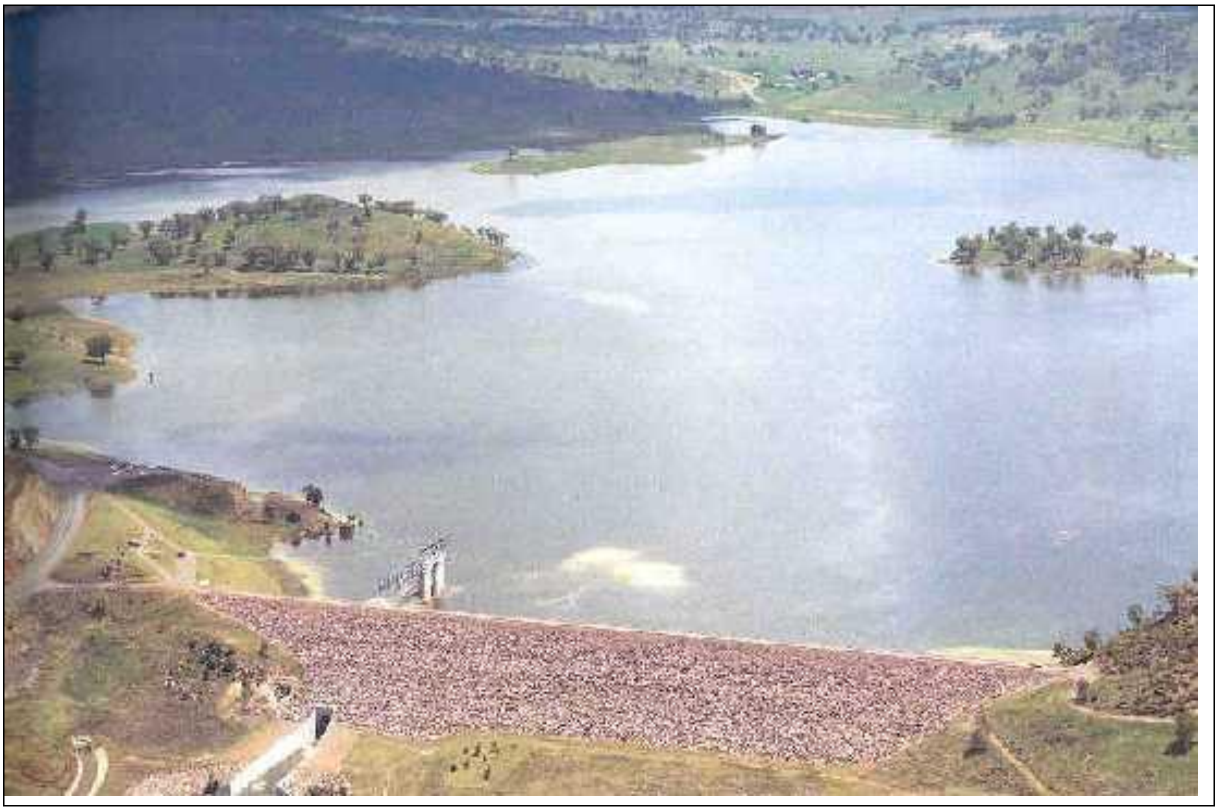
DRAFT REPORT FOR MDBC REVIEW

NSW Government

DEPARTMENT OF NATURAL RESOURCES

Peel River Valley



IQQM Cap Implementation Summary Report

Issue: 1

April 2006

NSW Government

DEPARTMENT OF NATURAL RESOURCES

Peel River Valley

IQQM Cap Implementation Summary Report

Issue: 1

April 2006

Chris Ribbons
Shahadat Chowdhury
Perlita Arranz

Advice and Comments

Robert O'Neill	– Water Resource Management Performance
Paul Simpson	– Water Resource Management Performance
Peter Christmas	– Barwon Region
Sam Samarawickrama	– State Water

Acknowledgments

The authors wish to thank past and present staff in the DNR's:
Surface and Groundwater Processes Unit, Hydrographic Section,
River Operations Section, Licensing Section and Policy Section.

Published by:
Water Management Division
New South Wales Department of Infrastructure Planning & Natural Resources
Parramatta

April 2006

Contents

Page

Figures

Tables

Executive Summary

What has initiated the work?

The Murray Darling Basin Ministerial Council Cap requires that NSW develop a suitable planning tool to enable review of water use and sharing arrangements in the Peel River Valley. The tool accepted as suitable for the purpose is a calibrated water balance model that includes all relevant important features on and in the system. Such a model is called an Integrated Quantity Quality Model or IQQM for short.

Scope of this report summarises the Peel –IQQM status

This report summarises and documents the IQQM calibration and model use for simulation of the MDBMC Cap.

Purpose is to prove model suitability as a Cap estimation tool and present Cap modelling results

The primary purpose of this IQQM summary report is to demonstrate to the reader that the developed model includes all of the important features in the system, and closely replicates records of flow and 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 Peel Valley IQQM.

Calibration and validation over the 1982-2003 period demonstrates model suitability

Chapter 3 describes the model calibration and validation results. Comparison is made between time series observed data and time series model simulated data. Quality ratings were applied to the model calibration. The modelled water diversions were generally a close match to the observed water diversions. Model end-of-system flows were of "high" quality for comparison of alternate management options. Model storage behaviour had a "high" quality rating. Overall, the model achieved a "very high" quality rating, demonstrating the model's suitability for the intended purposes.

Statement of model adequacy for comparing management options

The Peel River Valley IQQM can now be accepted as calibrated and validated to a satisfactory degree. The model is suitably robust for 100+ year scenario running and for comparison of impacts from alternative management scenarios.

1993/94 Cap scenario run

In Chapter 4 the newly upgraded model was used to carry out a 1993/94 Cap scenario run. This involved fixing development conditions in the model to 1993/94 planted areas and licence volumes, configuring appropriate operating rules, and running the model for the 100+ year period from 1892 to 2004 inclusive. The results show NSW not to be in breach of the Cap over both the short and longer term for the current level of development.

Improvements

Chapter 5 lists a series of potential short and long term model improvements that have been identified.

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.

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

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

Coefficient of Determination – A statistical term that describes the degree of correlation between two data sets (usually observed and simulated data points). Its value is always expressed as a decimal less than 1.0, such that the closer its value is to 1.0, the better the correlation. The symbol $\mathbf{r^2}$ is often used to represent the coefficient of determination.

DNR – NSW Department of Infrastructure Planning and Natural Resources.

DLWC – Department of Land and Water Conservation (replaced by DNR in 2003).

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 - Flood Plain Harvesting is 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 which fills spare capacity in an on farm storage, but not via on allocation or off allocation diversions. Conceptually flood plain harvested water includes water:

- Pumped from the floodplain to the on farm storage (ie during large floods), using secondary lift pumps which are not metered.
- Entering the on farm storage because flood levels spill directly into the on farm storage.

General Security Licences – Licences that are supplied with water after high security licence needs are fully satisfied. These licences cover the great majority of irrigation licences both in terms of number and annual entitlements. In an annual accounting system announced allocations are made each year to indicate the percentage of annual licence entitlement volume that can be supplied. A annual accounting system was in place for the Namoi Valley under the 1993/94 Cap scenario.

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), the model 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 decision making process when deciding on the amount of area to plant. For example, given a drought period with dry antecedent climatic conditions, low on farm storage volume, 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 water supplies unless additional 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 operation of 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.

OFA - Off Allocation extraction is 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.

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

ONA - On Allocation extraction is 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 extraction rate for an irrigation node (ML/d).

Rainfall-runoff model - (see Sacramento model)

Rainfall harvesting – Is water obtained from local rainfall runoff on the land holder’s property that is caught and diverted into on farm storage filling. Existing water recycling systems are usually expanded to catch runoff from the planted and/or developed area of a property.

Reach – A defined length of river.

Regulated River – The section of river that is downstream from a major flow regulation storage that supplies water to irrigators.

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 – A rainfall-runoff model 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 and it uses local rainfall and evaporation data as well as catchment details. The model was developed by *Burnash et al (1973)*, in Sacramento California.

Storage Reserve – The amount of storage volume reserved or set aside for next year to ensure high security needs are met. 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. In the Peel Valley the water year commences on the 1st July and concludes on the 30th June.

1. Introduction

1.1. BACKGROUND TO IQQM

In 1986 the first daily time step modelling software, called the WARAS model, was developed by Lyall and Macoun (consultants) and applied to the Lachlan Valley. Building on the concepts in the WARAS model, DNR proceeded to develop a more generalised and complete modelling tool, in the form of the IQQM software. During the 1990's a large number of developments occurred in both water policy and IQQM. The MDBC cap and the river flow objectives required a much greater level of model complexity, where the short term variability of flows became increasingly more important. IQQM's have now been developed for all of the major inland regulated river systems (except the Murray River).

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

1.2. AIM OF IMPLEMENTING IQQM IN THE PEEL RIVER SYSTEM

Peel IQQM has being implemented from the headwaters of Chaffey and Dungowan Dams to the outlet of the Peel River into the Namoi River downstream of Keepit Dam. At this stage the Peel Valley has a separate IQQM and it estimates inflows into the Namoi River for a range of different development conditions in the Peel Valley. IQQM will provide a tool that is capable of simulating daily hydrologic processes over a 100+ year period of varying climatic conditions from 1892 to the present.

The model only directly presented the behaviour of the regulated part of the Peel Valley. Irrigation and other water extractions in the unregulated part of the valley are not specifically modelled. However, all upstream land use changes and historical water extractions in a particular unregulated tributary are reflected in the gauged outflow from the tributary system.

The aims of developing and implementing the Peel IQQM model are:

(a) Under the Murray Darling Basin Ministerial Council (MDBMC) Cap, DNR is required to audit and assess compliance of the Cap with a modelling tool. The Peel IQQM will be the tool used by DNR to audit Cap compliance in the regulated part of the Peel Valley.

(b) DNR requires a tool capable of examining a range of river basin management policies and catchment development scenarios. This includes the need to assess the impact of the options on processes such as stream flows at various locations; irrigation behaviour; allocation reliability; storage behaviour and water quality. IQQM will quantify the effects of changes in policies and development conditions on all of the above processes by comparing the results from various scenarios.

1.3. STATUS OF IQQM IMPLEMENTATION

The development and use of the Peel IQQM has covered the following main steps:

- Build and calibrate the IQQM.

- Establish the 1993/94 development condition baseline model run for MDBMC Cap.
- Define alternative future management option proposals and model enhancements.

All model calibration, validation, 1993/94 development steps have now been completed and are documented in this report.

1.4. AIM AND OBJECTIVE OF THIS REPORT

The aim of this report is to submit the Peel IQQM for accreditation to the Murray Darling Basin Commission (under the Murray Darling Basin Agreement). As a part of this accreditation the report summarise the main findings and conclusions of the model calibration and development of the Cap model for auditing under Schedule F and assessment of long term diversions under Cap conditions.

1.5. SCOPE OF THIS REPORT

The scope of work covered in this report includes:

- Collation and assessment of input data (Chapter 2).
- Calibrating IQQM (Chapter 3).
- Establishing an agreed Cap (1993/94) development run (Chapter 4).
- Outlining model improvements (Chapter 5).
- Detailing climatic and streamflow stations (Appendix A).
- Detailing model configuration (Appendix B)
- Provide a node link diagram (Appendix C)
- Outlining irrigator planting decision (Appendix D)
- Describing quality assessment guidelines (Appendix E)
- Detailing 1993/94 Cap development conditions and management rules (Appendix F)

1.6. QUALITY ASSESSMENT SYSTEM

Sets of quality assessment guidelines (Appendix E) have been used to evaluate and report on the model’s calibration against observed data. There are five categories of quality assessment:

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

2. The Peel River Valley

2.1. CATCHMENT DESCRIPTION

The Peel River flows in a general north westerly direction and drains to the Namoi River about 5 km downstream Keepit Dam. The Peel River catchment bordered in the north and east by the Moonbi Range, in the south east by the Great Dividing Range and in the south and southwest by the Melville Range. Most of the runoff producing streams in the valley commences in the Moonbi Range and drain directly to the Peel River or to the Cockburn River. Due to uplifting of air masses by this range and consequent rainfall, this area contributes significantly to the river flow.

The Peel River flows in a northerly direction through mountainous country until its junction with Dungowan Creek at Dungowan. The Cockburn River joins the Peel River about 5 km upstream of Tamworth. The main tributary of Cockburn River is Mulla Creek and this and other tributaries catch runoff from the western slopes of the Moonbi Range.

The Goono Goono Creek drains to the Peel River in Tamworth after flowing through relatively flat terrain south of Tamworth. The creek rises on the steep slopes of the Great Dividing Range. From Tamworth, the Peel River flows in a general north westerly direction through flat fertile plains to Carroll Gap. Here the river is joined on both sides by a number of minor tributaries. The land slopes in the Peel Catchment are predominantly mountainous, about 51 percent of the total area of the valley having slopes of 15 degrees or more. Undulating to hilly and hilly to steep areas of the valley comprise 11% and 5% respectively of the total area. Flat areas comprise the remaining 33%.

The locations of the river flow gauging stations are shown in Figure 2.1. Chaffey Dam is located on the Peel River above the Dungowan Creek junction. Dungowan Dam is located part way up Dungowan Creek. The storage capacities of these two headwater storages are listed in Table 2.1.

Figure 2.1: Peel Catchment Map with River Gauging Stations

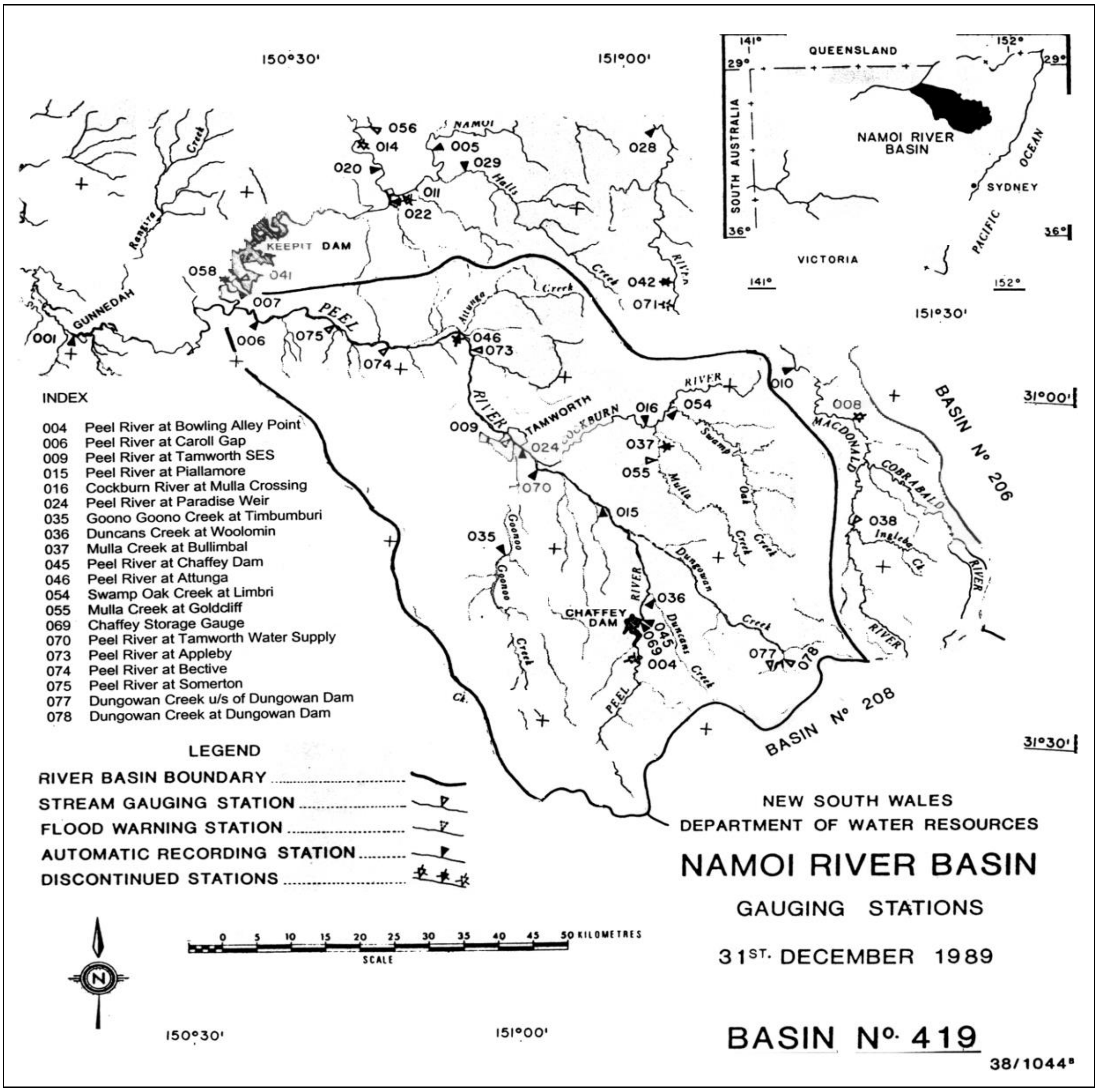


Table 2.1: Storage capacities

Storage	Total Capacity (ML)	Active Capacity (ML)
Chaffey Dam	61,830	59,470
Dungowan Dam	6,300	5,900

2.2. CLIMATIC DATA

The climatic data used to configure the model was obtained from the Bureau of Meteorology SILO database. Every effort has been made to collate the best available data to configure and calibrate the model. Three sets of meteorological data are used to set up the Peel River Valley IQQM.

- Rainfall
- Evaporation
- Temperature

2.2.1. Rainfall

Rainfall data is required by IQQM as input to the soil moisture accounting module (Section 3.5) in demand calculation, for computing the rainfall onto reservoir storage volumes (Section 3.6) and onto river reaches (Section 3.4). Rainfall data is also required for generating catchment inflows using rainfall-runoff modelling (Section 2.3.4).

Annual average rainfall varies over the Peel Valley, from 838 mm over the high ground in the east to 613 mm in the west. Details of Bureau of meteorology rainfall measurement sites were examined with Figure 2.2 show the location of the main rainfall sites with the river flow gauging stations. The site names and available records are listed in Table 2.2.

Figure 2.2: Rainfall gauge locations

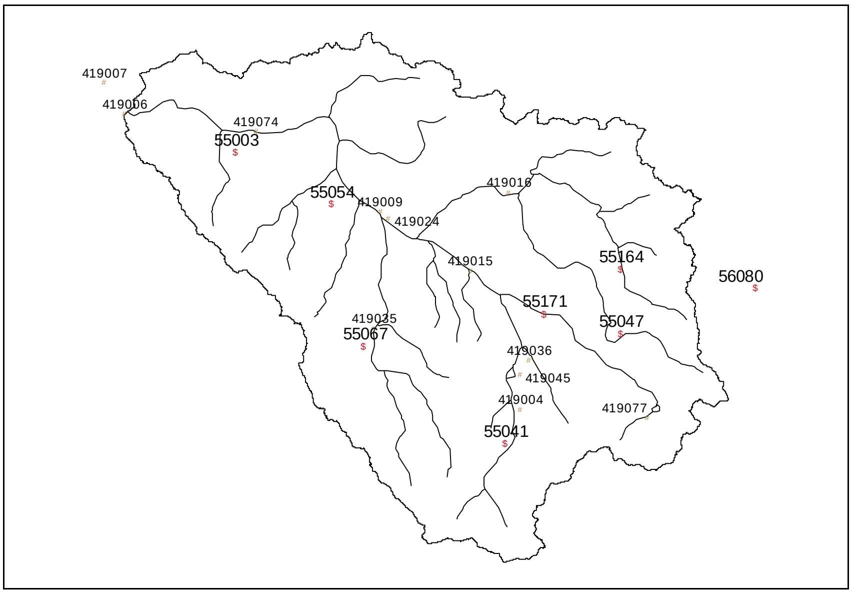


Table 2.2: List of rainfall long term stations in and near the Peel catchment

Station Name	Station No	Data Duration	Years with one or more months missing (not observed, interpolated/filled)
Somerton (Bective)	055003	1882 to 1996	1890, 1891, 1893, 1894, 1896, 1901, 1902, 1906, 1988
Nundle PO	055041	1891 to 1996	1894-1903
Niangala (Prestwick)	055047	1944 to 1978	1961, 1971, 1972, 1978
Tamworth Airport	055054	1890 to 1992	1941
Goonoo Goonoo	055067	1874 to 2004	1930, 2002, 2004
Weabonga (Stoneleigh)	055164	1912 to 2004	1912, 1920 to 1934, 1950, 1951,2004
Dungowan	055171	1900 to 1991	1900 to 1902, 1920 to 1923, 1925 to 1959, 1991
Tamworth(Oxley Lane)	055327	1993 to 2004	2004
Walla (Salisbury Cr)	056028	1893 to 2000	1990, 1992 to 1996, 1998 to 2000

Observed daily rainfall data with missing and accumulated data was obtained from the Bureau of Meteorology up to 1981. Any missing data was gap filled by correlation with surrounding rainfall stations (see Table A1). For demand calibration starting 1982 onwards, daily rainfall data was obtained from the SILO database that included both observed and interpolated data.

The rainfall station at Tamworth Airport (055054) was moved to Oxley Lane (055327) in December 1992. The SILO data for 055054 are interpolated data from 1993 onwards. For Peel IQQM modelling the observed rainfall at Oxley Lane (055327) was appended to the Tamworth Airport (055054) data from 1993 onwards.

Figure 2.3: Annual rainfall at Peel catchment from 1983 to 2003

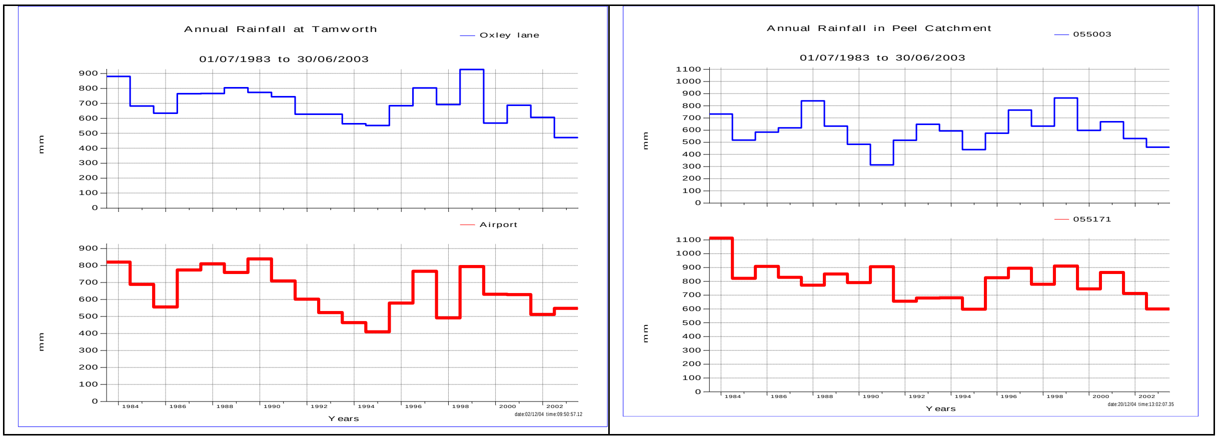


Figure 2.3 shows the annual rainfall patterns at the Peel catchment from 1983. The stations have the lowest rainfall in the water year 1994/95 except the station 055003 (Somerton) which has the lowest rainfall in 1990/91. The Somerton rainfall station is west of Tamworth and generally has lower rainfall values.

2.2.2. Evaporation

Evaporation data is used in IQQM to estimate the evapotranspiration from crops (Section 3.5), for computing evaporation losses from reservoirs (Section 3.6) and for evaporation losses from river reaches (Section 3.4). Evaporation data is also used for generating catchment inflows using Sacramento rainfall-runoff modelling (Section 2.3.4). The only observed pan evaporation measuring station in the Peel Valley is located at Tamworth airport (055054) with records from 1973 to 1992 and average annual evaporation of 1971 mm. The evaporation station at Tamworth Airport (055054) was moved to Oxley Lane (055327) in December 1992. There were inconsistencies between the two datasets that prevented the newer Oxley Lane evaporation data simply being appended to the data from Tamworth airport (see Section 3.1 for more detailed discussion). The observed and generated evaporation data at Tamworth was used to generate evaporation at other sites in the Peel Valley (see Table A2).

2.2.3. Temperature

Temperature data is used in the Peel IQQM to estimate the Tamworth water demand. The recorded maximum and minimum daily temperature at Tamworth (055054) is available for the period of 1957 to 1999. The Gunnedah and Quirindi temperature records are used to fill the gaps (if any) for that period in the Tamworth temperature data. The maximum temperature at Tamworth from 1892 to 1956 is generated using Tamworth rainfall from 1899 to 1999, known maximum and minimum temperatures for 1957 to 1999, and the statistical characteristics of the temperature data. The specific detail of the period is shown in the Table A3.

2.3. STREAMFLOW DATA

Streamflow data is used for model calibration and for model simulations. Time series flow data was extracted from the Department's HYDSYS database. A full listing of the gauging stations details are provided in Table A.4. The location of main stream gauging stations has been shown in Figure 2.1.

In the model calibration phase, streamflow data is required for all major tributaries represented in the model and at all key main stream gauging stations. The tributary inflows are used to achieve mass balance within each river reach, whereas the main stream gauges are used to derive losses and flow routing parameters for each river reach. In the model simulation phase, only the tributary inflows need to be provided as inputs.

2.3.1. Main stream gauging stations

Streamflow data for gauging stations along the Peel River were used for model calibration and no processing was carried out for this data and any gaps due to missing data were left as such. Selection of appropriate gauges to use in the Peel IQQM is discussed in Section 3.3.

The following four mainstream gauging stations listed in the table below are used to calibrate the river losses, flow routing and to provide model output locations. Note that the flow increases from Chaffey Dam to Carrol Gap with the biggest increase from Paradise Weir to Carrol Gap.

Table 2.3: Average and median daily flows in main stream gauges

Location	average (ML/d)	median (ML/d)
Peel R d/s Chaffey Dam (419045)	130	52
Peel R at Piallamore (419015)	256	78
Peel R at Paradise Weir (419024)	420	80
Peel R at Carrol Gap (419006)	626	129

The average and median flows were taken from observed flows from July 1982 to June 2003.

2.3.2. Gauged tributary inflows

The Peel River, in wet years, gains water as it flows downstream due to significant contribution from the various tributaries that drain into it. The available flow records limit explicit modelling of each of these tributaries. The tributaries that are not modelled explicitly are lumped with adjacent unnamed watercourses and represented as residual inflows to the river.

The following tributaries are modelled explicitly, with their locations shown in Figure 2.1.
Dungowan Creek (419077)
Duncans Creek (419036)
Cockburn River (419016)
Goonoo Goonoo Creek (419035)

The tributary gauges usually did not have a long enough period of record to cover the full period of intended model simulation (from the 1892 to 2004). However there was generally sufficient climate data to allow the use of the Sacramento rainfall runoff models to extend the tributary flow data.

2.3.3. Inflow into Dams

Inflows to Chaffey and Dungowan Dams were required for the purposes of model calibration and model simulation. Daily Chaffey Dam inflows for the period of dam operation (commencing June 1979) were estimated using back-calculation procedures (ie *Inflow = Change in Storage + Releases + Spills + Losses - Direct Rain*). For the periods prior to dam construction, Sacramento models were used to estimate inflows.

Inflow to Dungowan Dam was generated by using Sacramento model of the gauging station 419077 and multiplied by 1.3 for the catchment area of Dungowan Dam.

2.3.4. Ungauged tributary inflows

Gauging stations on the tributaries are generally located some distance upstream from the confluence with the main river, resulting in large areas of ungauged catchment. There are also some ungauged contributions from smaller streams and local area runoff. Peel IQQM makes allowances for the inflows from these ungauged catchments by the estimation of what is termed "residual" catchment inflows.

The flows contributing from ungauged catchment were estimated by mass balance calculations for the various river reaches along the river. In the mass balance, the losses and diversions must be estimated to calculate the residual. The diversions can be derived from observed diversions. Since losses are also not known, the process involves several iterations to satisfy the water balance in the reach. The residual inflows are initially estimated to be proportional to gauged tributary inflows. If this is not sufficient to maintain water balance at each reach for all flow ranges, a rainfall runoff model can be used to generate long term residual inflow.

