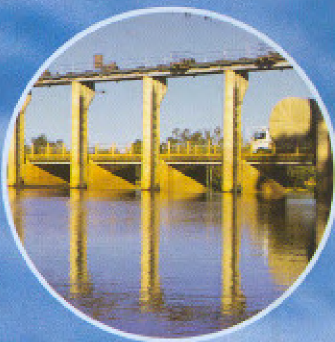

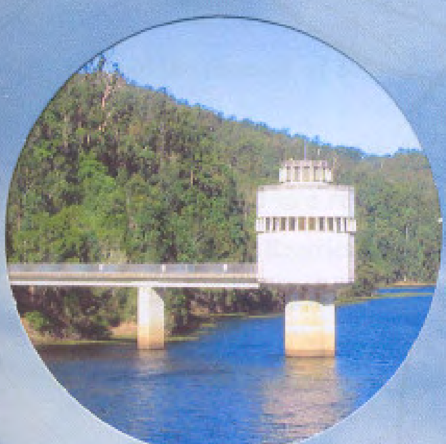

Report

Tweed River System Water Supply Security Review

Date: November, 2006

Ref: G – 81903-02-03-03

SunWater

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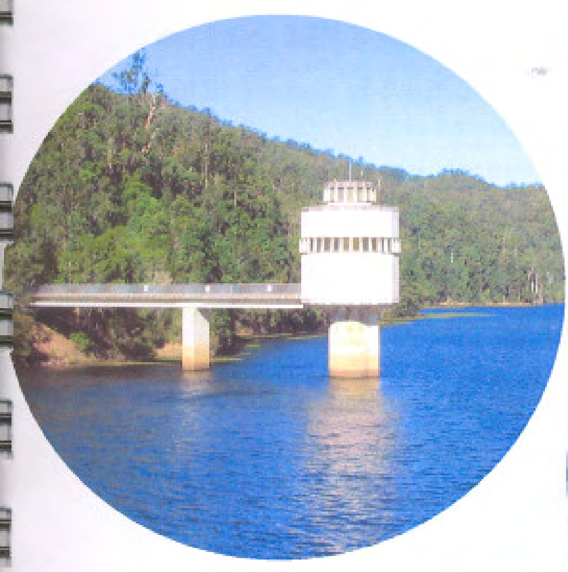

Report

Tweed River System Water Supply Security Review

Prepared for:
Tweed Shire Council

Date: November, 2006

Ref: G – 81903-02-03-03

EXECUTIVE SUMMARY

Tweed Shire Council, in order to complete its Integrated Water Cycle Management (IWCM) study, requested SunWater to review the security of the Tweed River System water supply. The IWCM study outlined a shortfall in water supply yield compared to forecast demands.

Background

Historic no failure yield (HNFY) is traditionally quoted as a measure of system yield. HNFY is the annual volume of water that could have been extracted from a water supply system operating over the historic period of record, without storages falling below minimum operating levels. Such an analysis is not truly predictive, as worse droughts than has previously been recorded are not taken into account, as may occur with current trends in climate change. The HNFY for the Tweed River System represents a probability in the order of 1 in 100 years.

HNFY estimates for the Tweed River System have continuously reduced with successive studies as more data and improved methods were used. The estimates in the 1980, 2002 and 2006 studies were 27,500, 18,000 and 16,200 ML/a respectively. In 1980, a monthly water balance method was used, while in 2002 and 2006, daily simulation models were used. Furthermore, in 2006, the 2002 model was recalibrated and the drought of 2002/03 was considered.

Recent droughts across Australia and a heightened awareness of the potential impacts of climate change have resulted in a review of drought security criteria. The adequacy of the HNFY criterion is now being questioned. Restrictions and contingency storages are suggested for improved water security, centering on the assumption that demands can be restricted to 80% of normal consumption.

In addition to these developments in security criteria, system operation is expected to be affected by new environmental flow requirements which are to be introduced for many storages in New South Wales, which require either the 80^{th} or 95^{th} percentile flow volume to be released downstream from a storage.