2.4. IRRIGATION INFORMATION

2.4.1. Irrigation licenses

Irrigators in Peel IQQM were represented as clustered groups, broken up to match the division of the river into the 4 gauged reaches. DNR records of total on allocation, off allocation diversions, crop areas and crop mixes were generally available for the calibration period, at the individual irrigator level. The information was collated into the irrigator groupings. Historically the Peel River was divided into five sections for river operation purpose, which are shown in Table 2.5. These five sections are used in the Peel IQQM.

Table 2.4: Peel Irrigators Groups and Entitlement as of 1999

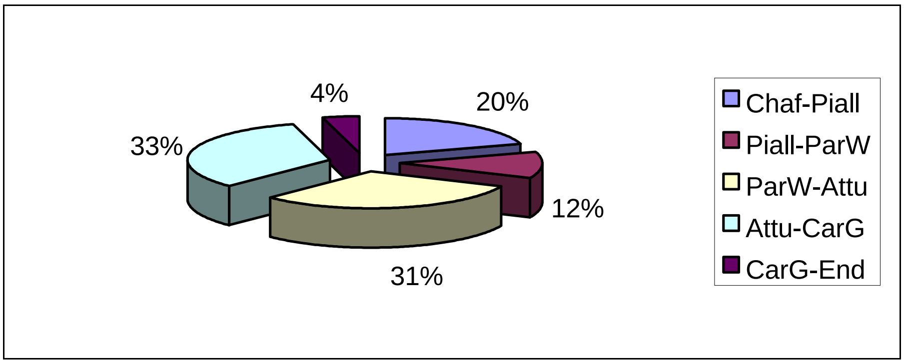
Reach	Reporting Group	General Security		High Security	
		No	ML	No	ML
1	Chaffey Dam to Piallamore (irr20)	48	6384	9	27
2	Piallamore to Paradise Weir (irr21)	32	3372	4	299
3	Paradise Weir to Attunga (irr22)	55	9315	12	491
4	Attunga to Carroll Gap (irr23)	35	10461	12	128
5	Carroll Gap to Namoi Junc. (irr24)	6	1371	0	0
	TOTAL	176	30903	37	945

The earlier method for managing water resources was by issuing licenses limiting irrigated area rather than irrigation volume. The area authorised for irrigation in 1944 was 716 ha to 104 licensees in the Peel Valley. There was a steady growth of authorised area to 1547 ha til 1964. However the authorised area sharply increased to 3246 ha with 272 licensees, in next five years, by 1969. The licences served by regulated water from Chaffey Dam were converted from area-based licences to volumetric licences during 1981/82 season. There has been an administrative embargo on the issuing of new licences (with the exception of stock, domestic, industrial and town water supplies) since 1980. This became a statutory embargo in 1981/82. The historic data on licensed irrigation volumes and licence types was analysed and separated into high security (HS) and general security (GS) licence portions.

There are licences for surface water extraction throughout the Peel Rivers system, both in the regulated sections below the dam, as well as in the unregulated parts of the catchment along the tributaries. Regulated licences are volumetric and have an annual licensed volume. Licences extracting water from streams outside the influence of regulated flows from the dams are known as unregulated. These licences were operating on the basis of a maximum authorised irrigable area and a lower flow limit for pumping (usually a visible flow at the nearest flow gauging station) until recently when the licences were also converted to volumetric limits. 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.

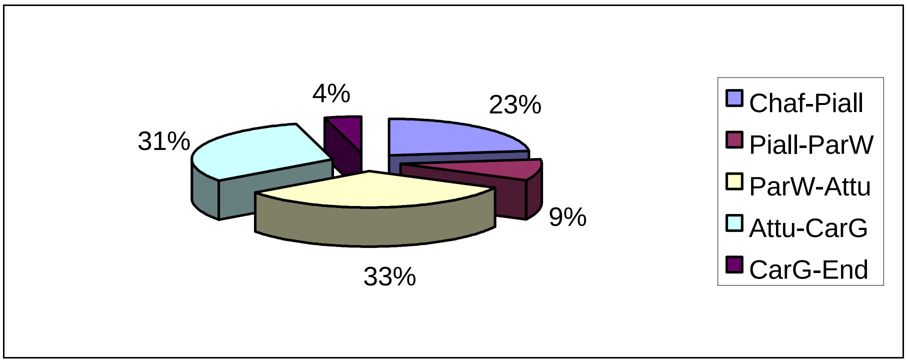
A typical geographic distribution of total licensed volumes, amongst the 5 reporting groups, is shown in Figure 2.4. Notice that 68% of licensed volumes are downstream of Paradise Weir.

Figure 2.4: Relative Distribution of Regulated Entitlement



Regulated licences in NSW are issued with conditions relating to the maximum authorised 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 system pumping capacity was about 4280 L/sec in 1995. Figure 2.5, shows a distribution of these capacities for the five irrigator groups. Notice that 68% of pump capacities are downstream of Paradise Weir.

Figure 2.5: Pump capacity distribution

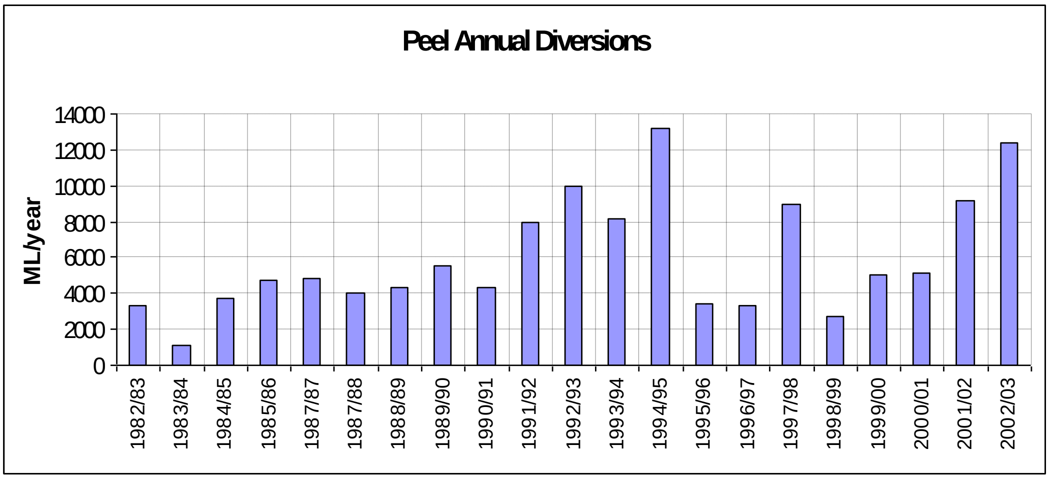


The Peel regulated users do not have significant on farm storage. In the historic records on allocation (ONA) and off allocation (OFA) usage for the Peel irrigators, the distinction between the two was often obscure or not available. The periods when OFA had been declared was more accurately documented. The absence of significant on farm storage and adequate pump capacity indicate that irrigation infrastructure may not limit diversions from the river.

2.4.2. Irrigation extraction data

DNR has historic records of on allocation, off allocation usage and high security diversions for the Peel River Valley from 1982. The plot of annual diversions is shown in Figure 2.6 below. The maximum recorded diversion was 13,192 ML in 1994/95 and the minimum was 1,071 ML in 1983/84 water year.

Figure 2.6: Irrigation diversions from 1982 to 2003

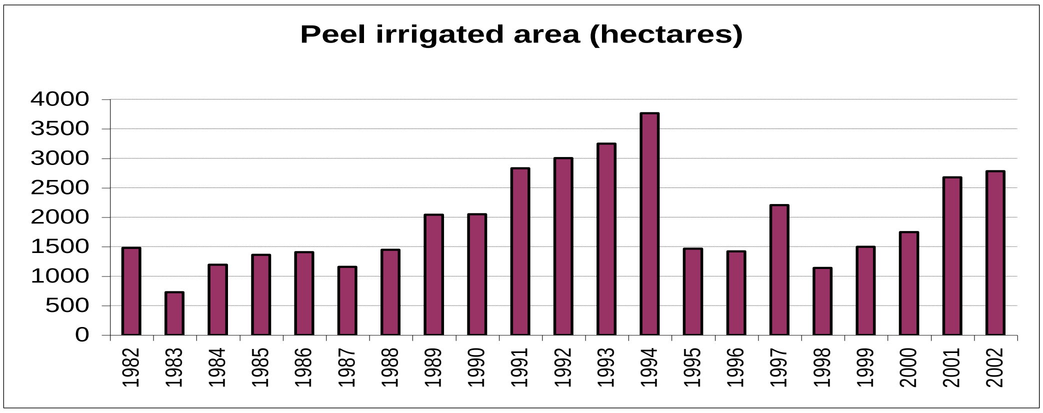


Historically the data has not always been collected at regular monthly intervals and Region has estimated the monthly usage in some circumstances. The annual totals were disaggregated to daily totals during flow calibration.

2.4.3. Crop areas and crop mixture

Historic records of total planted areas and crop type for regulated licence holders were available from the DNR licensing database from 1982. The data collected in the earlier years was generally obtained by a mail out process with percentage returns varying and limited follow up. In more recent times (since 1996) there has been a concerted attempt to improve the collection of good data on areas irrigated. Figure 2.7 below shows the recorded area irrigated in the Peel Valley.

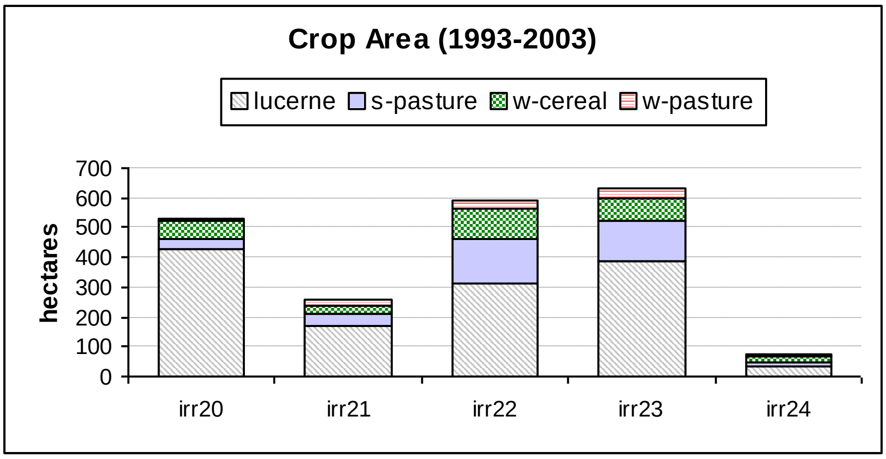
Figure 2.7: Area irrigated from 1982 to 2003



Lucerne is the dominant crop in terms of irrigated water use in the Peel Valley and constitutes the majority of irrigated crop area. In contrast, irrigated winter crop areas have generally been significantly lower than irrigated summer crop areas.

Historical records of the crop area irrigated for each group of irrigator is listed in Appendix D. Data from 1993 were perceived to be more reliable than earlier records. The average area irrigated from 1993 to 2003 is shown in Figure 2.8. The locations of the irrigator groups are listed in Table 2.4.

Figure 2.8: Average crop area per irrigator group from 1993 to 2003



Lucerne is a crop that needs about 3 years to be fully established. This means that lucerne growers do not have possibility of planting other crops during this period. The root of the fully established lucerne grows very deep: with reports indicating root depths from 3 up to 6 m and more. Lucerne root may have contact with Peel River aquifers and feeds partially from them. For example the water table of the aquifer was 4 to 6 meters deep in the area where lucerne was grown in April 1998.

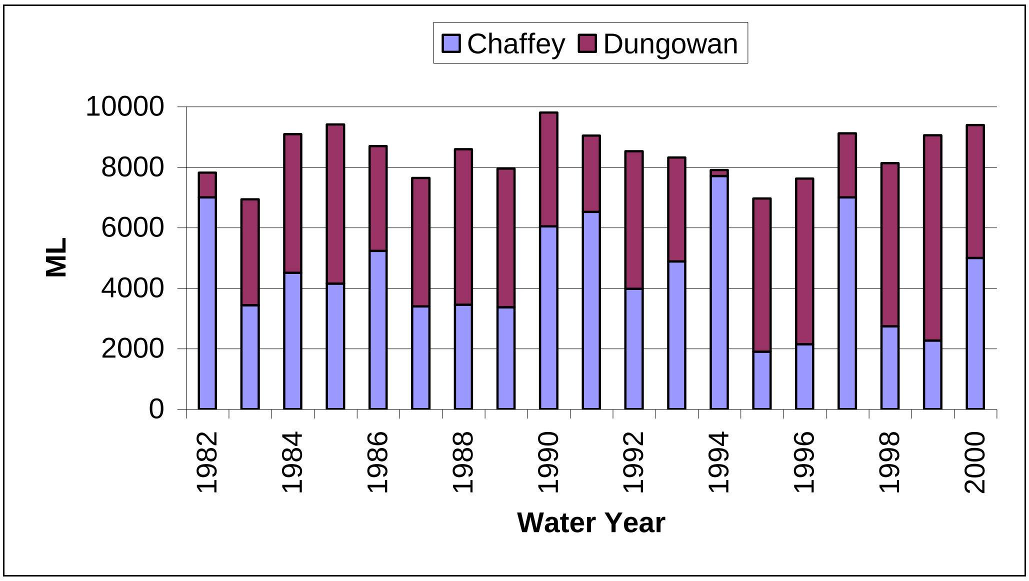
Lucerne can be used as a natural control of groundwater recharge as proved in DLWC and CSIRO Investigations (R Anderson and J Doyle, August 1997). In the five year trial conducted on Bengola Station south of Balranald, lucerne, unlike any other crops prevented completely any recharge from groundwater with the roots growing up to 8 meters deep on hills, 4 meters on the midslope and 3 meters on the flats.

Dryland lucerne is also grown along the Peel River, giving evidence that lucerne can survive and give yield on natural rainfall and feeding from aquifer only. Deep roots can access layers of soil that feed due to capillary forces from the aquifer. These roots grow predominantly during winter season and they can follow the aquifer downward movements in drier periods.

2.5. TOWN WATER SUPPLY

Tamworth water supply is a major user in the Peel Valley. There are periods when the town water usage alone exceeds the rest of the diversion from the river. Dungowan Dam was built to be the primary source for Tamworth town water supply, and is located on Dungowan Creek, a tributary of the Peel River. Dungowan Dam is operated solely by Tamworth City Council, and its operation is outside of the regulated Peel River system. Tamworth City Council also holds licences for the supply of water from Chaffey Dam, which was intended to supplement usage that Dungowan Dam could not provide either due to quantity or quality constraint. The town water diversion data is shown in the Figure 2.9 Although the urban water demand of the Tamworth City water demand has a high security license entitlement of 16.4 GL, the observed usage to date has not exceed 10 GL.

Figure 2.9: Tamworth Water Supply from Dungowan and Chaffey Dams



2.6. STOCK AND DOMESTIC REQUIREMENTS

Licensed volumes for stock watering and domestic supply purposes are high security entitlements in NSW, with around 10,000 ML licensed for these purposes in the Peel system. These entitlements are generally distributed as small amounts of additional entitlement with the general irrigation licences. There is no information enabling usage for this purpose to be distinguished from general irrigation.

Stock and domestic usage is negligible in Peel valley comparing to general security irrigation. Probably 11 ML of water was extracted in 1993/94 by 3 out of 16 stock and domestic use licences. Even less was used between 1983 and 1992. Five of these 16 licenses were without pump or exempt. DNR has little definitive record of exact amount of diversions for stock and domestic usage.

2.7. INDUSTRIAL EXTRACTIONS

The Peel water usage can be defined into three major groups, which are town water, irrigation and stock and domestic purpose. No other significant usage exists to date. There is a provision of 300ML high security water quarantined for industrial usage. No record of diversion against industrial license is available.

2.8. GROUNDWATER ACCESS

Ground water supply bores are available throughout the irrigation areas, and are used as an alternative water supply. In dry periods, ground water usage increases. Traditionally surface water irrigators have turned to ground water to balance shortfalls in surface water allocations. About 72 regulated surface water licensees are been identified along the Peel River who also possess ground water licenses. These irrigators have access to both the river water and ground water. They had about 9,000 ML of bore license entitlement together with about 12,300ML of surface water entitlement in 1999. No definitive information is available about the ground water diversion by these irrigators and how that diversion effects their river extraction volume.

2.9. RESOURCE ASSESSMENT

Under a volumetric allocation scheme all licences are issued with an annual entitlement volume. In any irrigation season, the amount of water available for general security irrigation is the announced allocation percentage times the annual entitlement volume. The allocation announcement is the result of a resource assessment process that takes into account:

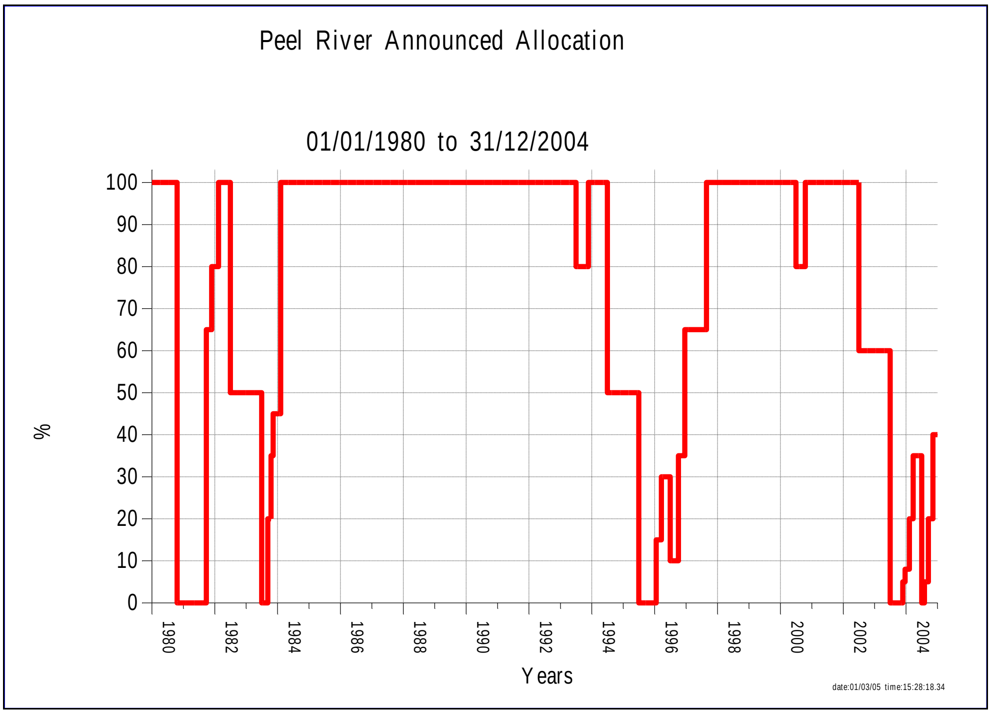
- all available water resources at that time
- water resources expected to become available for the remainder of the water year and
- an allowance for essential requirements to meet high security supplies, environmental and other reserves and expected losses

After these calculations are undertaken the remaining resources are then declared available for general security irrigation use and are expressed as a percentage of the total general security entitlement. The estimate of expected water resources is conservative and uses the driest recorded inflow and tributary sequence to estimate expected resources for the remainder of the water year.

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

The allocation assessments are made at the beginning of the water year (1st July for the Peel Valley), and then typically recomputed when there is a significant inflow to Chaffey Dam. The historical allocation announcements for the Peel Valley are presented in Figure 2.10.

Figure 2.10: Historical announced allocations



2.10. RIVER AND STORAGE OPERATION

The regulated river system is operated to ensure that maximum conservation of resource is achieved during regulated operation, and that flows in excess of the target at the end of the system are kept to a minimum. Flows in excess of requirements at the end of the regulated river system usually 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 and errors in forecasting system requirements.

2.10.1. Tributary utilisation

When making releases from storage to satisfy consumptive requirements, the river operator forecasts what contributions they expect from downstream tributaries and adjust the releases from the storage 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. Tributary flow utilisation in the Peel River is dependent on a number of issues involving the announcement of off-allocation and the river flow at various locations. Tributary utilisation factors during 1983 -1992 were very low. As explained in section dealing with orders, Chaffey Dam was mainly full during 1983 to 1992 period. This allowed majority of demand to be supplied by the Chaffey dam. The IQQM representation and calibration of tributary utilisation is discussed further in Section 3.6.

2.10.2. Operational surpluses

Operational surpluses result from errors in forecasting demands for irrigation and transmission losses, both of which can be quite variable, as well as general over- or under-ordering by irrigators. The variation in requirements often results in higher releases from storage than orders (based on crop requirements) plus average transmission losses would indicate.

Regulated water that leaves the system without being used is operational surplus. Tamworth water supply orders and diversions can be substantially different. Any ordered water that is not diverted appears at the end of system as the operational surplus.

Operational surplus in 1983 to 1992 is high. Chaffey Dam storage was mainly used for irrigation, town water supply and system transmission losses. The rest of the potentially useable catchment contribution mostly left the system as operational surplus. The IQQM representation and calibration of over-ordering is discussed further in Section 3.6.

2.10.3. Storage operating rules

Storage operation is the way that the officers in charge at the dam release water in response to irrigation and other orders and downstream flow requirements. The releases depend on what is perceived as losses and useful tributary inflows in the system.

Storage operation was determined by:

- discussion with dam operators,
- interpretation of orders and diversion data, and
- storage volume behaviour data.

Chaffey Dam storage was mainly full during 1983 to 1992 period. Due to low demand and high storage levels, the mode of operation of storage was very liberal. The operators used primarily storage resources to satisfy demand, and usage of tributary water was very limited. In later years, however, when the resources decreased and demand increased, the storage releases became less generous and the tributary utilisation was maximised.

Tamworth Town Water is supplied primarily from Dungowan Dam, up to the pipe capacity, and then supplemented from Chaffey Dam if necessary. When water quality in Dungowan Dam becomes unacceptable then the entire demand is supplied from Chaffey Dam, hence the cost of treatment is minimised.

The Tamworth Regional Council supplied the following Dungowan Dam storage volume and release rules;

- cease using Dungowan as the primary water source for Tamworth when the storage level falls to 50% of capacity
- maximum flow that can be extracted from the dam for Tamworth water supply is 255 Litres per second, giving a maximum daily extraction of 22 ML per day
- whenever inflow to the Dam is greater the 10 ML per day, 10 ML per day is released to the downstream watercourse

In practice, when the dam storage level is above 70% the daily discharge from the dam to the downstream watercourse is in the order of 12 to 16ML per day. This is due mainly to seepage and leakage from the dam at higher storage levels.

2.10.4. Flood mitigation releases

Although a flood mitigation role was not included in the legislation under which Chaffey Dam was built, nevertheless, the dam achieved reductions in flooding on several occasions. This was largely due to the volume of the flood being contained within the available empty storage volume. There are no defined rules for flood mitigation operation of Chaffey. There were a few arbitrary attempts to pre-release water from the Chaffey Dam outside of irrigation season in the past.

2.11. SURPLUS FLOW ACCESS

In the Peel River Valley downstream of Chaffey 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 flood mitigation releases from Chaffey Dam. Surplus flows in the Peel River Valley can be extracted for irrigation as off-allocation water.

The Peel River is divided into three reaches for off allocation declaration purpose:

- Chaffey Dam to Paradise Weir
- Paradise Weir to Attunga Creek junction
- Attunga Creek Junction to End of the river.

Assessments for access to off-allocation water are generally made on a reach by reach basis, depending on the amount of surplus flow available and the access that each reach has previously received in the water year. Although the Peel system characterises a travel time difference of about 4 days from Chaffey Dam to Carroll Gap, the off-allocation was usually announced simultaneously for the entire Peel River. The off-allocation announcement is not vital for water consumption by Peel users, as the irrigators can divert water only for the current crop requirement. Off-allocation coincides with increased water levels, which is usually related to rainy days. Therefore crop needs are mostly satisfied and diversions are lower then during on allocation.

Unfortunately, accurate records of off allocation extraction volumes were not readily available. What was available were the off allocation announcement periods, reach by reach (see Figures 3.22, and 3.23).

2.12. RIVER FLOW REQUIREMENTS

2.12.1. Minimum flow

Analysis of historic dam release records showed a minimum release of about 10 ML/d was generally maintained throughout the record period of 1982 to 2000 except the when the dam is lower than 30GL. The trend can be explained by the purposes of keeping the river wet (for more effective delivery of water orders), and for fulfilling the stock and domestic requirement.

A minimum flow of 5ML/d and more recently 10ML/d is maintained at Carroll Gap. Resource assessment of Chaffey Dam allocates 1500ML to keep minimum flow at Carroll Gap.

There is a minimum flow release constraint put on the Dungowan Dam. If the inflow into Dungowan dam is above 8.5 ML/day, the dam releases 8.5 ML/day for environment. When the inflow is below 8.5 ML/day, only half of the inflow is released. These releases are made into the river, independently of Tamworth town water supply releases that are made through a pipeline. There are a few unregulated irrigators downstream of the Dungowan Dam, which can access these flows.

Minimum flow of 40 ML/day at Paradise Weir during the irrigation season is noticed at some operational sheets. These are the sheets in which the orders to the dam are manually calculated in the past, based on irrigation orders and assumed inflows and losses. However, by plotting the daily ranked curve at Paradise Weir for October to March, it was proved that this rule was broken in more days than it was obeyed. In consultation with the river operators, it is confirmed that this rule was not strictly obeyed and that would be acceptable to omit it in the model.

2.12.2. Wetlands

There are no wetlands in the Peel system

3. Model Calibration and Validation

3.1. MODEL CONFIGURATION

The Peel regulated river was configured in IQQM using input data as described in Chapter 2. The number and types of nodes and links were selected in accordance with the aims of the modelling detailed in Section 1.2. The Peel IQQM model contains over 65 nodes and 64 links with hydrologic routing in 9 links. Details of the model set-up and presentation of the node-link diagram are contained in Appendix C.

Inflows were estimated for Dungowan and Chaffey Dams, 3 gauged tributary and 5 ungauged catchment inflows as described in Section 2.3. General security irrigators were represented in 4 groups based on river reaches.

Of the available rainfall stations in the valley, the following criteria are used to select an appropriate sub-set to use in the Peel 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;
- continuity and quality of data; and
- availability of nearby gauging stations that could be used to substitute missing data and/or disaggregate accumulated records.

Daily rainfall data was obtained from the Bureau of Meteorology and 4 sites were selected to represent 5 river reaches. There are 7 flow sites selected to calibrate the IQQM that are listed in Table A.1.

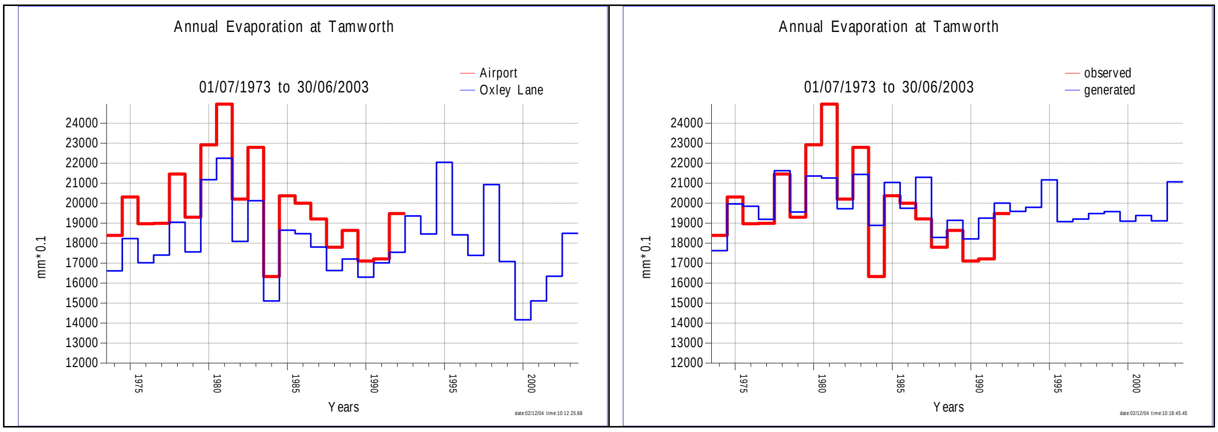
Evaporation data is used in IQQM to estimate the evapotranspiration from crops (Section 3.5), for computing evaporation losses from reservoirs (Section 3.5) and for evaporation losses from river reaches (Section 3.5). Evaporation data is also used for generating catchment inflows using Sacramento rainfall-runoff modelling (Section 2.3.4).

Evaporation, as measured in Class A pans, substantially exceeds average rainfall throughout the whole catchment. The annual average observed pan evaporation at Tamworth airport (055054) from 1973 to 1992 was 1971 mm and this is the only evaporation station in the Peel Valley. In December 1992, the station was moved from Tamworth Airport to Oxley Lane (055327), south of the airport. The Oxley Lane station has observed evaporation records from 1993 onwards. The evaporation data for Oxley Lane was obtained from the SILO database and it was a combination of interpolated data before 1992 and observed data after 1993. The plot of annual evaporation data from the two Tamworth data sets is shown in Figure 3.1. The estimated evaporation at Oxley Lane prior to 1993 was lower than that measured at Tamworth Airport. Enquires of the Bureau of Meteorology were not able to explain why the apparent differences in annual evaporation at the two sites.

For long-term simulation of the Peel IQQM, evaporation data is needed from 1892 to 2004 and given that observed data only commences around the 1970’s, data generation techniques have to be adopted to estimate the additional data.. IQQM generates monthly evaporation based on correlation with monthly rain days. The generated monthly evaporation maintains the mean of the monthly observed evaporation and then the data is disaggregated into daily evaporation using rain days. Given the need to obtain a correlation between evaporation and rain days over a long a period as possible the observed evaporation at Tamworth Airport (055054) was adopted in Peel IQQM with any missing values and extended data (to cover the 1892 to 2004 period) obtained from the technique used in IQQM for generation of evaporation.

Because observed evaporation was only available at Tamworth it was necessary to generate daily evaporation data at a number of other sites in the valley to ensure adequate distribution of evaporation data. The evaporation at Tamworth was used to derive evaporation at other sites and a gradient was applied to transfer values at Tamworth to the other sites (see Table A2). The estimated values at these sites were further adjusted and smoothed for rain day and non-rain day values at the site. This is done by assuming that evaporation during rain day is 75% of that during non rainy day, maintaining the total monthly evaporation.

Figure 3.1: Annual evaporation at Tamworth



To convert pan evaporation to potential evapotranspiration, the monthly values in Table 3.1 below were applied to the site evaporation to obtain site evapotranspiration.

Table 3.1: Pan factors to convert pan evaporation to potential evapotranspiration

Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
0.68	0.64	0.63	0.57	0.57	0.65	0.69	0.68	0.67	0.71	0.70	0.68

There were a number of other items considered either insignificant or too difficult to model adequately and therefore not configured during the calibration phase of the model, including:

- Unregulated irrigation diversions,
- Ground water extractions.

The regulated extraction comprised of five general security irrigator groups, four stock and domestic usage nodes and one town water supply node. There are two storages in the system, Chaffey and Dungowan Dams. The river regulation is modelled using all the demands and transparent release requirement from Dungowan Dam and minimum flow at Carroll Gap.

In case of Tamworth water demand modelling a multi-variable regression analysis was done using daily maximum temperature, rainfall and evaporation.

Stock and domestic entitlements were modelled using a fixed pattern of demand, representing the average use over the chosen calibration period.

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

Resource assessments (announced allocations) were forced 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. For the purposes of model simulation however, the allocation assessment process within IQQM is configured separately for specific scenarios.

3.2. LIMITATIONS AND EXCLUSIONS

A number of processes were not modelled either due to insignificance or lack of data or beyond the scope intend. Some processes like groundwater inflow to river and effect of antecedent soil moisture in river leakage were modelled in a simplified form.

Unregulated licences and crops have not been explicitly modelled due to a lack of suitable information to allow model calibration. The effects of unregulated licence activity will be present to some degree in the flow records used to produce inflows to the regulated system, especially in more recent years. No adjustment of inflows for changes in unregulated licence activity has been made.

High security usage (excluding town water supply) is modelled as fixed rate diversion independent of climatic condition that does not vary from year to year. Town water supply is modelled with the annual historical usage during the calibration stage of model development and with a fixed annual demand in the scenario modelling that does vary from year to year depending on climate.

Resource assessments (announced allocations) were forced to observed values during the calibration process because there are 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.

3.3. CALIBRATION OVERVIEW

Calibration of IQQM involves the adjustment of the processes and the variables in the model until the model satisfactorily reproduces historical data over a selected period of time. 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, a calibration process has been developed to proceed sequentially, progressively eliminating unknowns. The sequential process adopted in the Peel Valley involves four major steps. Each step estimates specific parameters for the step, whilst forcing all other parameters to observed data. At the end of the four stage process, all the estimated parameters are brought together to see how well the overall model calibration reproduces historical information. The four steps are summarised below, with an indication of which parameters are calibrated during each one:

- Flow calibration - to reproduce the observed flow hydrographs at key locations, given observed storage releases or upstream observed flows, tributary inflows and water extractions. For this process, irrigation and other water extractions are fixed to those observed historically. Routing parameters and transmission losses are calibrated.
- Irrigation diversion (demand) calibration - to reproduce observed irrigation extractions from the river, given observed crop areas and crop mix, and announced allocation. Crop factors and irrigation efficiency are calibrated.

- Storage calibration - to reproduce the observed Chaffey Dam storage volume throughout the calibration period. This involves calibration of the processes relating to irrigation ordering and river operation and off allocation. The crop area and announced allocation are forced to calibrate tributary utilisation and over order factors.
- Area planting decision - calibrates an irrigator's decision making process to reproduce observed crop planted areas. Maximum and minimum area, crop mix and farmers planting decision process are calibrated.

These steps were repeated whenever a later step identified significant problems with earlier parts of the calibration process.

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. Although crop data are available from 1982, more confidence is given to data collected post 1996/97 period. However, this data is only up to 2002/03 and may not cover all climatic conditions.

The periods chosen for the various stages of the calibration process varied depending on data availability.

- Flow calibration –post Chaffey Dam, 1982 to 2003 (*PeelF21a,PeelF22b, PeelF23d*)
  validation - pre Chaffey Dam; 1954 to 1979 (*PeelF12e,PeelF11a*)
- Diversion calibration – from 01/01/1982 to 30/06/2003 (with greater emphasis on 1996 onwards) ; *PeelS06b*
- Area planting decision – from 01/01/1993 to 30/06/2003 (with greater emphasis on 1996 onwards); *PeelA01a*
- Storage behaviour calibration – from 01/01/1982 to 30/06/2003 (with greater emphasis on 1996 onwards); *PeelS06b*

3.4. FLOW REPLICATION

The objective of this step is to calibrate the physical characteristics of the catchment by simulating the river system flows over the calibration period. The process establishes transmission loss, various routing parameters and validates the ungauged catchment inflow estimate. All known components of the water balance within the river valley are forced to the observed data. Known system inflows like gauged tributaries and reservoir inflows are used as inputs to the model. Irrigation and town water demands are extracted from river reaches as per the observed data. The remaining unknowns like river routing parameters, residual catchment inflows and transmission losses are calibrated by trial and error to achieve the best overall match to mainstream gauges.

Streamflow data is required at all key main stream gauging stations and for all major tributaries represented in the model over the calibration period. An extensive network of streamflow gauging stations represents the main river flows in the Peel River catchment. The following criteria were used to select an appropriate sub-set to use in calibration of the main stream flows:

- length of river reaches;
- isolation of key features such as tributary inflows and 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 four main river gauging stations selected for use in the model, thus creating three flow calibration reaches in the Peel River. For each reach, the observed flow is forced at the upstream node of the reach with missing values filled from nearby stations with the best correlation.

The water balance calculation for each reach requires residual inflow, diversions and losses. The diversions consist of town water supply and irrigation diversions. Daily recorded town water supply diversions are available from July 2001 and the rest of the period was estimated. Records of annual diversions are available in monthly and annual values. These were disaggregated on daily values by using the pattern of regulated flow in the river allocated for irrigation demand. This was done by removing the town water supply from the recorded Chaffey Dam releases. This is an iteration process to achieve observed flows, annual diversions and water balance for each reach.

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. Rainfall and evaporation onto the river surface were modelled explicitly by giving each reach an average width.

Presented here are the results obtained from the final calibrated assembled model for river flow replication at three gauging locations: Peel River at Piallamore, Peel River at Paradise Weir, and Peel River at Carol Gap. Objective measures of the quality of model fit achieved are presented in Table 3.5 based on the quality assessment guidelines described in Appendix E (DLWC, 1999).

Observed flows have quality codes of '130' (not quality coded) and '140' (interim rating) in HYDSYS. The level of confidence on flow ranges is not known or has not been thoroughly explored.

The aim of the flow calibration is to match the observed flow distribution, especially the 20%, 50% and 80% values and to match the observed total flow within the calibration period. The timing of the peaks and shape of flow hydrographs were simulated by calibrating the routing parameters.

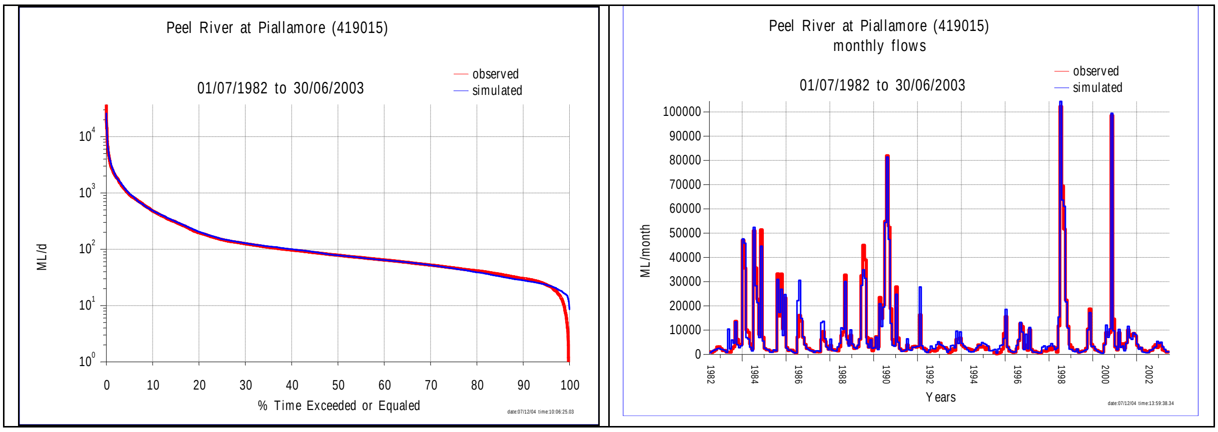
A plot of the flow duration curve shows the flow distribution in time and the monthly flows shows the variability of flow with time. Tables with average values within the low (0-20%), medium (20-80%) and high (80-100%) flow ranges of the observed indicates the model ability to simulate flows in these ranges.

3.4.1. Peel River at Piallamore (419015)

This gauge was used to calibrate the loss functions in the Peel River from Chaffey Dam to Dungowan Creek junction, Dungowan Creek and Peel River from Dungowan Creek junction to Piallamore.

The residual inflow (R1) from Chaffey Dam to Piallamore was derived by adding 57% of Cockburn River (419016) flow and 17% of Goonoo Goonoo Creek (419035) inflows. This has about 48% contribution (1982-2003) to the observed flows at Piallamore. This was split into 3 inflows, one from Chaffey Dam to Dungowan Creek junction (R1a,20%), Dungowan Creek (R1b,60%) and from Dungowan Creek junction to Piallamore (R1c,20%). The method used was based on area distribution and flow duration table taking into account the water balance. The figure below shows a good match of the flow distribution and monthly variability.

Figure 3.2: Peel River at Piallamore (419015)



The table below shows that 80% of the time (days), the observed flow is greater than 41 ML/d and the simulated flow is greater than 39 ML/d. On days when the observed flow is less than to 41 ML/d, the average observed flow is 28 ML/d and the average simulated flow is 44 ML/d. This difference is due to the model problem in the estimation and timing of residual inflow at low flow periods in this reach of the river. Some problems may also be happening during the estimation of the loss function on daily events. This flow range also is within regulated flow to satisfy downstream demands. Hence, there are possible timing problems on estimated residual inflow and daily diversions. There was not enough data to overcome these problems with flow calibration in this reach of the model.

Table 3.2: Observed and simulated flow range at the Peel River at Piallamore (419015)

range	***data type***	***Percentage of time (%)***	**flow at designated percentile (ML/d)**	**average for flows in the designated range (ML/d)**
low (between 80%ile and 100%ile)	*observed*	*80*	41	28
	simulated	*80*	39	44
medium (between 20%ile and 80%ile)	*observed*	*50*	78	86
	simulated	*50*	78	92
high (between 0%ile and 20%ile)	*observed*	*20*	197	953
	simulated	*20*	206	948
all	*observed*			256
	simulated			262

The 'medium range' is the average flow on days the observed flow is between the 80% and 20 % exceedance value. The medium flow range average for the simulated flow is the flow on days when the observed flow is within the medium flow range. The observed and simulated model results are vry close in the medium flow range.

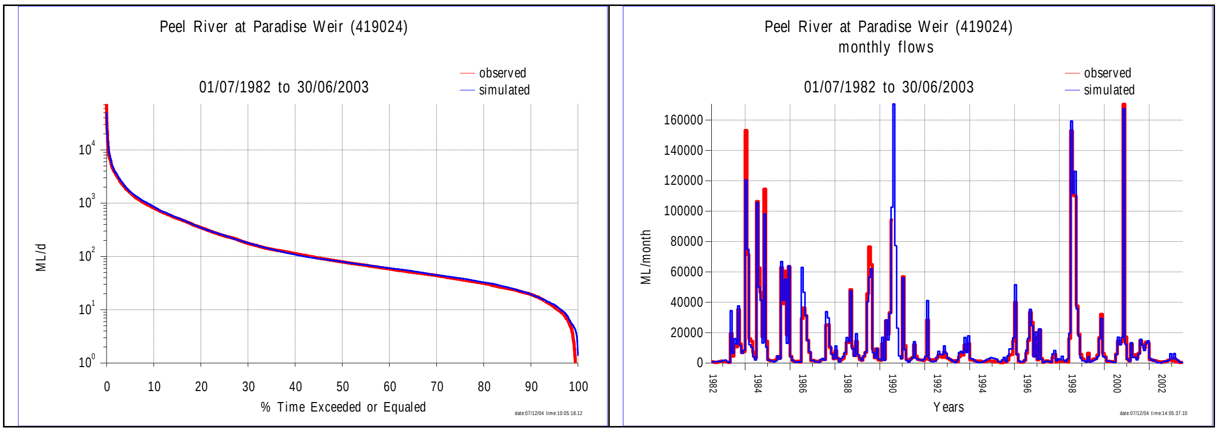
The 'high range' is the average flow on days the observed flow is greater than or equal to 20 % exceedance value. The high flow range average for the simulated flow is the flow on days when the observed flow is greater than 197 ML/d. The simulated high flow range average is less than the observed. This indicates that there are times when the residual inflow is underestimated or the loss function is not accurate at some events. For all flow range, the simulated flow is within 2 % of the observed flow. Discrepancy maybe due to timing differences between residual inflow estimates and dam releases made to satisfy downstream demands.

3.4.2. Peel River at Paradise Weir (419024)

This gauge was used to calibrate the residual and loss function in the Peel River from Piallamore to Paradise Weir. The residual was estimated to be 40% of the gauged flow from Cockburn River. In this reach, the Tamworth town water supply diverts the ordered water. In addition, there are also diversions for irrigation and stock and domestic demands. The ordered water has an estimated 17% contribution to the total observed flows at Paradise Weir.

The figure below shows a good match of the flow distribution and monthly variability. The observed flow is greater than or equal to 32 ML/d for 80% of the time. The corresponding value for the simulated flow is 33 ML/d.

Figure 3.3: Peel River at Paradise Weir (419024)



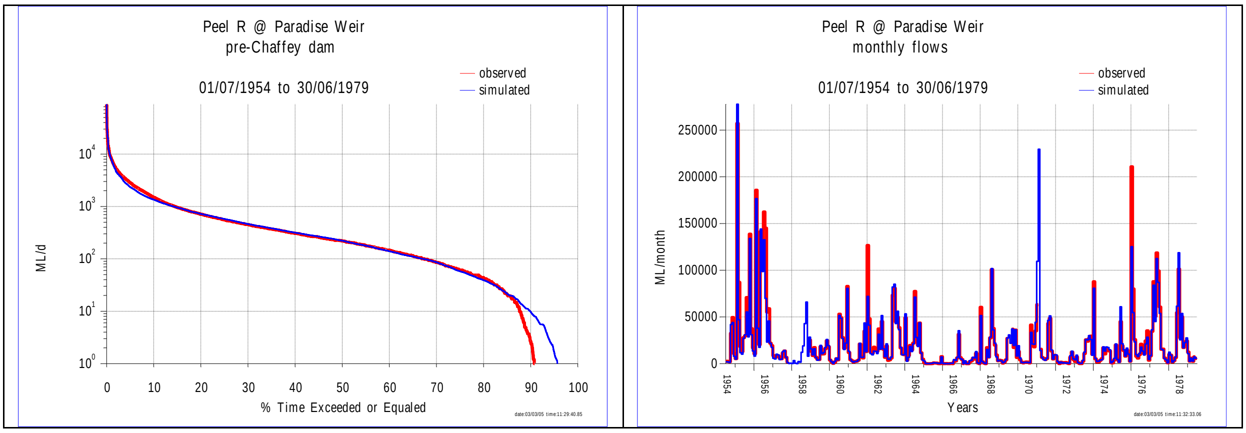
The table below shows the comparison of the flow range between observed and simulated flow. The medium flow range has good match of the observed and simulated flow. Overall, the simulated flow is higher than the observed flow by about 2%.

Table 3.3: Observed and simulated flow range at the Peel River at Paradise Weir (419024)

range	*data type*	*Percentage of time (%)*	flow at designated percentile (ML/d)	average for flows in the designated range (ML/d)
low	*observed*	*80*	32	19
(between 80%ile and 100%ile)	simulated		33	39
medium	*observed*	*50*	80	107
(between 20%ile and 80%ile)	simulated		79	107
high	*observed*	*20*	349	1756
(between 0%ile and 20%ile)	simulated		346	1780
all	*observed*			420
	simulated			429

The residual and loss functions between at Peel River at Piallamore and Paradise Weir were verified during pre-dam period from 1954 to 1978. The simulation period was limited by available observed data at Paradise Weir. There are no observed diversions but the estimated town water supply diversions were included. The maximum observed flow at Paradise Weir is 88,395 ML/d on February 25, 1955. This is higher than the observed flow of 72,492 ML/d on January 30, 1984 during the calibration period. Hence, this period was used to calibrate flow greater than 80,000 ML/d.

Figure 3.4: Peel River at Paradise Weir (419024) – 1954 to 1979



The simulated flows below 10 ML/day were higher than observed because of unaccounted irrigation diversions and estimated town water supply diversions. The median flow in this period is 220 ML/d, which is higher than that in the calibration period. The monthly time series shows that there are times when the simulated monthly flow is lower than observed. This may be to the underestimation of residual inflow during these periods.

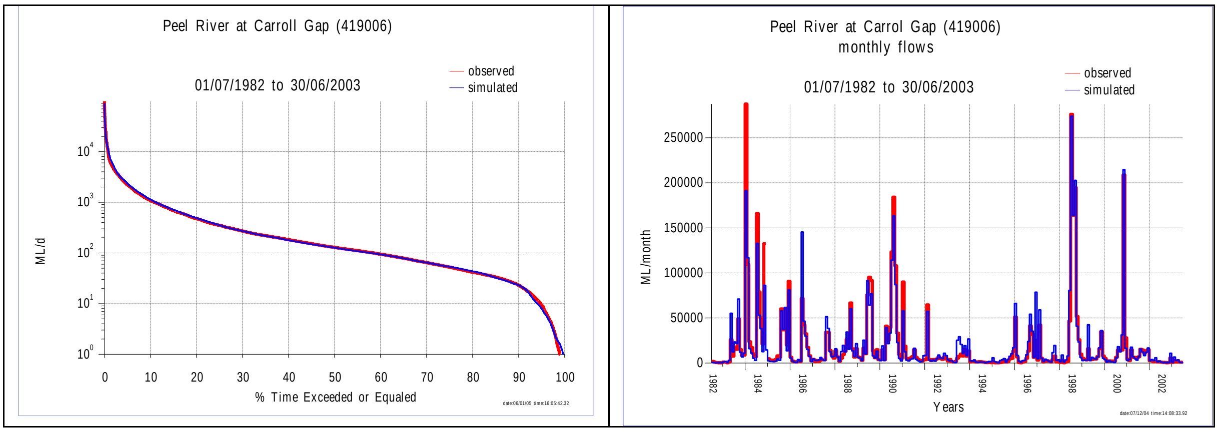
3.4.3. Peel River at Carrol Gap (419006)

This gauge was used to estimate the residual and loss function in the Peel River from ParadiseWeir to Carrol Gap. The residual catchment has an area about 40% of the total Peel catchment and is about four times the catchment area of Goonoo Goonoo Creek at the gauging station at Timbumburi (419035) the only gauged inflow to this section of river. The residual was estimated by mass balance using observed flows at Paradise Weir, Carrol Gap and Goonoo Goonoo Creek and estimated losses and diversions. Hence, in this reach, the residual and losses are both unknowns. Long term residual inflow was estimated using calibrated Sacramento rainfall runoff model. From the generated residual inflow, the losses were derived. When the losses and daily diversions were refined, the Sacramento derived residual inflow was again generated.

To simulate rainfall derived floodplain runoff and groundwater inflow to the Peel River, a dummy storage was modelled with releases calibrated using observed flows at Carrol Gap. The spill from the storage represents floodplain inflow from the residual catchment and the release of 20 ML/d from the storage simulates groundwater inflow to the river. The groundwater releases from the storage were reduced during dry periods as recognition of catchment dryness (Goonoo Goonoo Creek flow used as trigger for dryness). The inflow from the residual catchment forms a significant component of the river flow in the Peel River at Carrol Gap. There are diversions for irrigation and stock and domestic demands during these low to medium flow periods that make it very difficult to estimate the inflows from the residual catchment.

The figure below shows a good match of the flow distribution and monthly variability. The observed flow is greater than or equal to 42 ML/d for 80% of the time. The corresponding value for the simulated flow is 43 ML/d.

Figure 3.5: Peel River at Carrol Gap (419006) – 1982 to 2003



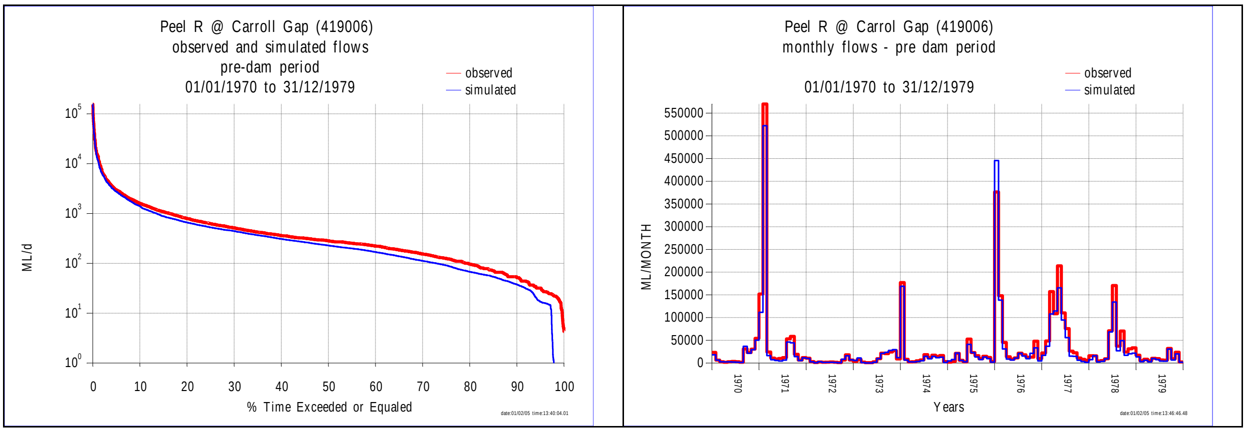
The table below shows the comparison of the flow range between observed and simulated flow. Overall, the simulated flow is higher than the observed flow by about 2%.

Table 3.4: Observed and simulated flow range at the Peel River at Carrol Gap (419006)

range	*data type*	*Percentage of time (%)*	flow at designated percentile (ML/d)	average for flows in the designated range (ML/d)
low (between 80%ile and 100%ile)	*observed*	*80*	42	22
	simulated		43	40
medium (between 20%ile and 80%ile)	*observed*	*50*	129	163
	simulated		127	171
high (between 0%ile and 20%ile)	*observed*	*20*	478	2642
	simulated		489	2639
all	*observed*			626
	simulated			638

The residual and loss functions were verified during pre-dam period. The simulation period from 1970 was limited by available observed data from Goonoo Goonoo Creek. The maximum observed flow at Carrol Gap is 155,706 ML/d on January 24, 1976. This is a lot higher than the observed flow of 98,576 ML/d during the calibration period. Hence, this period was used to calibrate flow greater than 100,000 ML/d.

Figure 3.6: Peel River at Carrol Gap (419006) – 1970 to 1979



The average observed flows at Carrol Gap was 1,073 ML/d during the pre-dam period. This is higher than the observed flows of 626 ML/d during the post-dam period. The median in pre-dam was 283 ML/d and in post-dam period, it was 129 ML/d.

The above figure shows that the simulated flow is lower than the observed. This may be due to higher residual inflows and/or lower losses during pre-dam period as compared to post dam period. The data quality at Goonoo Creek and at Peel River observed values might also contribute to the difference in the observed and simulated flows in this period. It is also possible that the observed diversions are lower than real values. If higher diversions are used in flow calibration, lower loss values will be used.

3.4.4. River flow replication quality.

The model flow frequency calibration quality assessment as described in Appendix E is in the table below. The evaluation is from 01/07/1982 to 30/06/2003. The low flow is the flow exceeded 90% of the time and the high is the flow exceeded 5% of the time.

Table 3.5 River flow replication quality

SUBJECT		FLOW FREQUENCY: VOLUME RATIO %'s				TIME SERIES MATCH	
Comparison point	Aspect Reported	Whole Range	Low Range	Mid Range 5% to 90%	High Range	"1-r^2"	CMAAD
Peel River @ Piallamore	Observed GL:-	1966	16	998	983	-	-
	Simulated GL:-	2021	18	1037	998	-	-
	Appar't Error:-	-2.7%	-12%	-3.9%	-1.6%	6%	11%
	Rating:-	High	Moderate	High	V. High	High	Moderate
Peel River @ Pardise Weir	Observed GL:-	3157	8.6	1389	1729		
	Simulated GL:-	3181	11.8	1418	1721		
	Appar't Error:-	-0.8%	-37%	-2.0%	0.5%	6%	6%
	Rating:-	V. High	V.Low	V. High	V. High	High	High
Peel River @ Carrol Gap	Observed GL:-	4797	7.5	1845	2770		
	Simulated GL:-	4814	8.2	1853	2758		
	Appar't Error:-	-0.4%	-9%	-0.4%	0.4%	18%	10%
	Rating:-	V. High	Moderate	V. High	V.High	Moderate	High
Model Run number: Peels06b.sqq							

3.5. DIVERSION VOLUME REPLICATION

3.5.1. Background and methodology

The main water users in the Peel are the Tamworth town water supply and irrigation demands. The Tamworth town water supply has high security and the irrigators have general security licence. There are periods when the town water usage alone exceeds the rest of the diversion from the river.

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

The objective of this step is to calibrate the crop water demand module over the calibration period (DLWC, 1998[c]). The parameters calibrated during flow calibration (routing, losses and residuals) are used. Crop areas and mixture and town water supply extractions are forced to observed data during the calibration period. Appropriate rainfall and evaporation data is selected to drive the crop demand module, which is then calibrated to replicate the observed diversions based on the observed areas planted. The IQQM modeller estimates the potential crop factors (Allen, et. al., 1998) to actual factors, 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]). Table A.1 and Table A.2 in Appendix A list the climate data that was used to estimate crop water requirements.

Crop factors for crops other then cotton, such as lucerne and cereals were estimated from guidelines published by the United Nations Food and Agriculture Organisation (Allen, et. al., 1998). These base factors were adjusted to suit estimated crop demand. The crop factors used for different crops are presented in Table C.3 in Appendix C.

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.

Because of the data uncertainty, the decision was made to focus the IQQM diversion calibration on total diversions and not on separate ‘on allocation’ and ‘off allocation’ diversion calibrations. This simplification is justified an absence of on farm storages in the Peel Valley, resulting in similar diversion behaviour for both ‘on-’ and ‘off-allocation’ periods.. However, efforts were made in setting up off allocation rules to match the available off allocation periods. The off allocation diversions are also shown with recorded data.

For the town water supply, the amount of water diversion is a function of population, temperature, evaporation and rainfall.

3.5.2. Irrigation Diversions

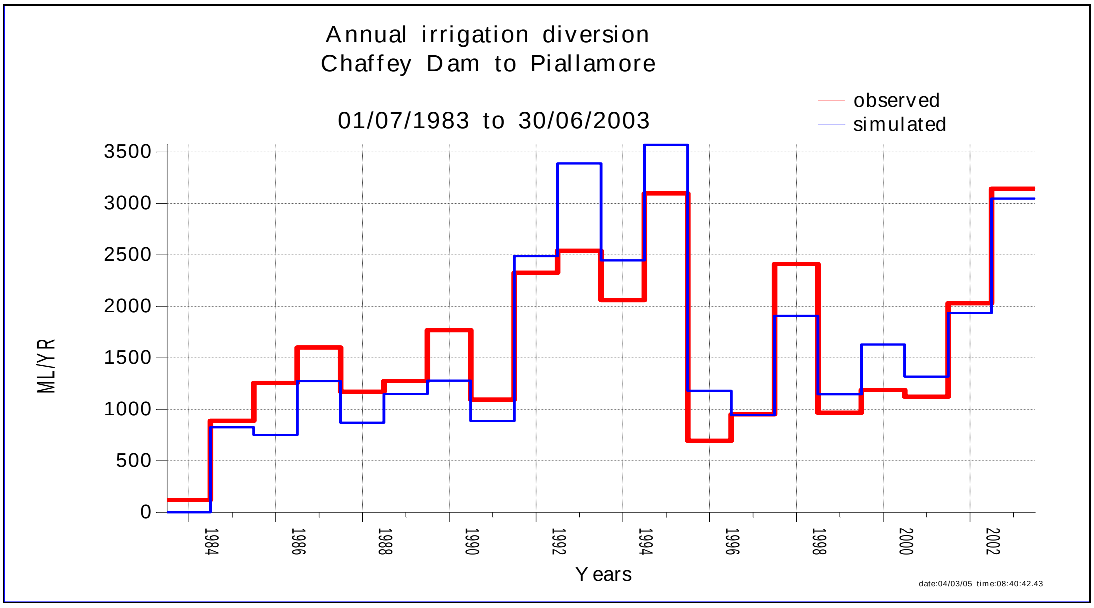
Input data on the crop area irrigated, rainfall and evaporation patterns and distribution affect the annual variation in simulated diversions. Although crop data are available from 1982, more confidence is given to data collected post 1996/97 period. However, this data is only up to 2002/03 and may not cover all climatic conditions. The observed area irrigated and announced allocation were input into the model as time series files to simulate crop demands and diversions. See Appendix D for the crop mix and areas from 1982. The locations of reaches are in the schematic diagram in Figure C.1.

Calibration parameters include soil properties with the allowable moisture depletion being the most significant parameter affecting the diversion pattern. The crop factors dictate the amount of water being depleted and calculate the crop demand.

3.5.2.1 Chaffey Dam to Piallamore

The rainfall station at Dungowan (055171) and the evaporation data used is the observed and generated evaporation from Tamworth reduced with monthly evaporation gradient. To get the simulation diversions closed to the observed values, the allowable soil moisture depletion was calibrated to 600 mm.

Figure 3.7: Observed and simulated annual diversions –Chaffey Dam to Piallamore

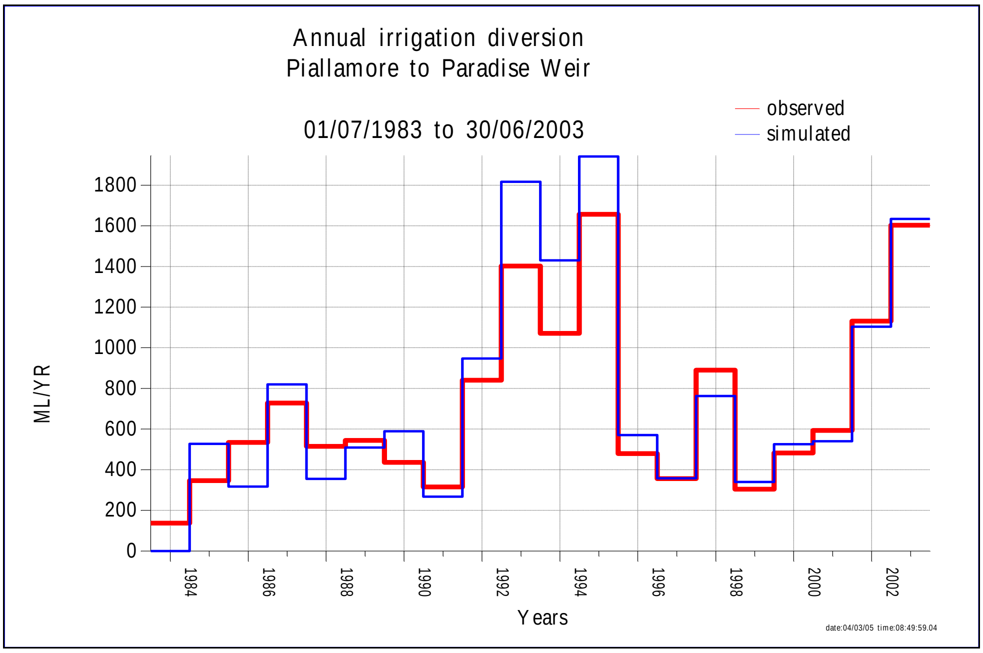


The figure above shows the observed and simulated diversions from 1983 to 2003. The simulated diversions in 1992 to 1996 are higher than observed. The rainfall was low in 1994/95 resulting in a diversion of 4.2 ML/ha. The lowest simulated diversion was in 1990/91 with 1.5 ML/ha (observed is 1.8 ML/ha) and the highest in 1992/93 with 4.5 ML/ha (observed is 3.4 ML/ha). The average annual observed diversion from 1983 to 2003 is 1,585 ML/year and the simulated is 1,602 ML/year (101% of observed).

3.5.2.2 Piallamore to Paradise Weir

The rainfall station at Dungowan (055171) was used. To get the simulation diversions closed to the observed values, the allowable soil moisture depletion was calibrated to 400 mm. The evaporation used is the observed and generated evaporation from Tamworth reduced with monthly evaporation gradient.

Figure 3.8: Observed and simulated annual diversions – Piallamore to Paradise Weir

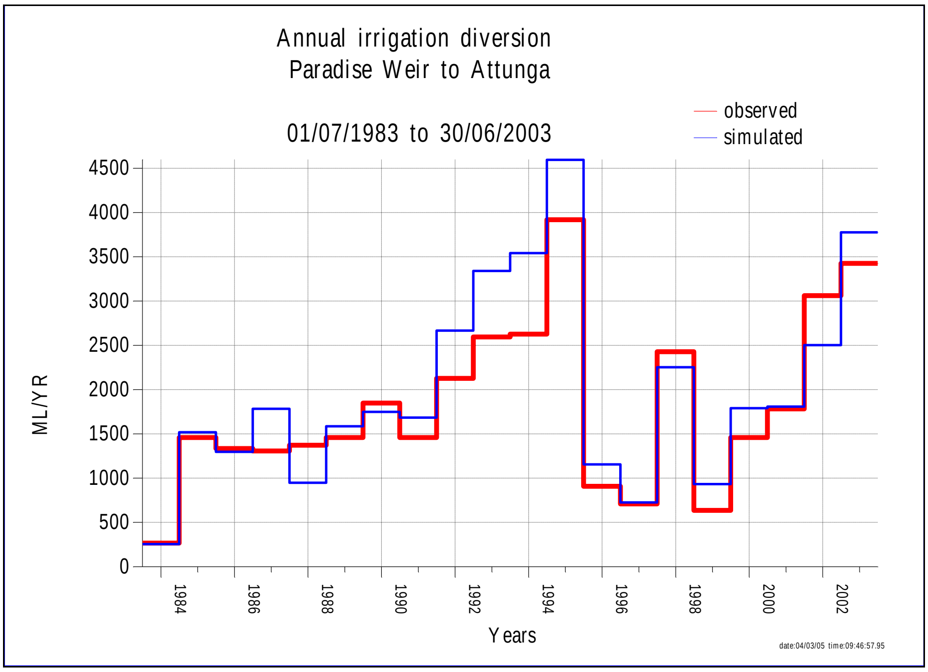


The simulated diversions in 1992 to 1995 are higher than observed but similar from 1998. The average observed diversion from 1983 to 2003 is 718 ML/year and the simulated is 767 ML/year (107% of observed).

3.5.2.3 Paradise Weir to Attunga

The rainfall station at Tamworth (055054) was used for rainfall and evapotranspiration demand. To get the simulation diversions closed to the observed values, the allowable soil moisture depletion was calibrated to 200 mm.

Figure 3.9: Observed and simulated annual diversions –Paradise Weir to Attunga



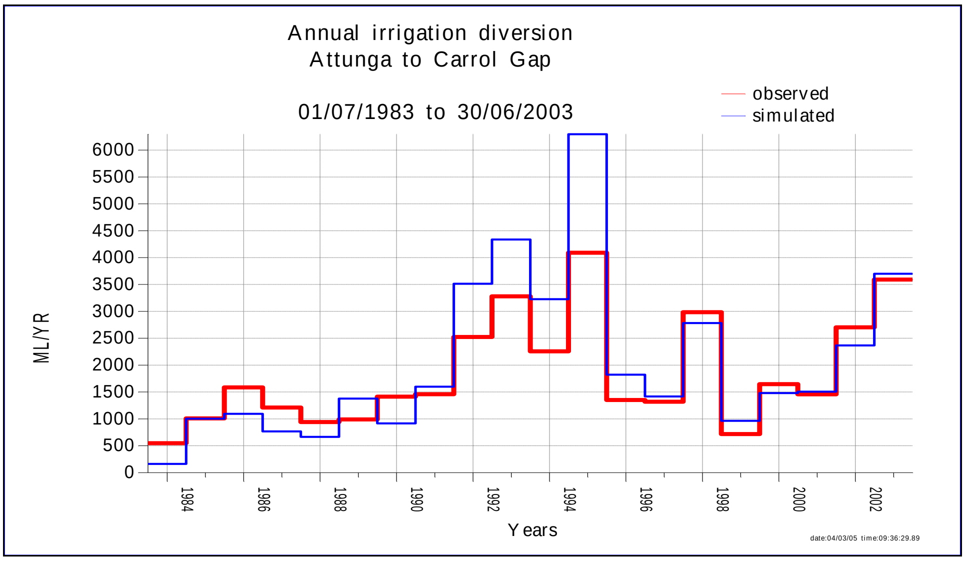
The average annual observed diversion from 1983 to 2003 is 1,809 ML/year and the simulated is 1,995 ML/year (110% of observed).

In 1994/95, the area irrigated is 963 hectares and the recorded diversion is 3,918 ML. This indicates that the recorded irrigation diversion is 4.1 ML/ha. This is a low rainfall and high evaporation water year. The observed evaporation at Tamworth Oxley Lane is 2,205 mm. The generated evaporation used in the model is 2,119 mm. The observed rainfall at Tamworth is 552 mm for the water year. Using Tamworth rainfall and evaporation, the simulated irrigation diversion of 4.8 ML/ha is required to supplement rainfall volume in satisfying crop demand.

3.5.2.4 Attunga to Carrol Gap

The rainfall station at Tamworth (055054) was used for rainfall and evapotranspiration demand. To get the simulation diversions closed to the observed values, the allowable soil moisture depletion was calibrated to 200 mm.

Figure 3.10: Observed and simulated annual diversions – Attunga to Carrol Gap



The average observed diversion from 1983 to 2003 is 1,854 ML/year and the simulated is 2,049 ML/year (111% of observed).

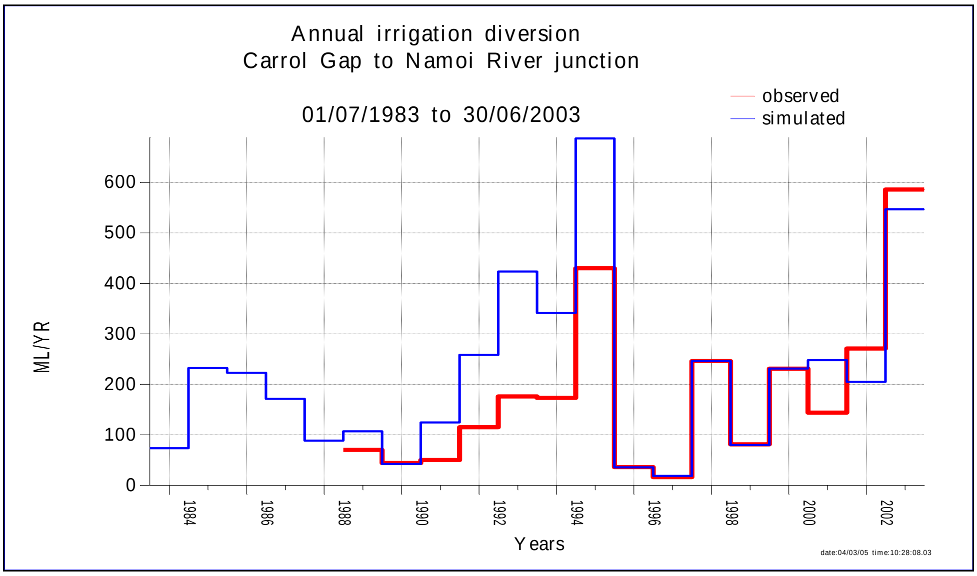
In 1994/95, the area irrigated is 1,278 hectares and the recorded diversion is 4,090 ML. This indicates that the recorded irrigation diversion is 3.2 ML/ha. This is a low rainfall and high evaporation water year. The observed evaporation at Tamworth Oxley Lane is 2,205 mm. The generated evaporation used in the model is 2,119 mm. The observed rainfall at Tamworth is 552 mm for the water year. Using Tamworth rainfall and evaporation, the simulated irrigation diversion of 4.9 ML/ha is required to supplement rainfall volume in satisfying crop demand.

According to Dept of Agriculture estimated crop demand, lucerne has a crop demand of 9 ML/ha and summer cereal has a crop demand of 6.7 ML/ha. If the recorded area irrigated is correct, the difference between the observed and simulated irrigation diversion needed for crop growth might have been satisfied by other sources, like groundwater, which was not included in the model.

3.5.2.5 Carrol Gap to Namoi River junction

The rainfall station at Somerton (055003) was used for rainfall and evapotranspiration demand. To get the simulation diversions closed to the observed values, the allowable soil moisture depletion was calibrated to 200 mm.

Figure 3.11: Observed and simulated annual diversions – Carrol Gap to Namoi River junction

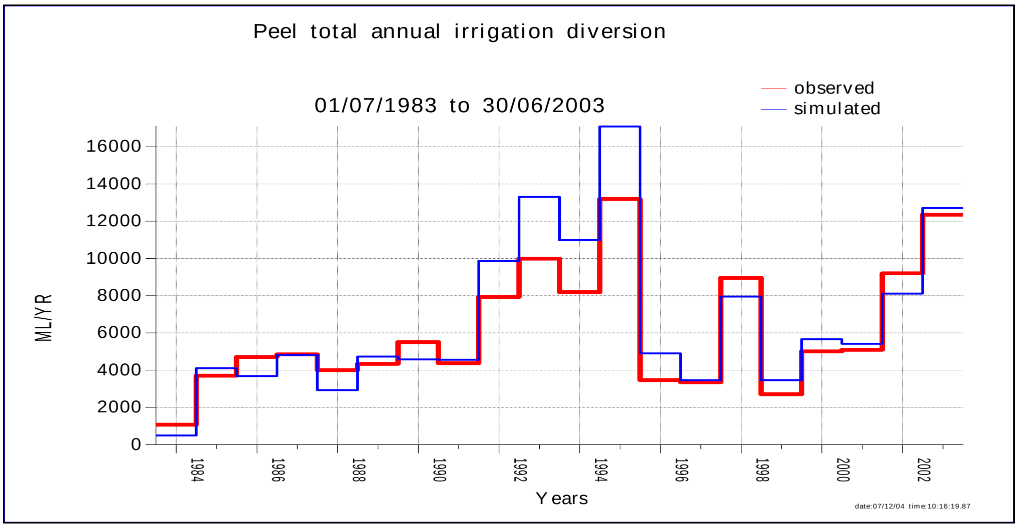


The average observed diversion from 1983 to 2003 is 178 ML/year and the simulated is 240 ML/year (135% of observed). Data from 1995/96 were considered to be more reliable than that prior to 1995.

3.5.2.6 Peel River total irrigation diversion

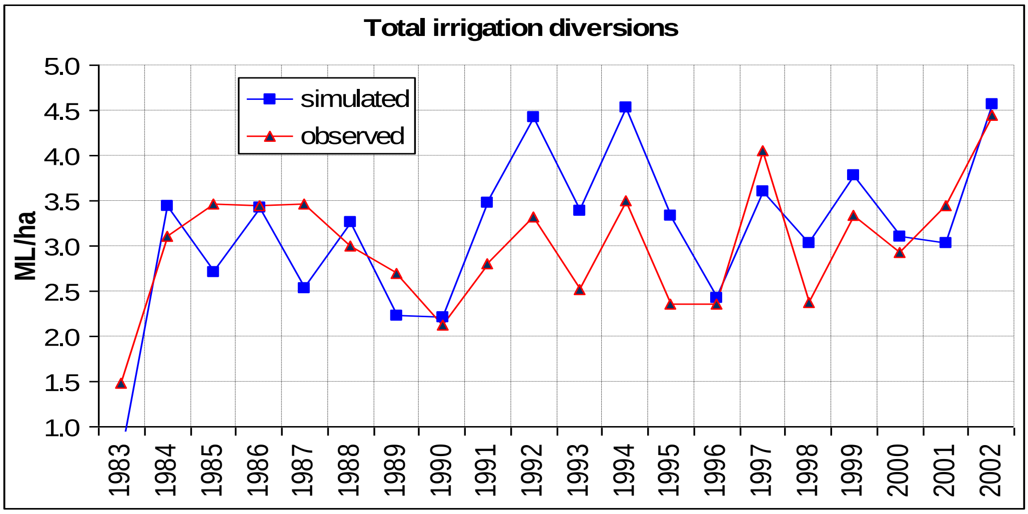
The Figure below shows the total observed and simulated irrigation diversion from the Peel River. The simulated diversion is similar to the observed values from 1983 to 1991, and from 1996 to 2003. The simulated diversion is more than the observed in the dry periods in 1991 to 1996.

Figure 3.12: Observed and simulated total annual diversions – Chaffey to Namoi River junction



The irrigation diversions have also been plotted as ML/ha comparison between the simulated and observed in Figure 3.13. In the 1994/95 dry period the observed ML/ha is 3.5 as compared to simulated ML/ha of 4.5. A similar dry period in 2002/03 showed closer match of observed and simulated application rates at 4.5 ML/ha.

Figure 3.13: Simulated and observed irrigation diversions in ML/ha



Also a comparison between ML/ha with rainfall was used to check the similarity and reliability of the data. The results in Figure 3.14 showed a marginally better correlation of rainfall (over the major growing season) and diversion for simulated data than the observed. Overall the match between simulated and observed data shows a fairly good match supporting the model calibration.

Figure 3.14: Relationship of simulated and observed irrigation diversions in ML/ha with rainfall

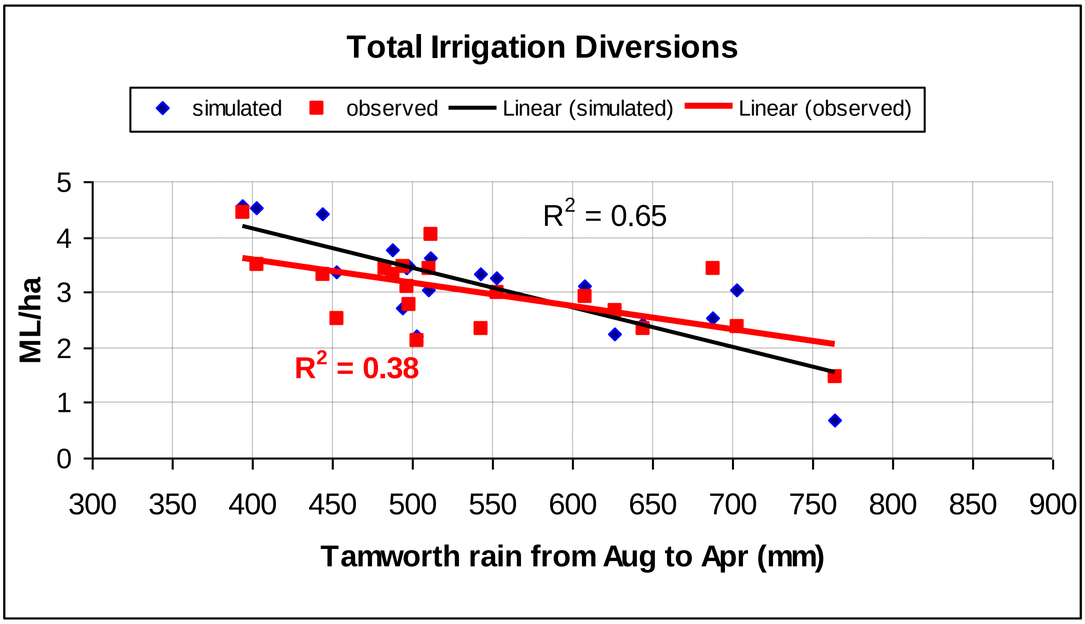


Table 3.6 summarises the calibration using the quality guidelines outlined in Appendix E.

Table 3.6 Total Irrigation Diversion replication quality

Diversion Type	Volume Ratio (%)	Apparent Error(%)	Quality Rating	CMAAD	Quality Rating
Total Irrigation Diversions	109	9	Moderate	18	Moderate
Model run number: Peels06b.sqq					

3.5.3. Estimation of town water supply diversion

There are a number of factors influencing water demand. These range from environmental factors such as climate, to socio-economic factors such as population, economic growth and water price. If the relationship between these factors can be understood and the relevant data collected, accurate projections can be made.

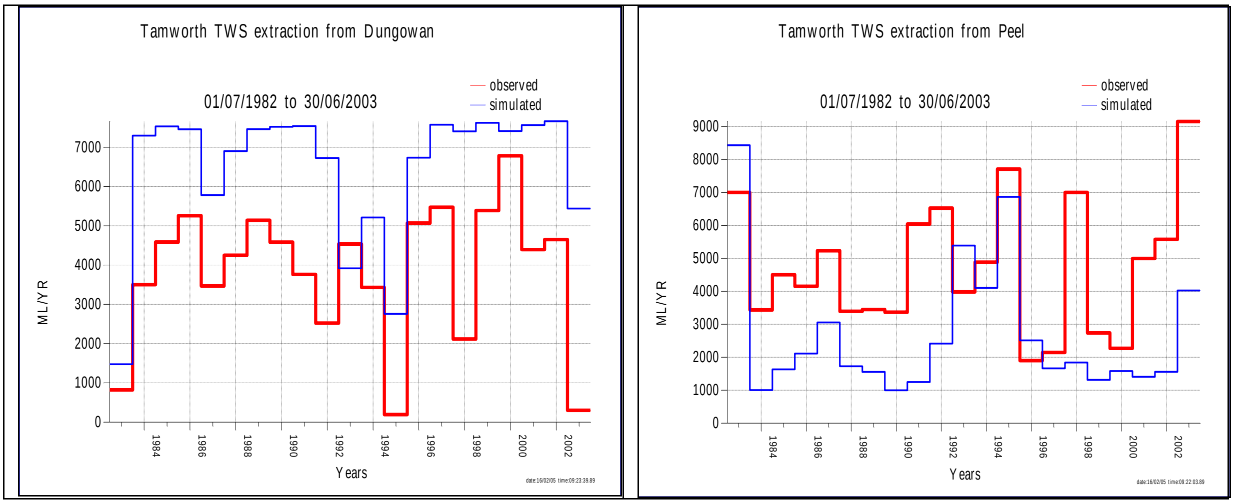
The most important influence on water demand is the influence of climate. The influence of climate on water demand is best quantified by using a time series model of monthly or daily water production. Time series models based on annual data, while widely used, are less reliable and should be avoided where shorter time series data are available. The climate indicators are maximum daily temperature, rainfall, evaporation, solar radiation, vapour pressure and relative humidity.

For Tamworth water demand modelling, a multi-variable regression analysis (see Appendix B) was done using daily population, maximum temperature, rainfall and evaporation and observed monthly demands. The period of the multi-variable regression calibration was from1997/1998 to 1999/2000. The 1997 to 1999 years were the most recent period, at the time of calibration, with monthly diversions from Council. Any period prior to that was very much influenced by non-climatic factors such as water price, economic growth, water restriction etc. This regression was used to estimate demands for the period 1982 to 1996 and any gaps in the observed data were filled with the estimated data.

Tamworth Town Water is supplied primarily from Dungowan Dam, up to the pipe capacity, and then supplemented from Chaffey Dam if necessary. Observed data were taken from estimated data and updated from recent data obtained from Tamworth City council.

The figure below shows that the simulated diversion from Dungowan Dam is more than observed. The average simulated extraction is 6.4 GL/yr and the observed is 3.8 GL/yr. On the other hand, the simulated diversion from the Peel River supplied by Chaffey Dam is less than observed. The average simulated extraction from the Peel River is 2.7 GL/yr and the observed is 4.7 GL/yr. This information suggests that Tamworth Council may not be strictly following the sharing rules adopted in the model. Anecdotal information suggests the water quality of Dungowan Dam impacts on Tamworth Council's decision to use either Dungowan Dam or Chaffey Dam water. This water quality decision making process is not modelled in Peel IQQM and may partially explain the differences shown in Figure 3.15.

Figure 3.15: Observed and simulated diversions from Dungowan Dam and Peel River for Tamworth town water supply



The figure below shows the observed and simulated total town water supply diversions. The average annual total simulated town water diversion is 8.8 GL/yr and the observed is 8.6 GL/yr (97% of observed).

Figure 3.16: Observed and simulated town water supply diversions

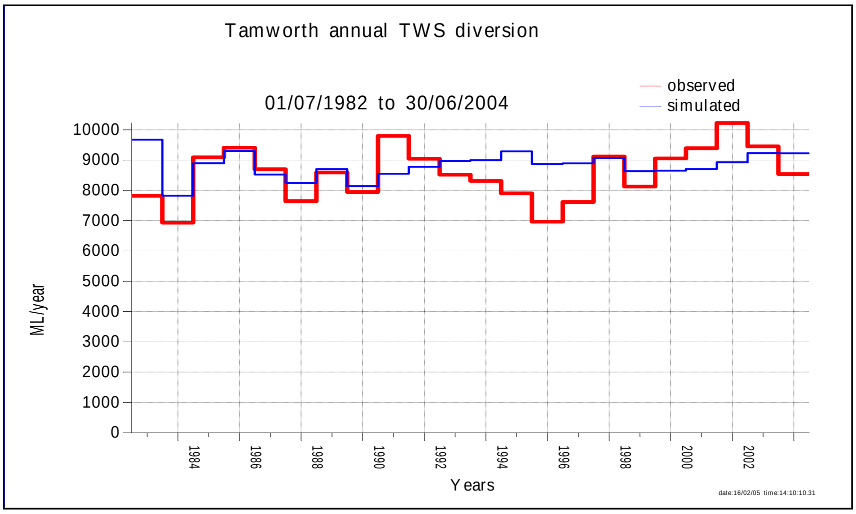


Table 3.7 summarises the calibration using the quality guidelines outlined in Appendix E.

Table 3.7 Tamworth diversion replication quality

Diversion Type	Volume Ratio (%)	Apparent Error(%)	Quality Rating	CMAAD	Quality Rating
Tamworth Diversions	104	4	High	8	Very High
Model run number: Peels07e.sqq					

3.6. STORAGE BEHAVIOUR REPLICATION

Storage behaviour replication by the model provides the best numerical check of the model's overall performance. All elements of the system contribute to the pattern of draw down and releases in the dam behaviour.

A number of model parameters are calibrated in the storage calibration process (DLWC, 1998[c]). To calibrate these parameters, the calibrated parameters from flow and demand calibration are used, while the crop areas are forced to observed data. The river operation parameters are then adjusted until the simulated storage behaviour, storage releases and end-of-system flows best match the observed data. The following details the different processes in storage calibration.

3.6.1. Inflow to dams

For the calibration of storage behaviour, dam inflows must first be derived. As discussed in Section 2.3.3 this was done using a back-calculation procedure (DLWC, 1998[g]) based on information obtained from dam Officer in Charge (OIC) sheets.

After a review of the available rainfall and evaporation stations and consideration of the criteria outlined in Section 3.4.1, the rainfall and evaporation stations listed in Table A.1and A.2 were selected to derive the storage behaviour in the model. Daily storage levels, releases, spills, evaporation and rainfall from 1979 were used to estimate dam inflows. These inflows were used for calibrating the storage behaviour.

For Dungowan dam, records of inflows, releases and spills were not available at the time of calibration. Since there is no observed inflow, the Sacramento model was used to derive inflow to Dungowan dam. The inflow was calibrated by using observed flows at Snowball and Dungowan creeks from 1975 to 1993 and factoring up to 30% for Dungowan catchment area.

3.6.2. Tributary utilisation

There is no specific information describing this process, and a simplified approach is used within IQQM that is then calibrated. The most common forecast for the expected flow from a tributary on a future day, is as a fixed fraction of the known flow on the current day (i.e. a recession assuming no rainfall in the water travel time between the storage). This is the method of representation 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, with factors for all ungauged tributaries equal to zero. In reality, the factors are not fixed, but they also vary with time and recent climatic conditions. The fixed tributary utilisation factors that produce the best calibration of storage behaviour over the calibration period are presented in Table C.5.

3.6.3. Operational surplus

There is no specific information describing this process in practice, and a simplified approach is used within IQQM that is then calibrated. The most common variation in the expected release from storage is as an increase in the releases above that expected from the summed orders and the average transmission losses. 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 the storage(s) for release.

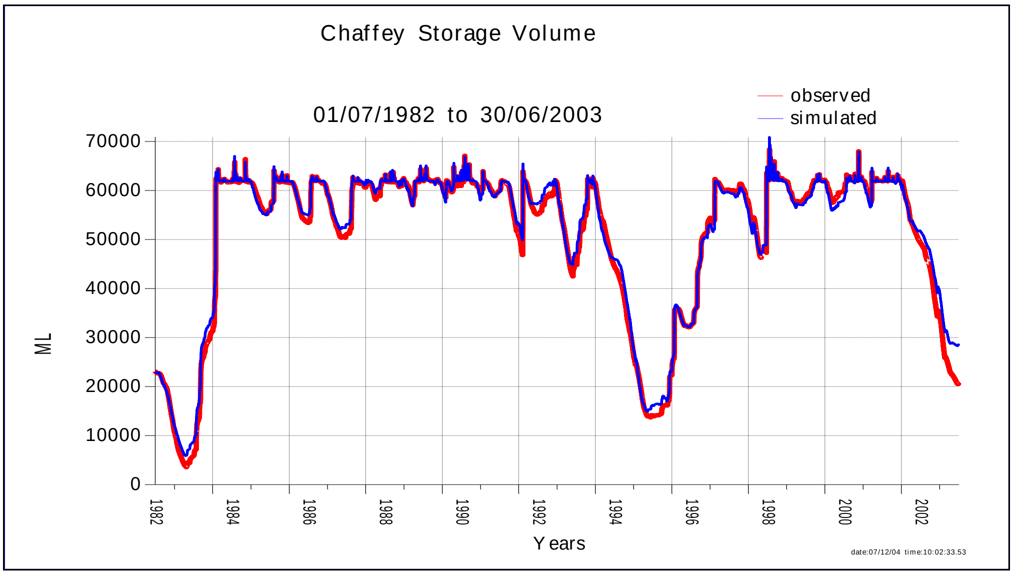
Typically, the over-order factors increase progressively down the main river because of the increasing uncertainty in transmission losses and greater flow attenuation with increased travel distance. For the Peel IQQM, the fixed over-order factor of 1.0 to 1.1 produced the best calibration of storage behaviour over the calibration period.

3.6.4. Results

3.6.4.1 Chaffey Dam

The following figure shows the storage calibration for Chaffey Dam.

Figure 3.17: Chaffey Dam – Observed and simulated storage volume



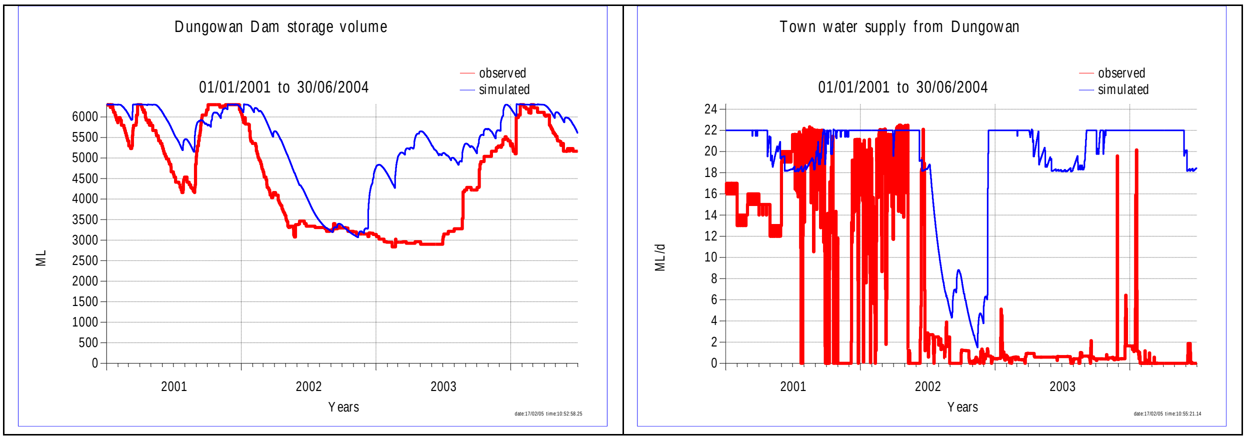
Note: Model run number: Peels06b.sqq

The simulated storage in 2003 was higher than observed. This was due to simulated releases being less than observed. This happens when rain and tributary inflows are sufficient to satisfy demands that release from the storage is not necessary. The difference in storage volume started in April 2002, which may indicate that the irrigators may have ordered and put more water in their crops than the simulated crop demand.

3.6.4.2 Dungowan Dam

The observed and simulated Dungowan Dam storage is in the figure below.

Figure 3.18: Dungowan Dam observed and simulated storage volume and town water supply



Note that the simulated storage is higher than observed especially in 2003. There are two issues with this calibration that require further consideration.

The simulated diversions from Dungowan to Tamworth are greater than the observed. This issue is discussed in Sections 2.10.3 and 3.5.3 where the rules for the combined operation of Dungowan and Chaffey Dams are discussed and information suggests Tamworth may not always follow the assumed rules. There are times when water from Dungowan Dam was not used to supply the town water demand due to occurrences of algae in the dam or other factors. There is not other information available at present to change the combined operation of the dams.

The second issue is the estimated Dungowan Dam inflows. As discussed in Section 2.3.3 the inflows to Dungowan Dam were estimated by Sacramento modelling of an upstream gauge and scaling those flows to allow for extra ungauged flow. The simulated inflows to Dungowan Dam in 2003 appear higher than the observed. The rise in simulated storage started in December 2002 when there was simulated high rainfall producing big inflow to storage. This raises questions about the quality of the Dungowan Dam inflows, however, the current approach is the best available with current data. Both the issues raised with Dungowan Dam storage calibration are discussed further in Section 5 with regards to model improvements.

Table 3.8 summarises the Dungowan and Chaffey Dam calibration using the quality guidelines outlined in Appendix E.

Table 3.8 Storage replication quality

Storage	Quality Indicator	Apparent Error	Quality Rating
Chaffey Dam	CMASDD	1	Very High
Dungowan Dam	CMASDD	31	Very Low

3.7. PLANTED AREA REPLICATION

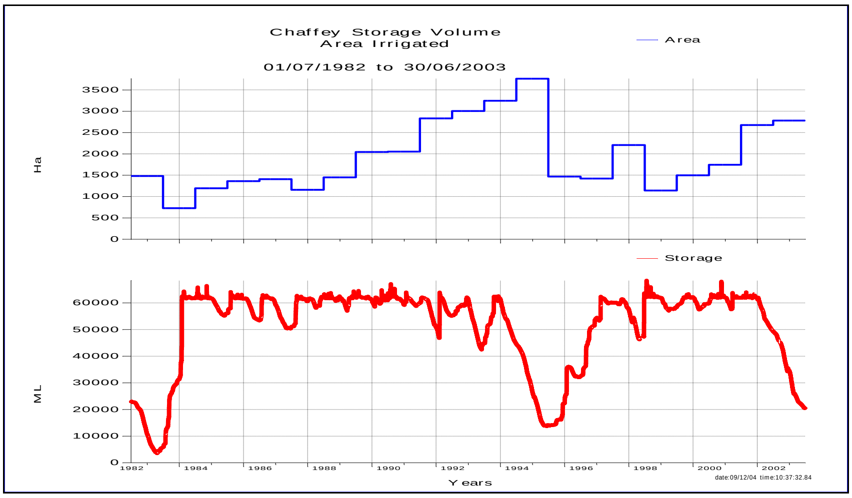
The area planted during the calibration and validation periods usually changes as a result of a number of factors including climate, development in the valley and market conditions. To consider this variability, area planted is forced during the calibration phase. However, to produce simulation runs in periods when observed areas are not available, a method to estimate area irrigated is required. This process is called the farmers planting behaviour.

Attempts to simulate farmer's behaviour in making decisions on the area to be irrigated are available in IQQM. Information on dates when decisions are made, available water from storage, soil moisture, rainfall in preceding months and announced allocation are some of the parameters considered when trying to understand the process. There are two options for estimating area irrigated in IQQM that simulate how the farmers make decisions, these are;

an area irrigated directly related to water resources at the decision date; or
a crop demand in ML/ha based on available water and soil moisture at decision date. The change in crop demand is based on the soil moisture classified as wet, average and dry climate. This is used in valleys where farmers perform soil moisture test to estimate crop demand. The available water is divided by the estimated crop demand (ML/ha) to derive area irrigated.

These methods were considered in trying to understand the observed area irrigated in the Peel Valley. Plotting the observed area irrigated with available water from Chaffey Dam in Figure 3.19 below indicates that the farmers irrigate more areas at times when the storage volume is low and/or water resources are also restricted. This is shown in the figure below, in 1994/95 and 2002/03, when the irrigated area is high during low storage volumes. The correlation between the area irrigated with available water is poor, hence no defined relationship.

Figure 3.19: Recorded area irrigated with Chaffey Dam storage volume



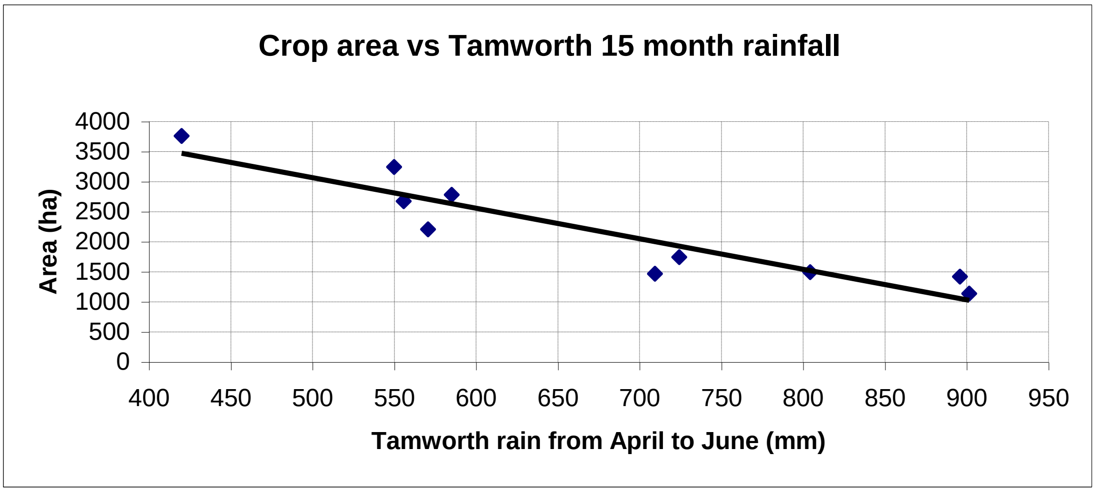
A range of other indicators including climatic conditions and lucerne prices were examined to try and better understand the area-irrigated data. A comparison of irrigated area with lucerne prices showed a good relationship, indicating that price for fodder products such as lucerne is probably a major driver of irrigated area. It is thought that many Peel Valley farmers maintain significant areas under lucerne at most time. However, these areas would only be irrigated at times when farmers could take advantage of high prices. The irrigation area data is further complicated by the significant "sleeper" factor or under usage in the valley. Normal annual water use is around 4,000 to 6,000 ML/water year compared to the total entitlement of about 31,000 ML. In the drier years when Chaffey Dam storage volumes and subsequent allocation levels are low, annual water use has exceeded 12,000 ML/water year.

As historical fodder prices are not available for the IQQM modelling period, a proxy indicator was required. Rainfall in the surrounding area was tested, with the assumption that drier conditions in the areas would favour higher prices for Peel farmers. A variety of combinations of antecedent and within year rainfall from stations in Tamworth, Kempsey, Gunnedah, Maitland and Moree were tested over a variety of periods prior to and including the year of interest.

Results indicated that the most appropriate relationship between rainfall and irrigated area was obtained using the rainfall at Tamworth. The use of other stations from outside the valley did not add additional predictive ability. The best rainfall period for predicting irrigated area in a given year was found to be the current water year plus the previous three months (ie. 15 months from April to June). This indicator includes rainfall that occurs after the traditional planting decision period of most crops in late spring, which initially seemed inappropriate. However, given that lucerne, the dominant crop, is perennial for a number of years and may be a dry land crop or irrigated for increased yield, the decision faced by irrigators is not so much a "planting" decision as a "watering" decision which may stretch across the water year. In this context, lack of rainfall and the consequent rising demand for fodder products could be met progressively through a water year by irrigating more of the lucerne.

Figure 3.20 shows the 15 month rainfall indicator versus irrigated area for 1993/4 to 2002/3. A regression line was derived from the recorded area and 15 months rainfall from April 1993 to June 2003.

Figure 3.20: Recorded crop area vs Tamworth 15 month rainfall

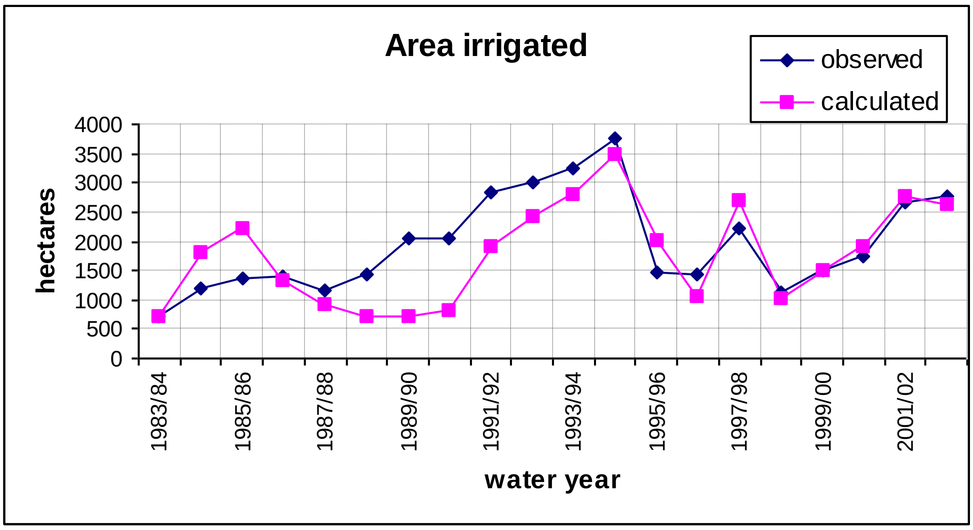


The equation for this line is:

Irrigated area = -5.08(Tamworth 15 month rainfall) + 5607

where irrigated area is for July to June (water year) in hectares and Tamworth rainfall is the rainfall in millimetres. The regression correlation, $r^2 = 0.86$. The regression equation was used to calculate the area irrigated from 1983/84 to 2002/03 water years, forcing the minimum area to be 725 hectares (planted in 1983). Figure 3.21 shows the results using the area derived using the 15 months rainfall indicator compared to observed area irrigated.

Figure 3.21: Observed and simulated area from 1983 to 2003



This approach for simulating area irrigated in the Peel Valley is considered the best option available at present. As seen in Figure 3.21 the approach reproduces observed area irrigated from 1993/94 through to 2002/03 fairly well, however, calculated area irrigated prior to 1993/94 is not reproduced well. The area irrigated data will continue to be monitored to see if the observed area versus rainfall relationship might change in the future.

Comparing observed with simulated planted area as specified in the Quality Assessment Guidelines in Appendix E.4 resulted to '*very high*' rating from 1993 to 2003 and '*moderate*' from 1983 to 2003.

3.8. OFF ALLOCATION CALIBRATION

There was a lack of detailed data for off-allocation diversions during the calibration period. 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.

IQQM models off-allocation periods using defined off-allocation reaches, which have surplus flow thresholds above which off-allocation is made available. As flows in excess of downstream requirements exceed the threshold level, off-allocation is made available to that off-allocation reach. As mentioned in Section 2.11, complete off allocation data are not available and therefore off allocation calibration was limited to replicate the announced off allocation periods. Table below shows the off allocation thresholds for various river sections.

Table 3.9 Adopted average flow surplus thresholds for Off Allocation Announcement

River reaches using OFA thresholds	Flow (surplus) thresholds in ML/d											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chaffey to Paradise Weir	60	60	60	60	60	60	30	30	30	30	30	30
Paradise Weir to Attunga	60	60	60	60	60	60	30	30	30	30	30	30
Attunga to End of System	100	100	100	100	100	60	60	60	60	60	60	60

The observed and simulated off allocation periods are shown in the figures below.

Figure 3.22: Observed and simulated off allocation periods Chaffey Dam to Paradise Weir

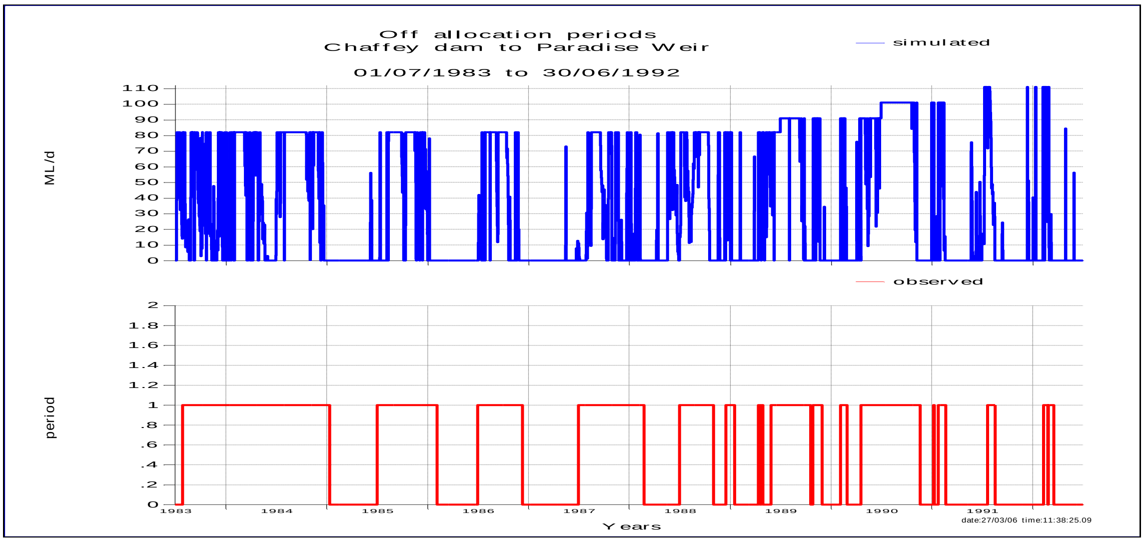


Figure 3.23: Observed and simulated off allocation diversions Paradise Weir to Attunga

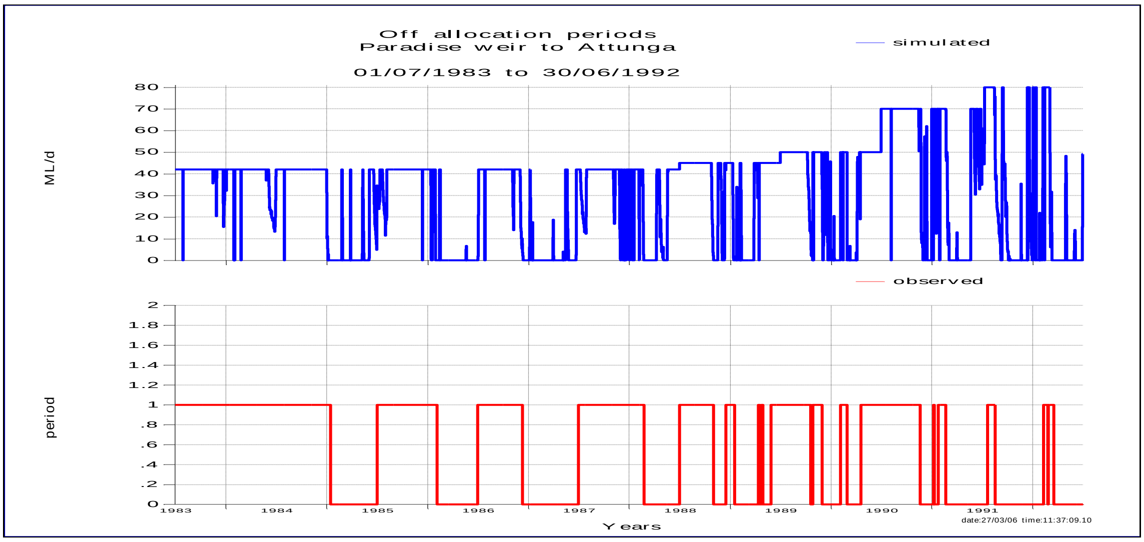
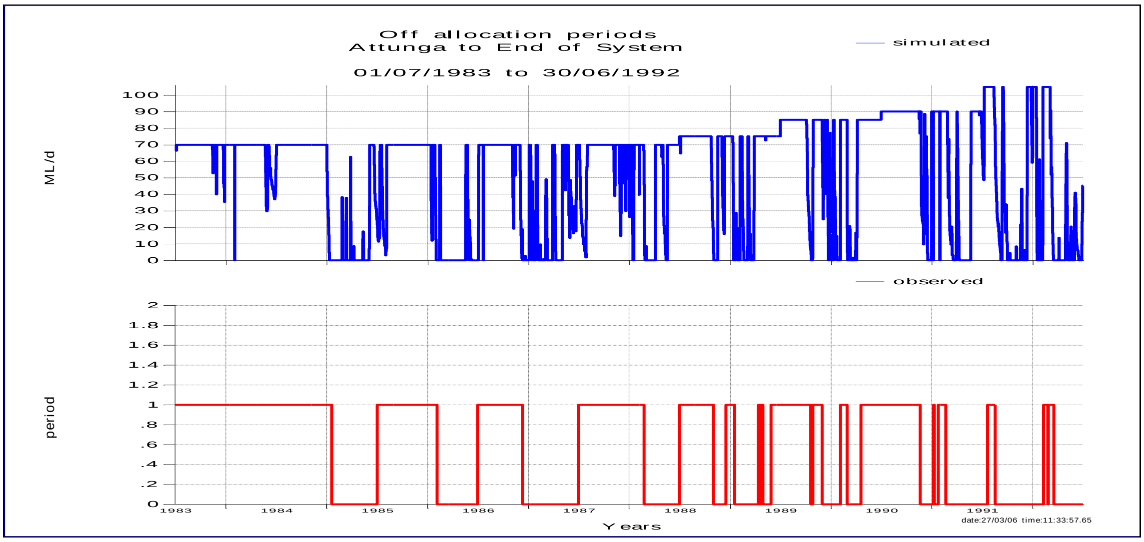


Figure 3.24: Observed and simulated off allocation diversions Attunga to End of System



The off allocation diversions are small compared to the total diversion especially in dry periods when the flow in the river is most of the time regulated. The irrigators in the Peel Valley do not have on farm storage, hence, any off allocation water would be diverted directly onto crops. The calibrated model generally reproduces period when off allocation is declared and the model will only divert off allocation water when there is crop demand.

3.9. ANNOUNCED ALLOCATION

Resource assessment involved the Department distributing the available water resources to all water users. Current and future needs of high security users are provided for initially and then remaining resources are allocated to general security users. The losses required for the operation of the system and any environmental needs are also taken into consideration during this process.

The following factors are taken into consideration in IQQM resource assessment:

- current volume available in the dam; and any downstream weirs;
- minimum expected inflow to the dam;
- minimum expected useful tributary inflow downstream of the dam;
- expected evaporation and transmission losses over the remainder of the irrigation season;
- all the essential requirements placed on the dam.

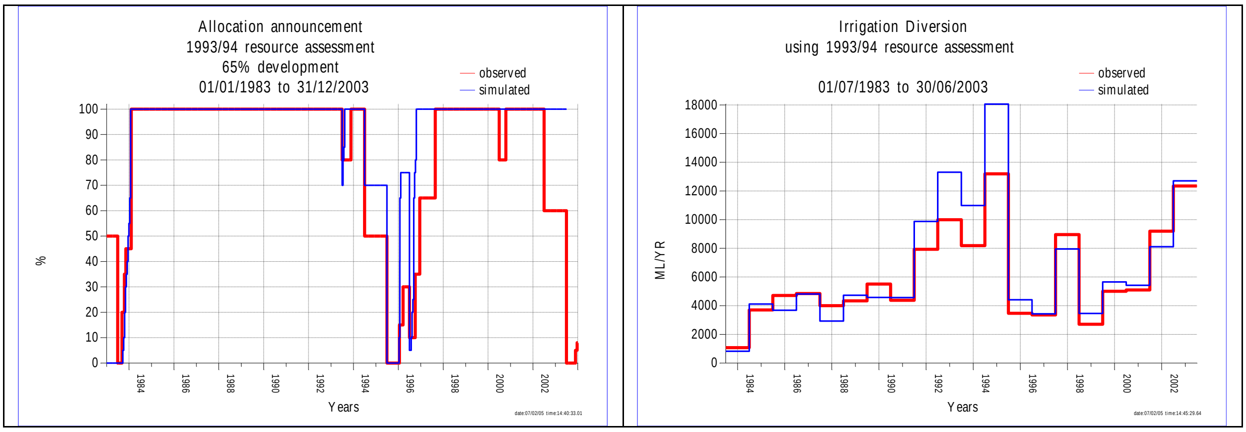
The result of a resource assessment is the announced allocation that limits the amount of water being diverted by general security users.

Over recent years a number of different parameters have been used in resource assessment. The utilisation factors, carry over reserve, minimum headwater and tributary inflows with monthly operation and transmission losses used for 1993/94, 2000/01 and 2003/04, are summarised in Table 3.11. Different calibrations were prepared to validate 1993/94, 2000/01 and 2003/04 resource assessment in the model.

3.9.1. 1993/94 resource assessment

For the Peel system, the development conditions or utilisation factor, carry over reserve and transmission/operation loss functions from 1993/94 were used to validate the announced allocation. In 1993/94 around 25% of irrigation entitlement was not active and even for those licenses that were active there was considerable under utilisation. The Department applied a utilisation factor of 0.65 in resource assessment to account for the large volume of entitlement not activated or utilised. In later years this policy was changed to an utilisation factor of 1.0 that allocated water to all users not just the active users. The observed and simulated allocation and the effect on simulated diversion are shown in the figure below. Note that in 1994/95 the simulated allocation is higher than observed. This higher allocation allowed more water for on allocation diversions.

Figure 3.25: Observed and simulated allocation – 1993/94 resource assessment

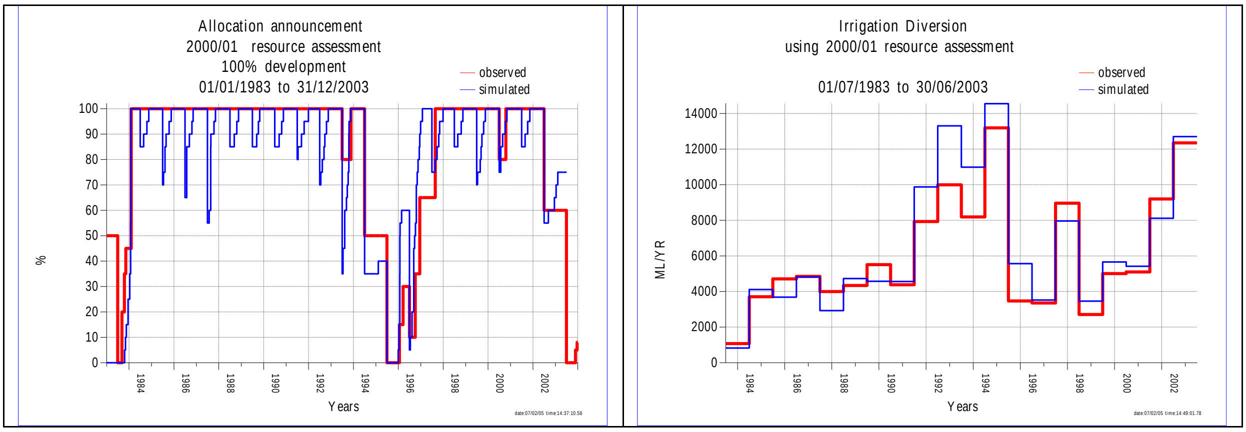


A utilisation factor of 1.0 was used by the Department in calculating the announced allocation after 1994.

3.9.2. 2000/01 resource assessment

The development condition (1.0) and transmission/operation loss functions from the 2000/01 system file were used to validate the announced allocation. The carry over reserve of 12 GL is similar to that used for 1993/94 run. The observed and simulated allocation and the effect on simulated diversion are shown in the figure below.

Figure 3.26: Observed and simulated allocation – 2000/01 resource assessment



The reduced simulated allocation prior to 1994 is due to the development factor of 1.0 being used compared to the 0.65 factor previously. The simulated allocation from the year 2000 onwards is closer to observed than that using 1993/94 resource assessment.

Although the allocation announcements would be different under 1993/94 and 2000/01 resource assessment rules, the average annual irrigation diversions (over the long term) for both runs are similar at about 6.7 GL/yr. This shows that using similar series of crop area and high security diversions, the irrigation diversion does not change much with resource assessments used in the 1993/94 and 2000/01 run. The on allocation diversion may be reduced by low allocation announcements, but the off allocation diversions can satisfy crop water demand.

3.9.3. 2003/04 resource assessment

The 1993/94 and 2000/01 resource assessment were prepared during relatively well resourced periods with a short drought period in years 1993 to 1995. The 2003/04 resource assessments provide an indication on how the allocations would be calculated during dry period.

In the water year 2003/04, 5 resource assessments were made. The summary of the inflows, requirements and losses used in the calculation of announced allocation are shown in the table below. The Chaffey Dam minimum inflows were taken from statistics of the minimum Chaffey Dam inflow. The statistics of minimum monthly tributary inflows from Chaffey Dam to Tamworth were used. And multiplied by 50% to account for tributary utilisation.

The total general security entitlement used was 31.2 GL and the town water supply high security licence entitlement used was 10 GL. Other fixed requirements include 400 ML high security entitlements and 200 ML stock and domestic supplies. In July 7, 2003 the announced allocation was 0% and increased to 35% in March 24, 2004.

Table 3.10 Resource assessment in 2003/04

date	Chaffey min inflow (GL)	Trib min inflow (GL)	TWS demand GL	Trans & Operation Losses	Announced Allocation (%)
16/06/2003	3.70	2.70	10.00	7.90	0
13/11/2003	1.10	1.30	7.60	8.30	5
19/12/2003	1.10	0.60	6.70	7.20	8
27/01/2004	0.30	0.20	4.40	7.50	20
23/03/2004	0.00	0.00	2.00	7.70	35

In IQQM, the allocation was calculated every 14 days and no allocation is to be calculated after March. Actual allocations were generally announced in 5% increments, although there is the 8% allocation announced in December 2003.

For allocation validation, the simulated Chaffey Dam storage was forced (by changing calibrated parameters) to match the observed storage behaviour from July 2003 to June 2004. This was done by forcing the average daily observed TWS diversion from Dungowan Dam being limited to 0.6 ML/d (by limiting the pipe capacity to 0.6 ML/d). This will force Chaffey Dam to supply the Tamworth TWS demand closer to the observed diversion. To match the Chaffey Dam releases and observed values, the tributary utilisation factors were revised for this water year only. The tributary utilisation at

Dungowan and d/s Paradise Weir were assumed to be zero and 10% from other inflows upstream Paradise Weir. The Chaffey Dam observed and simulated storage behaviour are shown in the figure below.

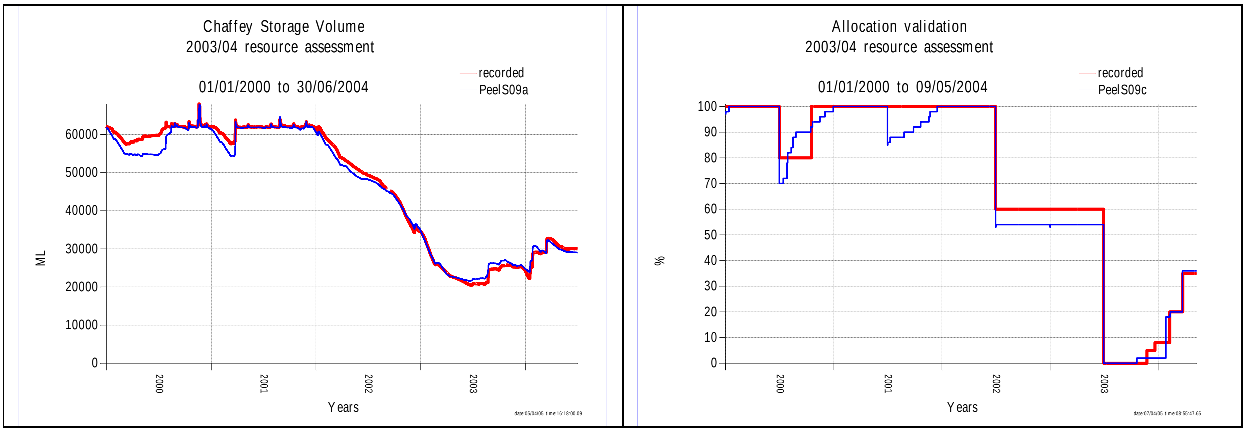
IQQM uses monthly transmission and operation losses in the resource assessment process that announced allocation. The loss numbers used in the model for calculating resource assessment were estimated based on the following guidelines;

- for allocation less than 25%, transmission loss is equal to 30% of remaining high security demand and 50% of low security licence volume.
- for allocation greater than 25%, transmission loss is equal to 30% of remaining high security demand and 30% of low security licence volume.
- operation loss is calculated with a minimum of 10 ML/d for 100 days
- estimated evaporation from Chaffey and Dungowan Dams were taken from the monthly maximum evaporation multiplied by a pan factor of 0.70 and multiplied by the storage surface area.

The town water supply demand is maximum in July and assumed to be decreasing with evaporation pattern. This pattern matches the average monthly diversion pattern. To get the irrigation diversions up to June 2004, the simulated crop areas were forced in the system file.

The figure below shows the observed and simulated storage and the observed and simulated allocation with revised transmission and operation losses. Note that in December 2003, the simulated allocation was slightly lower than observed. This may be due the fixed demand being different in the model when the allocation was calculated.

Figure 3.27: Observed and simulated allocation using 2003/04 resource assessment



In 2002/03, the calculated allocation in resource assessment report was 48% and the announced allocation was 60%. This real time decision making is not simulated in the model. The allocation in IQQM is calculated every 14 days, whereas in reality, the allocation was calculated whenever the real condition dictates as when there are sudden changes in the storage volume.

Table 3.11 Summary of resource assessment

	1993/94 assessment	2000/01 assessment	2003/04 assessment
Water Year	1st July to 30th June	1st July to 30th June	1st July to 30th June
Carry over reserve	12 GL	12 GL	12 GL
Dam Inflows (to end of season)			
July	3800 ML	3800 ML	3700 ML
August	3000 ML	3000 ML	3000 ML
September	2800 ML	2800 ML	2700 ML
October	2500 ML	2500 ML	2300 ML
November	2100 ML	2100 ML	1800 ML
December	1500 ML	1500 ML	1100 ML
January	700 ML	700 ML	1100 ML
February	700 ML	700 ML	400 ML
March	500 ML	500 ML	300 ML
April	500 ML	500 ML	100 ML
May	200 ML	200 ML	0
June	100 ML	100 ML	0
Tributary Inflows (to end of season)			
July	3000 ML	3000 ML	2700 ML
August	3000 ML	3000 ML	2700 ML
September	3000 ML	3000 ML	2700 ML
October	3000 ML	3000 ML	2300 ML
November	3000 ML	3000 ML	1900 ML
December	3000 ML	3000 ML	1300 ML
January	2500 ML	2500 ML	600 ML
February	2500 ML	2500 ML	200 ML
March	1000 ML	1000 ML	100 ML
April	1000 ML	1000 ML	0
May	500 ML	500 ML	0
June	500 ML	500 ML	0
Transmission & operation losses			
July	14400 ML	16600 ML	0% 7900 ML 50% 12000 ML 100% 16600 ML

Table 3.11 continued

August	14100 ML	16300 ML	0% 7700 ML 50% 11800 ML 100% 16300 ML
September	13600 ML	15600 ML	0% 7600 ML 50% 11450 ML 100% 15600 ML
October	12900 ML	14900 ML	0% 7400 ML 50% 10960 ML 100% 14900 ML
November	11800 ML	13700 ML	0% 7200 ML 5% 8300 ML 50% 10270 ML 100% 13700 ML
December	10200 ML	11800 ML	8% 7200 ML 50% 9400 ML 100% 11800 ML
January	8200 ML	9700 ML	20% 7500 ML 50% 8320 ML 100% 11300 ML
February	5700 ML	7000 ML	0% 4000 ML 60% 6500 ML 100% 8000 ML
March	3600 ML	4400 ML	35% 7700 ML 100% 8000 ML
April	2200 ML	2700 ML	0% 1000 ML 100% 7000 ML
May	1300 ML	1600 ML	0% 600 ML 10% 1600 ML
June	500 ML	600 ML	0% 200 ML 100% 600 ML
Development Factor	65%	100%	100%
Irrigation entitlement	30159 ML	30159 ML	31200 ML
HS S&D	163 ML	163 ML	600 ML
HS Tamworth	10000 ML	10000 ML	10000 ML
HS Industry	300 ML	300 ML	0
HS Carrol Gap minimum flow	1500 ML	1500 ML	0

3.10. OVERALL MODEL CALIBRATION

The overall model calibration quality has been assessed using a combination of selected key indicators (see Appendix E). The results of applying this evaluation process from July 1983 to June 2003 are summarised in Table 3.12.

Table 3.12 Overall model quality rating (July 1983 to June 2003)

(Run PeelS06b)

ITEM	Irrigation Diversions		Flow at Paradise W		Flow at Carrol Gap		Chaffey Storage Volume
Apparent error in :	**V Ratio**	**CMAAD**	**V Ratio**	**CMAAD**	**V Ratio**	**CMAAD**	**CMASDD**
Indicator Value I	8	18	2	6	1	10	1
Quality Rating of I (QI)	Moderate	Moderate	Very High	Very High	Very High	Very High	Very High
Lower limit of QI: LL	5	15	0	0	0	0	0
Upper limit of QI : UL	15	20	2	10	2	10	2
Std lower limit of QI: SL	10	10	0	0	0	0	0
Std upper limit QI: SU	15	15	5	5	5	5	5
Standardised indicator: SI	11.5	13	5	3	2.5	5	2.5
Average Std Indicator: AI	6.1		No of Calibration Year: NY			20	
OVERALL QUALITY INDICATOR OI			2.6		**Very High**		

Overall the following comments are made on the model calibration.

<u>Flow replication (Table 3.5)</u> - For each of the three flow reaches calibrated the quality rating ranged from high to very high for the whole flow range. The worst quality rating was in the low flow range when moderate and very low quality was achieved.

<u>Total irrigation diversion replication (Table 3.6)</u> – Over the 20 years of comparison the total simulated diversions exceed total observed diversions by about 9%. Most of the mismatch occurs in the 1991/2 – 1994/5 periods. This is a period leading into drought and what may be a small amount of development in area irrigated. There were also some concerns that the data prior to 1996 may have quality problems and hence the data after 1996 was focused on for model calibration. The simulated and observed diversions from 1996 onwards match very well.

<u>Tamworth diversion replication (Table 3.7)</u> – The simulated and observed Tamworth diversions match very well with about a 4% error. There are problems with the mixture of diversions from Dungowan and Chaffey Dams.

<u>Chaffey Dam storage behaviour replication (Table 3.8)</u> – The simulation of Chaffey Dam storage behaviour has a very high quality rating.

<u>Dungowan Dam storage behaviour replication (Table 3.8)</u> – The simulation of Dungowan Dam storage behaviour has a very low quality rating. There is only 3 years of data and the main problem lies in the estimation of dam inflows. This is an area of the model that could be improved if extra data becomes available.

The overall quality rating for the calibration outlined in Table 3.12 is very high.

4. 1993/94 Development Conditions (Cap) Scenario

The Peel River valley is part of the Namoi River valley, a designated river valley under Schedule F of the Murray-Darling Basin Agreement [MDBMC, 2000], and is consequently required to be managed with the Namoi system to ensure that diversions do not exceed those expected under 1993/94 levels of irrigation infrastructure and management rules, ie, the stipulated MDBMC Cap. The DNR Peel IQQM will be used to estimate this diversion limit and therefore provide an assessment 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 Peel Valley. This chapter outlines how the IQQM has been further developed to perform a simulation of the valley with 1993/94 levels of development and long term climatic conditions (ie the *Cap scenario)*. This chapter also outlines how the Cap scenario has been used for short term Cap auditing, ie the *Cap audit scenario*.

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

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

4.1. CAP IN BRIEF

The Peel River IQQM has been used to simulate Cap conditions for a 113 year period from 1892 to 2005. It has also been used to simulate the Cap conditions for the 1997/98 to 2004/2005 water years for Schedule F accounting requirements. The following assumptions were used to represent Cap conditions:

- Operation of Chaffey and Dungowan Dams as per 1993/94 conditions;
- Pump capacity as installed in the 1993/94 irrigation season;
- The average mix of crop types as observed from July 1993 to June 2003 (the availability of better data after 1996/97 and the small amount of change in the valley prompted the largest amount of data to be used);
- Planted areas based on correlation with Tamworth 15 month rainfall from April in the previous water year to June in the current water year;
- The historical level of demand for Tamworth town at 1993/94 with a set of Tamworth Council operational rules that share the water in Dungowan and Chaffey Dam;
- Management rules for river flows and water users that were applicable for the 1993/94 irrigation season.

4.2. CLIMATIC DATA

4.2.1. Rainfall

For the long term simulations, the observed rainfall data was gap-filled and extended back from 1981 to 1892 via correlation with nearby rainfall stations (see Table A.1). SILO observed and interpolated rainfall data were used from 1982 to 2004.

4.2.2. Evaporation

For the long term simulations, the evaporation data is generated based on a relationship between monthly evaporation totals and number of rain days in the month. The observed evaporation at Tamworth was used to generate long term evaporation at Tamworth and at all the other sites (see Table A.2).

4.3. FLOW DATA

4.3.1. Streamflows

The observed data for the tributary gauging stations selected for use in the model (Table A.5) were collated, gap-filled and extended using Sacramento rainfall-runoff models such that they covered the intended simulation period.

The ungauged catchment contributions were then derived based on applying the methodology outlined in Table A.6 to the long-term gauged tributary inflows.

4.3.2. Inflows into the dams

Inflows to Chaffey Dam from 1979 to date were derived from back calculation of storage details. To derive the long-term inflows to Chaffey Dam prior to the back-calculated dam inflows (the storage was constructed in 1979) a Sacramento model was set up and calibrated for the stream gauge at 419004 (Peel River @ Bowling Alley Point). To allow for the small distance and catchment between gauging station 419004 and the dam only the daily flow were routed. The Sacramento model was used to estimate the storage inflows from 1892 to 1979.

Inflow to Dungowan Dam was generated by developing a Sacramento model of the catchment above gauging station 419077. These results were also multiplied by the proportion of the Dungowan Dam catchment not covered by the station (times 1.3) to allow for runoff from the catchment area of Dungowan Dam downstream of the gauge.

4.4. IRRIGATION INFORMATION

Parameters such as crop irrigation efficiencies and tributary utilisation factors have been determined during calibration and validation periods (1982 – 2003). A full listing of parameters describing the Peel IQQM Cap scenario is included in Appendix F.

The 1993/94 Cap scenario described in this report only relates to the regulated system at present. It is intended that, if sufficient information should become available, the model would be expanded to represent unregulated licences explicitly. The general security entitlement used was as per recorded data of the 1993/94-irrigation season. The pump capacity was as per the departmental record of 1993/94. However due to the absence of any on farm storage and relatively small irrigated area compared to entitlement, the pump capacity has little influence on diversion. Table 4.1 shows the irrigation development in the 1993/94 irrigation season with the average irrigated area distribution. The distribution of the area irrigated was based on the average of the observed area irrigated from 1993 to 2003.

Table 4.1: Irrigation Related Input for 1993/94 condition

Location	Entitlement (ML)	Pump Size (ML/d)	Area irrigated distribution (%)
Keepit to Piallamore	6204	74	25
Piallamore to Paradise Weir	3405	55	14
Paradise Weir to Attunga	8890	100	28
Attunga to Carroll Gap	10301	75	30
Carroll Gap to Namoi Junction	1400	25	3
TOTAL	30200	329	100

The total entitlement was taken from the recorded 'Peel River Allocation Assessment for 1993/94' on July 29, 1993. The development factor used in the allocation assessment was 65%. Parameters such as crop irrigation efficiencies and tributary utilisation factors have been determined during calibration and validation periods. A full listing of parameters describing the Peel IQQM Cap scenario is included in Appendix F.

4.4.1. Crop areas (area irrigated determination)

As noted previously, an examination of historical planted areas suggested that the area planting decision taken by irrigators was not based on a traditional planting of crops based on water resource availability. Instead an "area irrigated" decision, based on Tamworth rainfall provided the best reproduction of observed crop areas (see Section 3.7). The irrigated total area varies from 725 to 3472 hectares with the highest irrigated crop area during lowest rainfall season.

4.5. CROP MIX

The crop type distribution shown in Appendix D indicates a relatively stable crop mix from 1993/94 to 2003. The model simulates crop water demand, which in turns triggers diversion. From a modelling perspective two crops are of different type if their water demand, based on evapotranspiration, is significantly different. The average crop mix observed from 1993 to 2003 was used for Cap conditions and is shown in Table 4.2.

Table 4.2: Crop Type Distribution (%)

Crop Name	Upstream of Piallamore	Piallamore to Paradise Weir	Paradise Weir to Attunga	Attunga to Carrol Gap	Attunga to Namoi Junction
Lucerne	78	58	51	60	46
Summer Pasture	5	14	24	21	18
Winter Pasture	1	6	4	5	2
Summer Cereals		2	2		
Winter Cereals	12	9	17	12	31
Wheat	3	2	2	2	3
Vegetables	1	9			
Total	*100*	*100*	*100*	*100*	*100*

4.5.1. High security irrigation

Other than Tamworth's town water supply entitlements, there is less than 1 GL of high security entitlement within the valley and therefore high security irrigators are not modelled explicitly within the Peel IQQM.

4.5.2. Unregulated use

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

It is important to note, however, that the tributary inflows used in the Peel IQQM have been estimated 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 Peel 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.

4.6. TOWN WATER SUPPLY

Town water supply is modelled in Peel IQQM with the high security entitlement considered during resource assessment and a use is included in the model to represent 1993/94 development. The high security Tamworth town water supply entitlement of 10,000 ML was used for the Cap run as this was the practice used in 1993/94. Note that Tamworth had an entitlement of 16,400 ML but this was not used in resource assessment in 1993/94. The Tamworth demand algorithm was set at 1993/94 diversion levels (8,314 ML) by setting the appropriate population level (33,700) as an input factor.

4.7. STOCK AND DOMESTIC

Based on DNR Regional estimates, an overall average demand per annum for licensed stock & domestic users (for 1992-95 period) was established for each of the five reaches with an identified demand. Monthly use patterns were adopted to match nearby TWS patterns, with those adopted listed Table C.2**.** The average annual diversion is 243 ML/year.

4.8. INDUSTRIAL AND MINING EXTRACTIONS

As these amounts are negligible relative to irrigation amounts, they have not been represented explicitly in IQQM. In 1994 the entitlement was around 300 ML and the use was around 50 ML.

4.9. GROUNDWATER ACCESS

No conjunctive use groundwater licences exist in the regulated Peel River and therefore in the IQQM calibration process no allowance was made for conjunctive groundwater and surface water usage. Also there is no information regarding concurrent use of separate regulated surface water and groundwater licences for irrigating areas. Therefore the model assumes no groundwater contribution towards simulated crop areas.

4.10. RESOURCE ASSESSMENT

Section 3.9.1 discusses the various resource assessment methods historically used in the Peel Valley. The main features of the resource assessment system that were in place for the 1993/94 season are listed below:

- Chaffey Dam operation.
- Annual accounting
- Maximum allocation of 100%
- No carryover of unused allocation
- No borrow from the following year's allocation;
- 12 GL carry over reserve
- minimum headwater and tributary inflows
- transmission and operation losses
- development factor of 0.65
- A volume of 10 GL set aside for Tamworth supply.

A full listing of parameters used can be found in Table 3.7 and Appendix F. The total entitlement was taken from the recorded 'Peel River Allocation Assessment for 1993/94' on July 29, 1993. The development factor used in the allocation assessment was 65%. As discussed in Section 3.9 there have been changes to the resource assessment rules used between 1993/94 and 2003/04. The resource assessment parameters that operated in 1993/94 were used in the modelling of 1993/94 development.

4.11. RIVER AND STORAGE OPERATION RULES

4.11.1. Tributary utilisation

Appropriate tributary utilisation factors were determined during the calibration and validation period (1982 – 2003). The adopted factors for the Cap scenario are listed in Table C.5.

4.11.2. Operational surplus

For the Peel IQQM, the fixed over-order factor of 1.0 to 1.1 produced the best calibration of storage behaviour over the calibration period. These factors were adopted for the Cap scenario.

4.11.3. Off allocation thresholds

The off allocation threshold described in Table 3.7 were adopted for the Cap scenario.

4.12. RIVER FLOW REQUIREMENTS

4.12.1. Minimum flows

Table 4.3 shows the adopted minimum flow requirements at various locations for the Cap scenario.

Table 4.3: Minimum flow requirements

Location	Minimum flows
Chaffey Release*	10 ML/d if Storage greater than 30GL
Dungowan Release	Transparent up to 8.5 ML/d
Carroll Gap	5 ML/d

*as calibrated, not DNR rule

4.12.2. Replenishments

No replenishment diversion exists in the Peel system.

4.12.3. Wetlands

No wetland diversion exists in the Peel system.

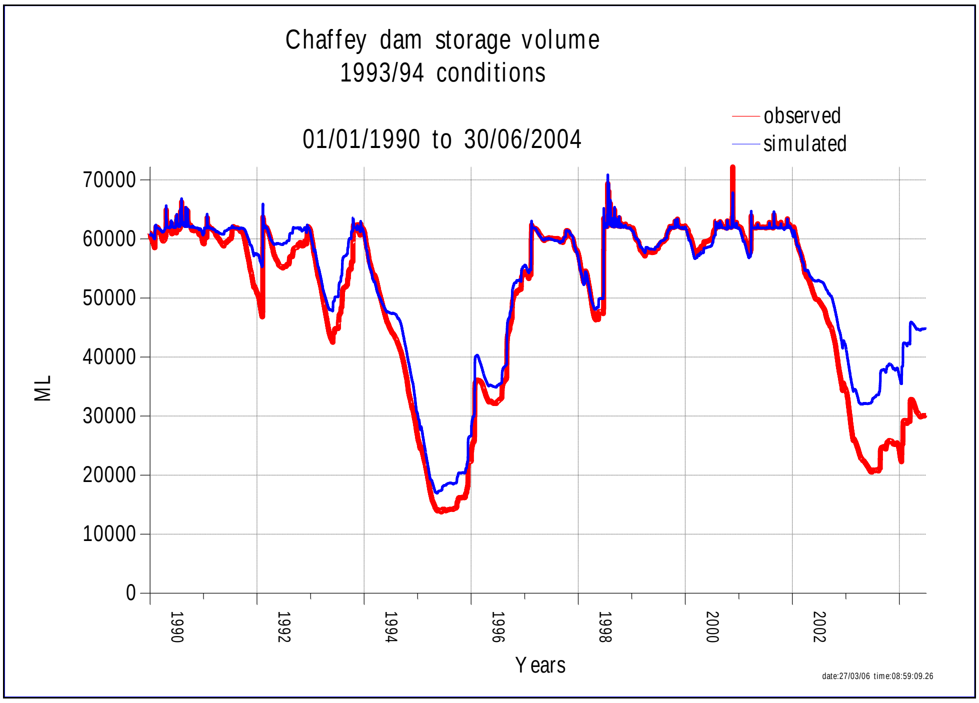
4.13. COMPARISON WITH 1990 TO 2004 PERIOD

To assess the robustness of the Cap scenario with varying climate seasons, a simulation was performed from 1990 to 2004. This period, including more recent years, was chosen because information suggests that Peel Valley development has not really changed from 1993/94 through to present. The one area that has shown changed development is diversions by Tamworth City Council and this change is shown in the following results. The observed and simulated results were compared to observed Chaffey Dam storage, planted areas, irrigation diversions, Tamworth diversions and end-of-system flows. The system file for this run is *PeelC65m90.sqq*. Chaffey Dam storage volume was initialised for conditions at the start of the 1990.

4.13.1. Modelled and observed Chaffey Dam storage

Figure 4.1 below shows the simulated storage behaviour with 1993/94 cap conditions. The simulated Chaffey Dam storage behaviour matches closely the observed storage behaviour up until the year 2002. The reason for the difference relates to two matters. The model is simulating 1993/94 Tamworth demand of 8.3 GL compared to the actual demand Tamworth demand between 9.5 GL and 10.0 GL. Also examination of the observed data shows most of Tamworth's demand was actually met from Chaffey Dam where as the rules in the model state that most of the demand should have been satisfied from Dungowan Dam..

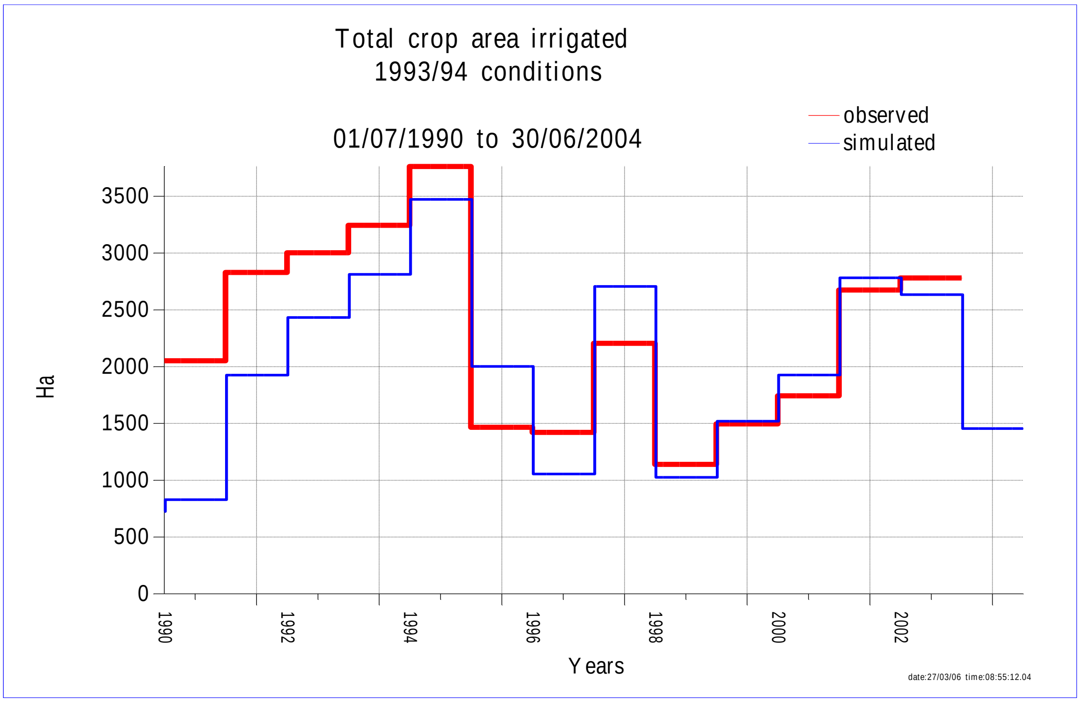
Figure 4.1. Observed and simulated Chaffey Dam storage under 1993/94 conditions



4.13.2. Modelled and observed areas

The observed and simulated areas irrigated are shown in Figure 4.2. The simulated area irrigated is lower than observed up to 1994 and matches observed area after 1994 very well. As discussed earlier in the report the area irrigated is a function of rainfall at Tamworth and was calibrated over the 1993 to 2003 period.

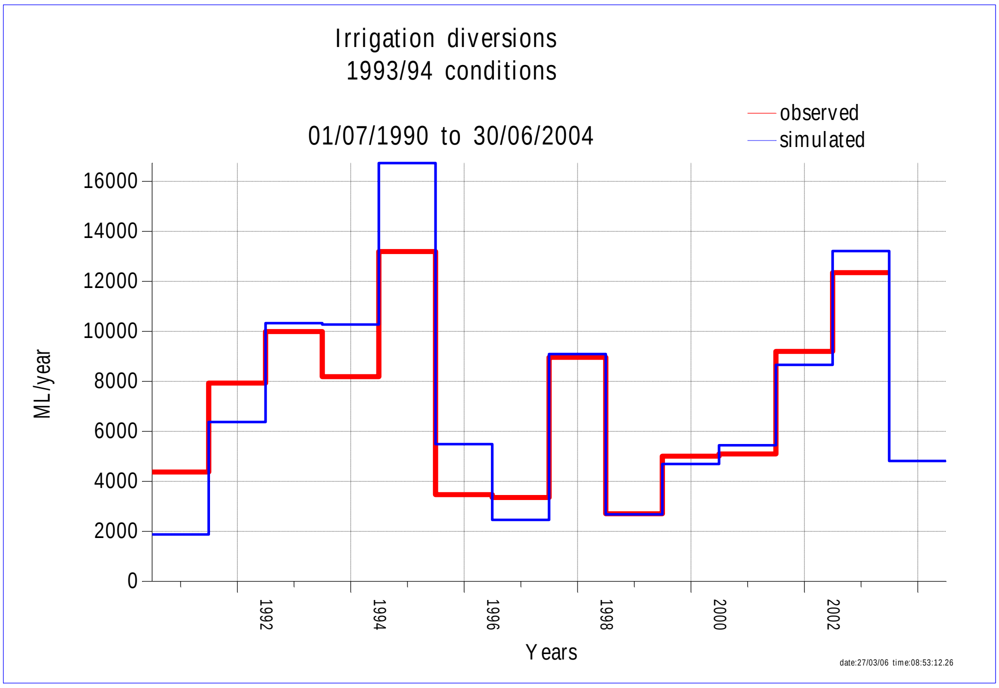
Figure 4.2 Observed and simulated area irrigated



4.13.3. Modelled and observed irrigation diversions

The observed and simulated irrigation diversions are shown in Figure 4.3. The volume ratio for the 1990-2004 period is 100%. The simulated diversion (10.3 GL) is higher than observed (8.2 GL) in 1993/94. Overall the simulated volume of diversion matches observed diversions very well..

Figure 4.3 Observed and simulated irrigation diversions

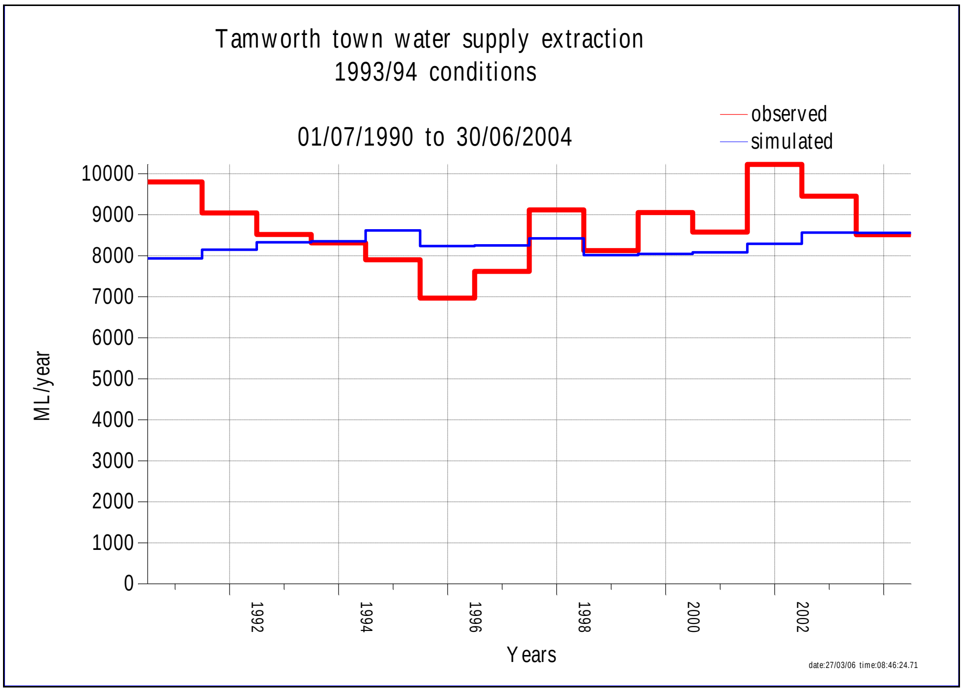


4.13.4. Modelled and observed town water supply diversions

The diversions from Dungowan Dam for Tamworth water supply are not included in the current Diversion Definition Register, as they have traditionally been managed outside of the main regulated system. However, it is now proposed that these diversions be included in the Register, as both the observed diversions and modelled Cap targets are now available. All subsequent discussion of Tamworth diversions in this chapter refer to the total Tamworth diversions from both Dungowan Dam and the Peel River, unless otherwise specified.

The observed and simulated annual town water supply at Tamworth is similar at 8.3 GL in 1993/94 as shown in Figure 4.4. The average observed town water supply diversion for the 1983-2004 period is 8.6 GL/year. The simulated Tamworth diversions are generally less than the observed diversions after 1999.

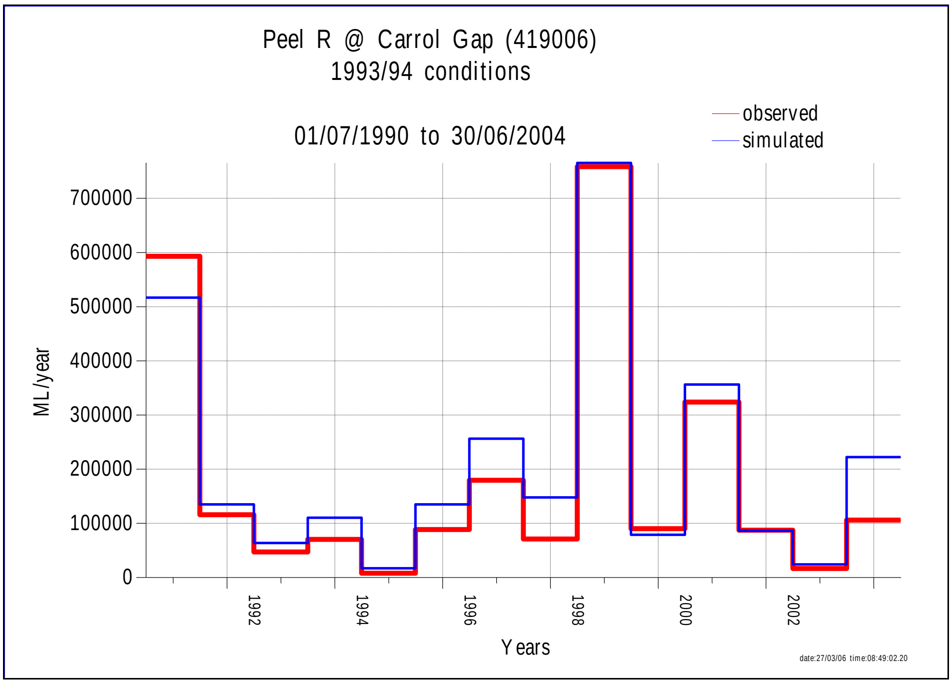
Figure 4.4 Observed and simulated town water supply diversions



4.13.5. Modelled and observed flows at Carrol Gap

The observed and simulated annual flows at Peel River at Carrol Gap (419006) are shown in Figure 4.5. The volume ratio for the 1983-2004 period simulated verses observed annual flow is 107%. The simulated flow in 1993/94 is higher than observed which may be due to underestimating losses in this period. The high flow in 1998/99 matches well with the observed but lower than observed in 1990/91. The low flows in 1994/95 and 2002/03 matches well with observed. The simulated flow in the water year 2000/01 is higher than observed.

Figure 4.5 Observed and simulated flows at Carrol Gap



4.14. 1993/94 CAP MODEL RESULTS

4.14.1. Long term Cap annual diversions

Table 4.4 summarises the model results for the 1993/94 development condition Cap model over the long term of 1892/93 to 2003/04 for a period of 112 years. The Peel IQQM system file for this run is *PeelC65K.sqq*. The starting volumes in Chaffey & Dungowan Dams were set at 50%, given the dams filled within 2 months; no sensitivity testing of starting conditions was undertaken.

Table 4.4: Summary of the 1993/94 development condition simulation run

Summary Aspect	***Sub-aspect***	***Average***	***Maximum***
Water usage	Tamworth town water supply (GL) (Dungowan diversions)	8.4 (6.8)	9.5 (7.6)
	Irrigation Diversion (GL)	6.7	17.6
	Stock and Domestic (GL)	0.24	0.24
	Total (GL)	15.3	
Crop Area	Area irrigated (ha) every August 1	1700	3472
River flows	Peel River at Carrol Gap (GL)	265.7	1237.0

Peel Reliability on 01/07	100%	75%	50%	5%
(% of years that achieved ≥ stated % allocation)	71	80	84	93
Peel Reliability on 01/01	100%	75%	50%	5%
(% of years that achieved ≥ stated % allocation)	87	92	94	97

4.14.2. 1993/94 Cap audit (Schedule F accounting simulation)

To assess Cap performance in each valley designated in Schedule F of the Murray-Darling Basin Agreement (MDBMC, 2000), annual Cap simulations using the relevant IQQM are performed. In the Peel Valley, the Cap simulation 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, IQQM is started several weeks before the commencement of the 1997/98 water year, to allow for the river system to fill with water and to provide a better starting soil moisture store. 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.

The annual Cap simulation results for the 1997/98 to 2002/2003 irrigation seasons are presented in Table 4.5, with a comparison to the observed data. The Peel IQQM system files used for this analysis was *PeelC97a.sqq*.

Table 4.5: Peel Valley preliminary Schedule F account

	Modelled				Observed				Difference
	Irrigation	TWS (Peel)	TWS (Dungowan)	Total	Irrigation	TWS (Peel)	TWS (Dungowan)	Total	
1997/98	10.6	1.2	7.2	19.0	9.1	7.0	2.1	18.1	0.9
1998/99	2.7	0.6	7.4	10.7	2.8	2.7	5.4	11.0	-0.4
2000/01	4.7	0.7	7.3	12.7	5.0	2.3	6.8	14.1	-1.4
2000/01	5.4	0.8	7.3	13.5	3.3	6.9	1.7	11.9	1.6
2001/02	8.7	0.9	7.4	17.0	9.2	5.6	4.7	19.4	-2.4
2002/03	13.2	2.9	5.7	21.8	12.6	9.2	0.3	22.1	-0.3
2003/04	4.9	1.1	7.5	13.5	5.1	8.2	0.3	13.6	-0.1
2004/05	6.1	1.2	7.5	14.8	10.7	4.5	5.0	20.2	-5.4
Cumulative total	56	9	57	123	58	46	26	130	-7
Long-term average Cap estimate:	6.7		8.4	15.1					
20% of Long-term average Cap estimate:				3.0					

These results show for the Peel Valley that cumulative difference between simulated and observed diversions is more than 20% of the long term average diversion under 1993/94 conditions. However as the Peel Valley is part of the total Namoi Valley then Cap is assessed for the whole valley. Table 4.6 shows the Namoi Valley Cap assessment.

Table 4.6 Namoi Valley Schedule F Cap assessment

	Modelled				Observed				Difference
	Irrigation On allocation	Irrigation Off allocation	Flood Plain Harvesting)	Total (No FPH)	Irrigation On allocation	Irrigation Off allocation	Flood Plain Harvesting)	Total (No FPH)	
1997/98	166	73	40	239	152	57	n/a	209	30
1998/99	180	52	12	232	194	39	n/a	233	-2
2000/01	208	49	0	257	229	26	n/a	258	-1
2000/01	185	65	16	250	210	48	n/a	265	-15
2001/02	231	11	0	242	263	1	n/a	266	-25
2002/03	169	6	0	175	194	0	n/a	194	-19
2003/04	38	79	2	117	30	42	n/a	82	35
2004/05	142	23	26	165	64	33	n/a	97	68
Cumulative total	1316	358	96	1674	1335	245	n/a	1603	70
Long-term average Cap estimate:				251					
20% of Long-term average Cap estimate:				50					

When the two valleys are combined the cumulative difference between simulated and observed diversions are less than 20% of the long term average diversions under 1993/84 development and under Schedule F these would note be a triggering of Cap exceedence

5. Improvement Plans

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 operational 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 simulation, the Commission will be informed of the changes to the results, and the reason why the changes occurred.

5.1. UPGRADES TO THE FLOW CALIBRATION

5.1.1. Extended streamflow records

Since the outset of implementing the Peel 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.

5.1.2. 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.

5.1.3. 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 re-derive the estimated contribution from their associated residual catchments.

5.1.4. Antecedent conditions based losses

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

5.1.5. 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 loss processes in a river reach. Inclusion of this feature will require refining of the flow calibration.

5.2. UPGRADES TO THE DEMAND AND AREA CALIBRATION

5.2.1. 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 DLWC 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 re-calibration of the IQQM in the future. It is envisaged that this upgrading process would occur on approximately a five (5) year cycle.

5.2.2. 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 determines 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.

5.2.3. 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.

5.2.4. 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.

5.2.5. 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.

5.2.6. On-farm storage operation

On farm storage operation is not significant in the Peel Valley at present. However in the future if on farm storage operation becomes significant and data becomes available they may be explicitly modelled to represent on farm activities such as increased access to off allocation flows, rainfall harvesting and reuse of irrigation tailwater.

5.3. UPGRADES TO THE STORAGE BEHAVIOUR MODELLING

5.3.1. Dungowan dam inflows

Dungowan Dam inflow is now based on Sacramento rainfall runoff model. The lack of a good continuous period of storage level and outflow restricted any more accurate inflow estimation. The more accurate inflow and hence the storage characteristic will be modelled when a good set of records will be available.

5.3.2. 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.

5.3.3. 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.

5.4. UPGRADES TO SUPPLEMENTARY WATER MODELLING

5.4.1. Improved off-allocation modelling

At present, off-allocation is modelled in each reach based on a single threshold per month that is applied for similar months every year. In reality, announcing off-allocation is a much more complex and variable process.

5.5. GENERAL UPGRADES

5.5.1. 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.

5.5.2. 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.

5.5.3. Tamworth town water supply from Dungowan Dam and Chaffey Dam

The town water supply demand was modelled to be satisfied by Dungowan Dam with Chaffey Dam supplementing shortfalls. However, there are several occasions when the water quality of Dungowan Dam was not acceptable to be used for town water supply, resulting to more observed diversions from the Peel River (Chaffey Dam) than simulated. To simulate the daily diversions from the Peel River, information on Dungowan Dam storage, inflows and releases to Dungowan Creek must be available. Decision rules on which storage to supply the town water supply demand which may be dependent on the water quality in Dungowan Dam may be included in future town water supply modelling.

References

R Anderson and J Doyle, August 1997

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998, *Crop Evapotranspiration; Guidelines for computing crop water requirements,* FAO Irrigation and Drainage Paper No. 56, Food and Agriculture Organisation of the United Nations, Rome, Italy.

Aitken, A.P. 1973, *Assessing systematic errors in rainfall-runoff models,* Journal of Hydrology. 20 (1973), pp. 121-136.

Burnash, R.J.C. et al. 1973, *A generalised streamflow simulation system: conceptual modelling for digital computers.* Joint Federal-State River Forecast Centre, US National Weather Service and California Dept. of Water Resources, Sacramento, California.

DLWC 1998[a], *IQQM User Manual,* Report No. TS 96.079, NSW Department of Sustainable Natural Resources.

DLWC 1998[b], *IQQM Reference Manual,* Report No. TS 94.048, NSW Department of Sustainable Natural Resources.

DLWC 1998, *Hydrology Unit Technical Practice Notes*, NSW Department of Sustainable Natural Resources.

- DLWC 1998[c], *Overview of IQQM Implementation Procedure*, implmnt2.doc.
- DLWC 1998[d], *Assessing the Quality of an IQQM Calibration*, assess.doc.
- DLWC 1998[e], *Derivation of Loss Nodes in IQQM*, rot4loss.doc.
- DLWC 1998[f], *The Gap Filling Module in IQQM*, gapfill.doc.
- DLWC 1998[g], *The Back-Calc Dam Inflows Module in IQQM*, backcalc.doc.
- DLWC 1998[h], *Estimating Residual Catchment Contributions*, residual.doc.
- DLWC 1998[i], *Calibrating and Using the Sacramento Model*, sacrment.doc.
- DLWC 1998[j], *Disaggregating Diversions Using Unaccounted Differences*, cardpac.doc.
- DLWC 1998[k], *Estimating Routing Parameters in IQQM*, routing.doc.
- DLWC 1998[l], *Description of the Daily Climate Model in IQQM*, climrep.doc.

DLWC 1999, Assessing the quality of an IQQM calibration, a series of 9 documents, Qualnof9.doc

- DLWC 1999[a], *Definition of general principles used*, qual1of9.doc
- DLWC 1999[b], *IQQM individual reach & Sacramento flow calibration*, qual2of9.doc

- DLWC 1999[c], *Assembled reach flow validation*, qual3of9.doc
- DLWC 1999[d], *Storage behaviour calibration*, qual4of9.doc
- DLWC 1999[e], *ONA diversion calibration*, qual5of9.doc
- DLWC 1999[f], *Planted crop area calibration*, qual6of9.doc
- DLWC 1999[g], *OFA extraction calibration*, qual7of9.doc
- DLWC 1999[h], *Assessment of practical model quality*, qual8of9.doc
- DLWC 1999[i], *Assessment of model validation quality*, qual9of9.doc

Doorenbos J., and W.O. Pruitt 1984, *Guidelines for predicting crop water requirements,* FAO Irrigation and Drainage report No. 24, Food and Agriculture Organisation of the United Nations, Rome, Italy.

Allen, R. G. et al., 2000, Crop evapotranspiration. Guidelines for computing crop water requirement, FAO Irrigation and Drainage report No. 56, Food and Agriculture Organisation of the United Nations, Rome, Italy.

Lyall and Macoun Consulting Engineers 1986, *Lachlan Valley computer model, WARAS programmers manual,* version 1.0 – December 1986, done for the NSW Water Resources Commission (WRC)

Murray-Darling Basin Ministerial Council 1996, *Setting the Cap*, ISBN 1 875209 96 4, prepared by the Independent Audit Group.

Murray-Darling Basin Ministerial Council 2000, *Review of the Operation of the Cap; Overview Report of the Murray-Darling Basin Commission, Appendix E.* ISBN 1 876830 05 0, prepared by the Independent Audit Group.

Murray-Darling Basin Commission 1998, *Schedule F agreement.*

Appendix A. Climatic and Stream flow Stations

Table A.1: Rainfall Stations Used for the Peel Valley IQQM

Primary Rainfall Station		Period of Record	Rainfall stations used for gap-filling		Correlation between Primary Station and Gap-filling Station		Where Rainfall Data Used
Name	**No.**		**Name**	**No.**	**Volume Ratio**	**r^2 of wettest month**	
Somerton (Bective Estate)	055003	1882 to 2004	Tamworth (Airport)	055054	0.917	0.793 (Jan)	IQQM simulation modelling: Peel River between confluence with Attunga Creek and confluence at Namoi River. (Reach 5) Demand calibration from Carrol Gap to Namoi River Sacramento model to generate residual inflow upstream Carrol Gap
			Somerton (Post Office)	055050	1.029	0.782 (Jan)	
			Somerton (Clermont Park)	055118	1.057	0.708 (Jan)	
			Somerton (Girraween)	055011	0.997	0.753 (Jan)	
			Tamworth West	055222	0.973	0.812 (Jan)	
Nundle (Post Office)	055041	1890 to 2004	Nundle (Benoni)	055078	1.268	0.893 (Jan)	Sacramento modelling for: (a) Duncans Creek at Woolomin (GS 419036). (b) Peel River at Chaffey Dam (GS 419045). (c) Cockburn River at Mulla Crossing (GS 419016). (d) Peel River at Bowling Alley Pt (GS 419004). (e) Dungowan Creek u/s Dungowan Dam (GS 419077) ie inflow to Dungowan Dam Back calculation to estimate inflows into Chaffey Dam.
			Woolomin (Cullwulla)	055189	1.204	0.773 (Jan)	
			Bowling Alley Point	055298	1.226	0.934 (Jul)	
			Chaffey Dam	055302	1.383	—	
			Nundle (Keeva)	055245	1.232	—	

Table A.1: Rainfall Stations Used for the Peel Valley IQQM

Primary Rainfall Station		Period of Record	Rainfall stations used for gap-filling		Correlation between Primary Station and Gap-filling Station		Where Rainfall Data Used
Name	No.		Name	No.	Volume Ratio	r^2 of wettest month	
Tamworth (Airport)	055054	1876 to 2004	Tamworth West	055222	1.058	0.733 (Dec)	IQQM simulation modelling: Peel River between Dungowan Confluence to Paradise Weir (Part Reach 1 & Reach 2) Demand calibration from Paradise Weir to Carrol Gap Sacramento model for residual upstream Carrol Gap
			Tamworth (Inverness)	055279	0.991	0.931 (Jan)	
			Warral (Hillsia)	055158	1.000	0.866 (Jan)	
			Somerton (Glen Burn)	055140	1.029	0.692 (Jan)	
			Tamworth (Oxley Lane) 1993 to 2004	055327	--	--	
Goonoo Goonoo Station	055067	1873 to 2004	Quirindi (Post Office)	055049	0.971	0.697 (Jan)	IQQM simulation modelling: Peel River between Paradise Weir to Attunga (Reach 3) Sacramento modelling to generate runoff: Goonoo Goonoo Creek at Timbumburi (GS. 419035). Sacramento model for residual upstream Carrol Gap
			Werris Creek PO	055062	0.932	0.667 (Jan)	
			Pine Ridge	055037	1.154	0.664 (Jan)	
			Manilla PO	055031	0.968	0.678 (Jan)	
			Tamworth (Airport)	055054	1.005	0.749 (Jan)	
Uralla (Salisbury Court)	056028	1865 to 2004	Uralla Post Office	056034	0.890	0.799 (Jan)	Sacramento modelling to generate runoff: Cockburn River at Mulla Crossing (GS 419016).
			Uralla (Mihi)	056065	1.019	0.786 (Jan)	
			Walcha Post Office	056035	0.881	0.662 (Jan)	
			Armidale Radio St 2AD	056002	0.996	0.663 (Jan)	
			Uralla	056063	0.940	0.920 (Jan)	

Table A.1: Rainfall Stations Used for the Peel Valley IQQM

Primary Rainfall Station		Period of Record	Rainfall stations used for gap-filling		Correlation between Primary Station and Gap-filling Station		Where Rainfall Data Used
Name	**No.**		**Name**	**No.**	**Volume Ratio**	**r^2 of wettest month**	
Dungowan	055171	1890 to 2004	Data extracted from SILO database				IQQM simulation from Chaffey Dam to Paradise Weir (Reach 1 and 2). Demand calibration upstream Paradise Weir

Table A.2: Evaporation Stations Used for the Peel Valley IQQM

Evaporation Station			Source Stations Used to Generate-Evaporation at Primary Station			Ratio of Long Term Evaporation Volume Between Source to Primary Location				Where Primary Evaporation Used
Name	No.	Period	Name	No.	Period	Month	Ratio	Month	Ratio	
Tamworth Airport	055054	1973 to 1993	Observed data extended from 1892 to 2004 using IQQM evaporation generation technique							Demand calibration from Paradise Weir to Carrol Gap; Sacramento model for residual upstream Carrol Gap,Goonoo Goonoo Ck, Cockburn River
Nundle (Post Office)	055041	1800 to 2000	Tamworth (Airport)	055054	1876 to 1993	Jan Feb Mar Apr May Jun	0.88 0.87 0.86 0.88 0.89 0.87	Jul Aug Sep Oct Nov Dec	0.90 0.90 0.91 0.90 0.89 0.88	Dungowan Creek, Peel River from Chaffey to Dungowan Creek junction. Sacramento modelling to generate inflow from Duncans Creek (419036) Chaffey Dam evaporation
Dungowan	055171	1800 to 2000	Tamworth (Airport)	055054	1876 to 1993	Jan Feb Mar Apr May Jun	0.97 0.96 0.96 0.96 0.97 0.96	Jul Aug Sep Oct Nov Dec	0.97 0.98 0.98 0.97 0.97 0.96	Demand calibration upstream Paradise Weir

Table A.2: Evaporation Stations Used for the Peel Valley IQQM

Evaporation Station			Source Stations Used to Generate-Evaporation at Primary Station			Ratio of Long Term Evaporation Volume Between Source to Primary Location				Where Primary Evaporation Used
Name	**No.**	**Period**	**Name**	**No.**	**Period**	**Month**	**Ratio**	**Month**	**Ratio**	
Somerton (Bective)	055003	1800 to 2000	Tamworth (Airport)	055054	1876 to 1993	Jan	1.03	Jul	1.02	Demand calibration from Carrol Gap to Namoi River.
						Feb	1.03	Aug	1.02	
						Mar	1.04	Sep	1.03	
						Apr	1.04	Oct	1.03	
						May	1.03	Nov	1.03	
						Jun	1.02	Dec	1.03	

Table A.3: Temperature Record at Tamworth Airport (055054)

Maximum Temperature	
1892 to 1959	Generated data
1959 to 1992	Mostly recorded
1993 to 2004	Gap filled by neighbouring station details downloaded from SILO database
Minimum Temperature	
1892 to 1959	Generated data
1957 to 1992	Mostly recorded. Few gaps are filled as shown below
1992 to 2004	Gap filled and or extended by: Tamworth AWS (055325) : 1992 to 1999; Quirindi (055049): 1882 to 1999 and Gunnedah SCS (055024): 1965 to 1999

Table A.4: Availability of Observed Stream Flow

Station number	Station name	Catchment Area (Sq Km)	Lat (S)	Long (E)	Period collected *as of June 2004*	Number of data days
419004	Peel River at Bowling Alley	310	31.3978	151.1431	01/1915-10/1970	20362
419006	Peel River at Carrol Gap	4670	30.9400	150.5260	02/1973-06/2004	11376
419009	Peel River at Tamworth	3080	31.092	150.9250	071993-06/2004	3866
419015	Peel River at Piallamore	1140	31.1830	151.0650	11/1936-0620/04	24304
419016	Cockburn River at Mulla Crossing	907	31.0630	151.1250	12/1936-06/2004	23751
419024	Peel River at Paradise Weir	2410	31.1020	150.9380	01/1974-06/2004	11027
419035	Goonoo Goonoo Creek	459	31.2720	150.9150	12/1969-06/2004	11678
419036	Duncans Creek at Woolomin	93	31.3211	151.1567	06/1965-12/1986	7588
419045	Peel River at D/S Chaffey Dam	407	31.3430	151.1420	12/1968-06/2004	12853
419073	Peel R at Appleby Crossing	3190	30.9667	150.8500	10/1996-03/2004	2708
419074	Peel R at Bective	3700	30.9683	150.7317	10/1996-06/2004	2800
419075	Peel River at Somerton	4160	30.9400	150.6467	10/1996-03/2004	2708
419097	Goonoo Ck at Meadows Lane	600	31.1814	150.9236	08/2002-03/2004	602

Table A.5 Gauged catchment inflows for the Peel Valley IQQM (gap filled and extended by Sacramento Model)

Station Name	Station No	Rainfall	Evaporation	Sacramento Model Calibration Period
Peel River at Bowling Alley Point	419004	Nundle PO (055041)	Nundle PO (055041)	28.4.1915 to 30.9.1970
Dungowan Creek	419077	Nundle PO (055041)	Tamworth Air (055054)	1.12.1974 to 1.12.1993
Duncans Creek @ Woolomin	419036	Nundle PO (055041)	Nundle PO (055041)	17.6.1965 to 30.11.1986
Cockburn River @ Mulla Crossing	419016	Nundle PO (055041) Uralla (056028)	Tamworth Air (055054)	1.1.1937 to 30.6.1997
Goono Goono Creek @ Timbumburi	419035	Nundle PO (055041) Goono Goono (055067)	Tamworth Air (055054)	17.12.1969 to 31.12.1997

Table A.6: Ungauged catchment inflows for the Peel Valley IQQM

Location	Reference Gauge Name	Gauge No	Relationship
Chaffey Inflow	Peel River at Bowling Alley Point	419004	Chaffey Dam inflows estimated by back calculation between 1979 and present. Prior to the dam construction the gauged flows at 419004 were gap filled and extended by Sacramento modelling. Observed and estimated flows at 419004 were routed downstream to 419045 based on observed data.
Dungowan Inflow	Dungowan Creek	419077	Observed flow at 419077 gap filled and extended by Sacramento modelling. Flows scaled by 1.3 to allow for catchment area between gauge and dam
Upstream of Piallamore	Cockburn River @ Mulla Crossing Goono Goono Creek @ Timbumburi	419016 419035	Inflows were derived during flow calibration as 57% of 419016 plus 17% of 419035
Piallamore to Paradise Weir	Cockburn River @ Mulla Crossing	419016	Inflows were derived during flow calibration as 40% of 419016
Paradise Weir to Carroll Gap	Sacramento Model		Sacramento model calibrated to water balance between 419024 and 419006

Table A.7: Estimates of ground water inflow in Peel

Location	Recharge ground water when	Discharge to the River when:
Pradise Weir to Carroll Gap	Groundwater storage that has inflow from a Sacramento model. The recharge of the groundwater storage is from the sacramento modelled inflow derived from the residual between Paradise Weir to Carroll Gap (see above). The groundwater storage capacity is 20 Gland it always releases 20 ML/d as groundwater inflow to river. A drought trigger is used to reduce the 20 ML/d inflow to the river.	A base flow of 20 ML/d is released all year except drought years. Drought conditions are triggered by a virtual storage of 10 GL that has inflow from Goono Goono River and a constant outflow of 32 ML/d. The base flow of 20 ML/d is proportionally reduced to a 0 ML/d flow when this virtual storage empties.

Table A.8: Flow Routing Parameters

River Reach	Length (Km)	Area (Km^2)	Lag (day)	k_1	m_1	Q_2	k_2	m_2
Chaffey Dam to Duncans Ck Jn	9	6	0	1.0	0.75			
Duncans Cr Jn to Dungowan Cr Jn	21	14	0	1.0	0.75			
Dungowan Creek	20	40	0	1.0	0.75			
Dugowan Cr Jn to Piallamore	7	10	0	1.8	0.75			
Piallamore to Cockburn Rv Jn	21	9	0	4.3	0.72	10,000	0.10	0.70
Cockburn River to Water Supply G	6.3	5	0	4.3	0.72	10,000	0.10	0.70
Water Supply G to Paradise Weir	3	2	0	0.5	0.80	20,000	0.10	0.70
Paradise Weir to Attunga Cr Jn	36	24	0	0.5	0.80	20,000	0.10	0.70
Attunga Cr Jn to Caroll Gap	22	41	0	0.5	0.80	20,000	0.10	0.70
Cr: Creek, Rv: River, Jn: Junction				k_1, k_2: non linear routing parameter, the multiplier m_1, m_2: non linear routing parameter, the exponent valid Q_2: The flow threshold above which k_2, m_2 is used				

Appendix B. Town Water Demand Modelling

The development of the regression model makes use of an inverse tan based transformation function where it is considered appropriate for the regression equation. The regression equation for the prediction of water demand is:

$$Y_i = B_0 + B_1 \times f_1(X_{1i}) + B_2 \times f_2(X_{2i})$$

Where:
Y_i=daily water demand per capita (L/d)
B_0=7167.9
B_1=-4706.8
B_2=159.64
X_1=Soil Moisture index
X_2=Maximum Temperature (°C)

$$f_n(X_{ni}) = \tan^{-1}\left(\left(X_{ni} - \frac{(S_{nU} + S_{nL})}{2}\right) \times \left(\frac{\pi}{S_{nU} - S_{nL}}\right)\right)$$

Where S_U = Upper shape constant
S_L = Lower shape constant

Shape constants are:
Soil Moisture Index: S_U= -110.65, S_L= -307.48
Maximum Temperature: S_U= 39.62, S_L= 27.79

The soil moisture index is based on a simple bucket model where rainfall is placed in a bucket and evaporation is taken out. The following VB code is used to calculate the index:

```
temp01 = smi(i-1) + rm * ra(i) – (em * ev(i)) ^ ep*smi(i-1)*0.01
If temp01 > 100 Then
   smi(i) = 100
ElseIf temp01 < 0 Then
   smi(i) = 0
Else
   smi(i) = temp01
End If
```

Soil Moisture Index Parameters:
Rainfall multiplier (rm): 2.78
Evaporation multiplier (em): 0.31
Evaporation power (ep): 2.76

This is modelled as 3.7 node in IQQM with input parameter of population.

Appendix C. Model Configuration

The river was divided into 9 river reaches for model definition and calibration.

Table C.1: Functional elements represented in IQQM (run no C65)

Element Type	River Section	Node #	(Node no) Description of Items
Gauged Inflow	1	60	Inflow to Chaffey Dam
	2	100	Inflow to Dungowan Dam
	1	62	Duncans Creek
	3	70	Cockburn River
	5	74	Goono Goono Creek
Ungauged Inflow	1,2,3	14,109,16	Residual inflow Chaffey Dam to Piallamore
	3	71	Residual inflow from Piallamore to Paradise Weir
	5	80	Tamworth sewage inflow
	6	56	Net residual inflow from Paradise Weir to Carroll Gap
Channel Loss	1,2,3	15,17,68	Loss up stream of Piallamore
	3	72	Loss from Piallamore to Paradise Weir
	7	76	Loss from Paradise Weir to Caroll Gap
	6	55	Drought loss
River flow routing calibration location	3	65	Piallamore guage 419015
	5	73	Paradise Weir gauge 419024
	7	78	Caroll Gap gauge 419006
Storages	1	61	Chaffey Dam
	2	106	Dungowan Dam
	6	84	Groundwater
	8	11	Virtual drought storage
General security Irrigator Group extractions	3	64	Irrigators upstream of Piallamore
	3	66	Irrigators from Piallamore to Paradise Weir
	5	79	Irrigators from Paradise Weir to Attunga
	7	105	Irrigators from Attunga to Carroll Gap
	7	90	Irrigators downstream of Carroll Gap
Stock and Domestic extractions	1	111	Users of Dungowan Dam water
	3	121	Users from Chaffey Dam to Piallamore
	3	122	Users from Piallamore to Paradise Weir
	5	123	Users from Paradise Weir to Attunga
	7	124	Users from Attunga to the end of the river
TWS extractions	4	134	Total Tamworth Demand
	3	67	Water supplied from Chaffey Dam
	1	108	Water supplied from Dungowan Dam
Confluences	1 & 2	63	Duncans Creek and Peel River
	3 & 4	71	Residual and TWS excess u/s Paradise Weir
	5 & 6	82	Residual/Groundwater u/s Carrol Gap
	7 & 8	86	Virtual drought index storage
Off-allocation reaches	3	104	Upstream of Piallamore
	5	103	From Piallamore to Attunga
	7	77	From Attunga to end of the river.
Flow control nodes	1	59	Minimum Chaffey Dam operational release
	2	110	Transparent release from Dungowan Dam
	7	50	Minimum flow at Carroll Gap

Figure C.1: The Schematic Diagram of the Peel IQQM

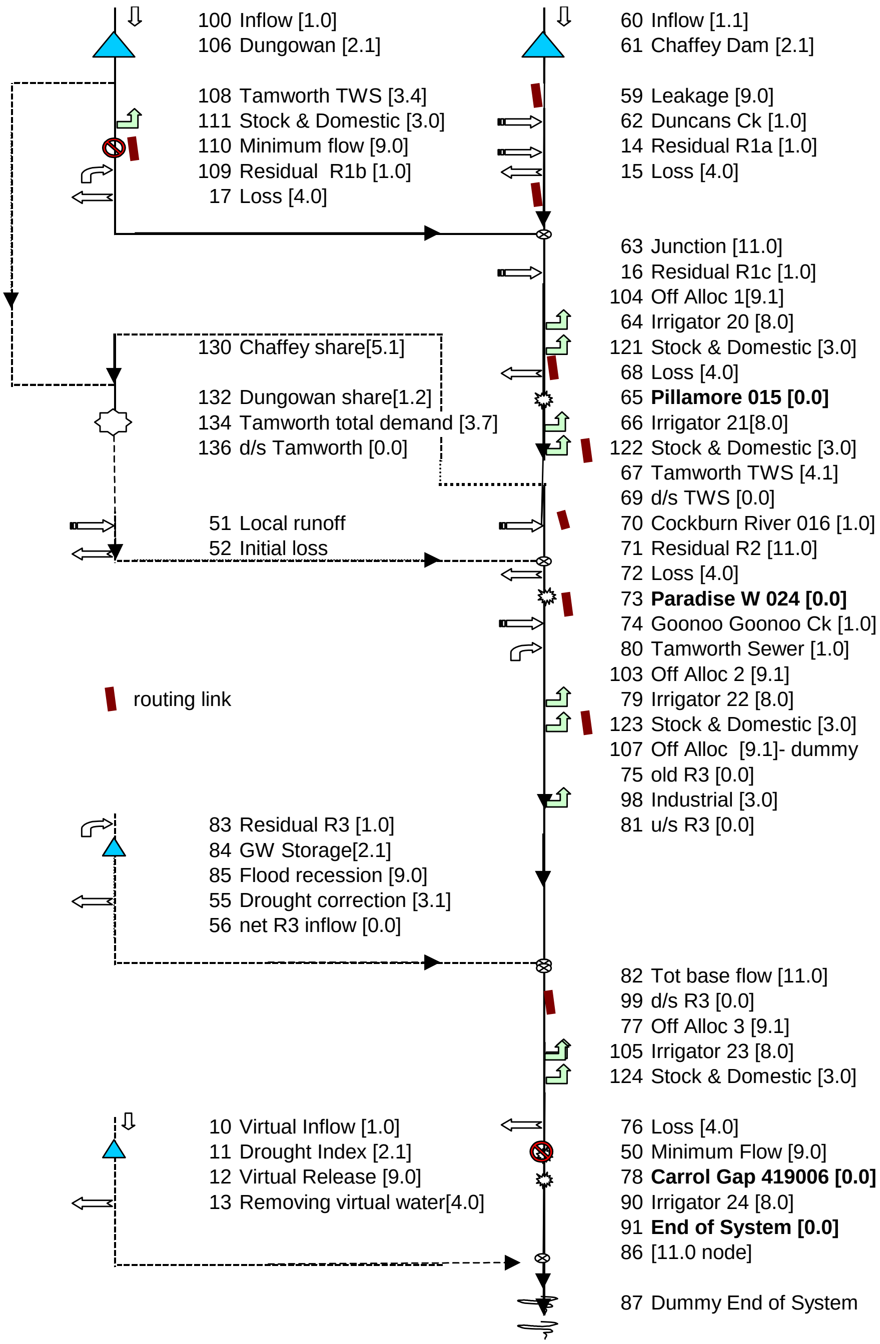


Table C.2: Average Stock and Domestic Usage Demand

Daily Demand (ML/d) = Annual Demand (ML/a) X Daily Pattern

Month	Pattern	Month	Pattern	Reach	Demand (ML/a)
January	0.0038	July	0.0016	Dungowan Creek	81
February	0.0036	August	0.0013		
March	0.0045	September	0.0013	Upstream of Piallamore	16
April	0.0038	October	0.0026	Piallamore to Paradise W	65
May	0.0028	November	0.0030	Paradise W to Attunga	24
June	0.0010	December	0.0036	Attunga to Namoi Junction	58

Table C.3: Crop factors and irrigation efficiency

Crop Name	Efficiency	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lucerne	0.95	0.75	0.80	0.80	0.75	0.40	0.40	0.40	0.70	0.70	0.70	0.70	0.70
S Cereal	0.90	1.10	0.80	0.40	0.10	0.01	0.01	0.01	0.01	0.01	0.40	0.35	1.00
W Cereal	0.90	0.01	0.01	0.01	0.01	0.30	0.30	1.10	1.10	0.30	0.30	0.01	0.01
S Pasture	0.90	0.70	0.70	0.60	0.01	0.01	0.01	0.01	0.01	0.01	0.50	0.50	0.70
W Pasture	0.90	0.01	0.01	0.01	0.60	0.60	0.90	0.90	0.90	0.80	0.80	0.01	0.01
Wheat	0.90	0.01	0.01	0.01	0.01	0.30	0.30	0.90	1.10	1.00	0.25	0.01	0.01
Vegetables	0.90	0.70	0.60	0.50	0.20	0.01	0.01	0.01	0.20	0.20	0.30	0.40	0.50
Summer Oil	0.90	0.40	0.80	0.80	0.50	0.01	0.01	0.01	0.01	0.01	0.01	0.40	0.40
Winter Oil	0.90	0.01	0.01	0.01	0.01	0.40	0.40	0.80	1.00	0.40	0.01	0.01	0.01
Forage	0.90	0.50	0.50	0.40	0.01	0.01	0.01	0.01	0.01	0.01	0.50	0.50	0.50
Legume	0.90	1.10	0.50	0.30	0.01	0.01	0.01	0.01	0.01	0.01	0.40	0.50	0.50
Fallow	1.00	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

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

Table C.4: Irrigation nodes parameters

User Group	order time (days)	over order factor	Adepletion (mm)	rainfall station
Chaffey to Piallamore (Iirr20)	0	1.0	600	Dungowan (55171)
Piallamore to Paradise W (irr21)	1	1.0	400	Dungowan (55171)
Paradise W to Attunga (irr22)	2	1.1	200	Tamworth (55054)
Attunga to Carrol Gap (irr23)	3	1.1	200	Tamworth (55054)
Carrol Gap to Namoi R (irr24)	3	1.1	200	Somerton (55003)

Table C.5: Tributary utilisation factors

Tributary Inflow	utilisation (%)
Duncans Creek	50
Dungowan Creek	50
Cockburn River	20
Goonoo Goonoo Creek	20
Residuals u/s Paradise Weir	20
Residuals u/s Carrol Gap	10
Sewage effluent (4.3 ML/d)	100

Table C.6 Adopted average flow surplus thresholds for OFA announcement

River reaches using those OFA thresholds	Flow (surplus) thresholds in ML/d											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chaffey to Paradise Weir	60	60	60	60	60	60	30	30	30	30	30	30
Paradise Weir to Attunga	60	60	60	60	60	60	30	30	30	30	30	30
Attunga to End of System	100	100	100	100	100	100	60	60	60	60	60	60

Appendix D. Recorded Crop Areas

D.1 RECORDED CROP AREA IRRIGATED

The crop mixes per water year for each group of irrigators are shown on the tables below.

Table D.5.1. Crop area irrigated from Chaffey Dam to Piallamore

Year start	forage	legume	lucerne	summer cereal	summer pasture	summer oil	vegies	winter cereal	winter oil	winter pasture	wheat	Total
1982	30	0	253	15	9	0	0	68	0	19	42	436
1983	2	0	113	0	0	0	0	0	0	29	0	144
1984	0	0	176	94	4	25	0	20	0	30	0	349
1985	0	0	231	66	11	18	0	12	18	54	6	416
1986	0	0	301	42	40	26	0	19	0	52	6	486
1987	4	0	270	28	12	0	0	0	0	71	0	385
1988	0	0	382	16	53	0	0	0	0	18	0	469
1989	21	0	399	17	62	0	0	0	0	29	62	590
1990	0	0	405	18	146	0	25	33	0	3	0	630
1991	0	0	451	10	158	0	0	75	0	52	14	760
1992	0	0	527	0	119	0	0	58	0	25	22	751
1993	0	3	478	0	64	0	0	80	0	35	0	660
1994	0	4	604	18	110	0	0	93	0	4	19	852
1995	0	4	301	0	5	0	0	57	0	0	40	407
1996	0	8	379	0	0	0	10	84	0	0	0	481
1997	0	0	411	0	4	0	0	29	5	0	24	473
1998	0	0	372	0	0	0	10	20	0	0	0	402
1999	0	0	418	0	0	0	0	15	11	0	0	444
2000	0	0	405	15	0	0	0	33	0	0	25	478
2001	0	0	472	0	48	0	0	72	6	0	15	613
2002	0	0	464	0	64	0	0	144	0	0	15	687

Table D.5.2. Crop area irrigated from Piallamore to Paradise Weir

year start	forage	lucerne	summer cereal	summer pasture	vegetables	winter cereal	winter oil	winter pasture	wheat	total
1982	30	39	5	41	9	0	0	5	45	174
1983	0	110	0	0	0	0	0	8	0	118
1984	0	129	0	12	0	12	0	17	0	170
1985	0	103	0	0	2	0	0	53	9	167
1986	0	160	0	70	0	0	0	7	3	240
1987	0	117	0	0	0	0	0	7	0	124
1988	0	132	0	46	0	7	0	0	7	192
1989	0	157	0	68	0	11	0	31	8	275
1990	0	99	0	54	2	10	0	39	0	204
1991	5	164	0	77	0	12	0	65	23	346
1992	0	256	0	125	10	12	0	0	11	414
1993	12	219	2	136	19	33	0	86	19	526
1994	5	238	16	137	3	25	0	90	13	527
1995	0	116	13	8	15	6	0	0	0	158
1996	0	120	0	0	10	29	10	0	0	169
1997	20	153	4	22	30	31	0	0	16	276
1998	0	83	0	0	40	0	0	0	0	123
1999	10	150	0	0	0	0	0	0	0	160
2000	30	153	0	0	18	15	0	0	0	216
2001	30	247	16	50	8	83	0	10	0	444
2002	20	212	0	80	2	48	0	3	25	390

Table D.5.3. Crop area irrigated from Paradise Weir to Attunga

year start	forage	lucerne	summer cereal	summer pasture	vegetables	winter cereal	winter oil	winter pasture	wheat	total
1982	53	199	19	9	0	50	0	17	56	402
1983	16	143	2	37	0	5	0	34	0	237
1984	0	184	54	62	2	69	0	17	0	388
1985	0	204	0	20	0	35	0	62	0	321
1986	6	298	47	35	12	7	0	22	0	427
1987	23	195	54	47	0	0	0	13	8	340
1988	0	195	42	158	0	0	0	28	0	423
1989	23	287	222	145	0	0	0	106	0	782
1990	0	296	18	231	0	33	0	51	0	629
1991	0	383	8	282	0	71	0	52	0	796
1992	0	364	8	221	25	133	0	67	9	827
1993	4	461	0	260	30	164	0	80	20	1019
1994	0	525	14	173	0	181	0	50	20	963
1995	0	216	0	78	0	59	0	22	20	395
1996	0	175	0	46	0	93	0	0	10	324
1997	0	276	30	136	0	153	10	46	18	669
1998	0	141	52	66	0	5	0	15	0	279
1999	0	311	0	92	0	21	5	20	20	469
2000	0	299	0	152	0	110	0	0	0	561
2001	0	397	0	210	10	139	0	0	20	776
2002	20	340	0	245	0	114	0	18	10	747

Table D.5.4. Crop area irrigated from Attunga to Carrol Gap

year _start	forage	legume	lucerne	summer cereal	summer pasture	summer oil	vegetables	winter cereal	winter oil	winter pasture	wheat	total
1982	59	0	162	0	58	0	2	73	0	30	66	449
1983	1	0	92	0	0	0	31	10	0	28	20	182
1984	0	0	121	27	33	24	4	21	0	21	0	251
1985	0	0	137	16	21	19	10	26	19	139	18	405
1986	0	0	134	10	0	0	35	5	0	30	0	214
1987	18	0	141	2	62	0	36	0	0	15	0	274
1988	0	0	228	0	89	0	18	7	0	0	0	342
1989	0	0	269	0	74	0	13	23	0	10	0	389
1990	0	0	351	0	123	0	6	55	0	0	0	535
1991	0	0	614	0	160	0	3	33	0	58	17	885
1992	0	0	527	0	252	0	5	59	0	46	20	909
1993	0	0	476	0	148	0	3	148	0	185	0	960
1994	0	0	760	0	295	0	6	179	0	0	38	1278
1995	0	10	401	0	45	0	5	31	0	0	0	492
1996	0	10	342	2	45	0	0	7	0	15	0	421
1997	0	0	430	0	111	0	0	91	0	45	36	713
1998	0	0	206	0	75	0	0	15	0	0	0	296
1999	0	0	288	0	30	0	0	0	0	30	0	348
2000	0	0	308	8	35	0	0	30	18	0	0	399
2001	0	0	322	0	309	0	0	125	0	0	15	771
2002	0	0	325	0	269	0	0	147	0	40	50	831

Table D.5.5. Crop area irrigated from Carrol Gap to Namoi River junction

year start	forage	lucerne	summer cereal	summer pasture	winter cereal	winter pasture	wheat	total
1982	1	12	0	0	6	0	0	19
1983	0	29	7	0	8	0	0	44
1984	0	35	0	0	0	0	0	35
1985	0	34	0	4	0	12	0	50
1986	8	27	0	3	0	0	0	38
1987	0	23	0	0	0	10	0	33
1988	0	12	0	10	0	0	0	22
1989	0	8	0	0	0	0	0	8
1990	0	20	0	2	32	0	0	54
1991	0	43	0	0	0	0	0	43
1992	0	54	0	40	8	0	0	102
1993	0	58	0	12	10	0	0	80
1994	0	69	0	17	38	12	6	142
1995	0	0	0	14	0	0	0	14
1996	0	0	0	10	16	0	0	26
1997	0	15	0	40	20	0	0	75
1998	0	20	0	0	20	0	0	40
1999	0	50	0	0	25	0	0	75
2000	0	50	0	0	40	0	0	90
2001	0	29	0	10	27	0	5	71
2002	0	53	0	28	33	0	12	126

Appendix E. 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.

E.1 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 E.1: Comparing actual gauged with model simulated flows over a period

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

Notes:-

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

E.2 STORAGE CALIBRATION QUALITY INDICATORS AND RATINGS

Table E.2: Comparing actual gauged with model simulated storage over a period

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

Notes:-

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

E.3 DIVERSION CALIBRATION QUALITY INDICATORS AND RATINGS

Table E.3: Comparing actual gauged with model simulated diversions over a period

(applicable for ONA, OFA and TOTAL diversions)

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

Notes:-

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

E.4 PLANTED CROP AREA CALIBRATION QUALITY INDICATORS AND RATINGS

Table E.4: Comparing actual recorded with model simulated planted crop areas

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

Notes:-

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

E.5 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 E.5.

Table E.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.

E.6 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:

5) Very High 0%<=x<=5%
6) High 5%<x<= 10%
7) Moderate 10%<x<=15%
8) Low 15%<x<=20%
9) 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 seven indicators are standardised and averaged (AI). That is, $AI = \sum SI,s / 7$. This average quality indicator is then adjusted for climatic representativeness of the calibration period on the following basis:

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

Where
OI = Overall quality indicator
AI = Average standardise quality indicator
NY = Number of years model is calibrated over

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

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

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

Appendix F. MDBMC Cap Development Conditions and Management Rules

Table F.1 Major process parameters

ITEMS	INPUT DATA
Long term simulation period	1.1.1892 to 30.06.2004
Calibration period	Storage: 1 July 1982 to 30 June 2003 Flow: mainly 1959 to 2003 GS Irrigation: 1982/83 to 1999/03 Off allocation period: 1983 to 1992 Town water: 1997 to 1999
Storage modelled	Chaffey Dam FSL 61830 ML, dead storage 2360 ML Dungowan Dam FSL 6300 ML, dead storage 300 ML
Total Irrigation Stock & Domestic, permanent plantation	Annual license entitlement (GS) Total(GS) 30159 ML Total (HS) ……163 ML* *active portion only, total issued is 771ML
Demand on Dungowan	Stock & Domestic : 90 ML/a
Tamworth water supply	Active entitlement 10 000ML/a* *active portion only, total entitlement is 16400ML/a Demand based on climatic condition: Long term annual average demand is set at 8300 ML equivalent to a population of 33700. Supply rules: Use Dungowan if it is > 4000 ML Do not use Dungowan if it is < 3000 ML Transition if Dungowan is within 3000ML to 4000ML Pipeline capacity is 22 ML/d Subject to above rules supplement from Chaffey if needed. No water restriction during drought.
Tamworth sewage effluent return flow	1560 ML/a (ie 60%* of 2600ML dry weather flow) Dry weather flow is used not wet weather average of 2800ML/a, as the rainfall run off is modelled explicitly Uniform flow throughout the year *an estimate to account for unregulated usage sensitivity of this estimate will be tested
Minimum flow requirements Dungowan outflow Carroll Gap	 Transparent dam if inflow < 10 ML/d Otherwise minimum release is 10 ML/d 5 ML/d

Table F.2 Major resource assessment parameters

<table>
<tr><td>Item</td><td colspan="4">Input Data</td></tr>
<tr><td>Water Year</td><td colspan="4">1st July to 30th June</td></tr>
<tr><td rowspan="14">Chaffey resource assessment</td><td colspan="4">Carry over reserve: 12000 ML
Minimum inflows and losses used in resource assessment (ML)</td></tr>
<tr><td>Month</td><td>Dam Inflow</td><td>Tributary Inflow</td><td>Transmission & operation losses</td></tr>
<tr><td>Jul</td><td>3800</td><td>3000</td><td>14400</td></tr>
<tr><td>Aug</td><td>3000</td><td>3000</td><td>14100</td></tr>
<tr><td>Sep</td><td>2800</td><td>3000</td><td>13600</td></tr>
<tr><td>Oct</td><td>2500</td><td>3000</td><td>12900</td></tr>
<tr><td>Nov</td><td>2100</td><td>3000</td><td>11800</td></tr>
<tr><td>Dec</td><td>1500</td><td>3000</td><td>10200</td></tr>
<tr><td>Jan</td><td>700</td><td>2500</td><td>8200</td></tr>
<tr><td>Feb</td><td>700</td><td>2500</td><td>5700</td></tr>
<tr><td>Mar</td><td>500</td><td>1000</td><td>3600</td></tr>
<tr><td>Apr</td><td>500</td><td>1000</td><td>2200</td></tr>
<tr><td>May</td><td>200</td><td>500</td><td>1300</td></tr>
<tr><td>Jun</td><td>100</td><td>500</td><td>500</td></tr>
<tr><td>Active entitlement used</td><td colspan="4">GS Irrigation: 30159 ML/a
HS S&D: 163 ML/a*
HS Tamworth: 10000 ML/a*
HS Industrial: 300 ML/a
HS Carroll Gap minimum flow: 1500ML/a
*active portion only, not the full entitlement</td></tr>
</table>