Study Objectives

The current study was carried out in order to update previous work by incorporating the latest data available and current strategic thinking on future planning for Tweed Shire. Efficient operation of the current scheme to minimise losses while satisfying environmental needs was explored, as well as future augmented system configurations, namely augmentation of Clarrie Hall Dam in the short term and construction of Byrill Creek Dam in the medium to long term.

In addition, Tweed Shire Council requested SunWater to investigate the provision of an additional degree of security to the system yields by considering the following security criteria:

- The Department of Energy, Utilities and Sustainability (DEUS) criteria, where restricted (80%) demand must still be obtainable if the worst drought starts when the storage is at the restriction trigger level, and restrictions are to occur no more than 5% of the time and no more often than 1 in 10 years on average
- Tweed Shire Council criteria, where restricted demand must still be obtainable, with staged restrictions (90%-85%-80%) imposed starting when Clarrie Hall Dam's defined commandable storage is at 50%; the commandable storage excludes a contingency volume equivalent to 80% of full demand, which will only be accessed in severe drought

Findings

The results for the existing system with application of the HFNY, DEUS and TSC criteria while meeting environmental flow (EF) requirements are summarised in the table below.

The storage volumes for Clarrie Hall Dam and Byrrill Creek Dam referred to in this report are commandable storage volumes, not full supply volumes with dead storage included. This is to maintain consistency with previous work.

The study has identified a reduction in the historical no failure yield from 18,000 ML/a (2002 Study) to 16,200 ML/a, mainly attributable to the 2002/03 drought being the worst on record for the Tweed River.

The implementation of the 95% environmental flow releases reduces the yield of the existing system to 14,000 ML/a, which does increase to 15,000 ML/a if restrictions are included. The introduction of both the 95% environmental flow requirement and the new contingency storage security criteria results in the existing system falling short of the current demand of 10,900 ML/a.

Table 1: Existing System Yields under Different Security Criteria

Method	Yield (ML/a)	Population	Commandable Restriction Volume (ML)	Restrictions	
				% time	Frequency (1:_ yr)
2002 Study HNFY	18,000	124,000	0	< 1%	< 115
2006 Study HNFY	16,200	111,000	0	< 1%	< 115
DEUS yield under existing EF d/s of CHD & BPW[1]	16,900	116,000	10,000	2.6%	10
DEUS yield under existing EF d/s of CHD & 95% flow d/s of BPW	13,750	90,000	9,000	1.8%	16
Yield under existing EF d/s of CHD & BPW, TSC restrictions and a contingency storage[2]	10,500	70,000	11,700	< 1%	29
Yield under existing EF d/s of CHD & 95% flow d/s of BPW, TSC restrictions and a contingency storage[3]	10,100	67,300	11,540	< 1%	13

[1] Current regulatory regime (existing EF rules d/s CHD and BPW: for CHD, lesser of inflow to dam and 1.1 ML/day Sep to Apr 0.8 ML/day May to Aug; for BPW, releases through fish ladder, flow vary from 0 to 25 ML/d when storage > 405 ML
[2] Contingency storage equals to 80% of demand (= 8,400 ML)
[3] Contingency storage equals to 80% of demand (= 8,080 ML)

The behaviour of the system under current and future demand conditions – with Tweed Shire Council (TSC) restriction rules and a contingency storage - was assessed. These demand conditions represent the water needed for populations of 71,500 (current), 75,000, 125,000 and 175,000 people. The system performances for each demand condition are given in Table 2.

Table 2: Existing System Performances for Current and Future Demand Conditions

Demand (ML/a)	Population	Restrictions		Contingency Volume (ML)	< Cont'y Volume		Minimum Commandable Storage (ML)	Criteria Pass/ Fail
		% time	Frequency (1:_ yr)		% time	Frequency (1:_ yr)		
10,100 (HNFY)	67,300	0	> 115	8,080	0	> 115	8,100	Pass
10,900 (Current)	71,500	2.8	7.0	8,720	0.3	58	7,400	Fail
11,250	75,000	3.4	6.4	9,000	0.5	58	7,000	Fail
18,125	125,000	25.4	1.1	14,500	22.0	1.1	0	Fail
24,500	175,000	100	<1.0	19,600*	100	< 1	0	Fail

* Greater than CHD Full Supply Volume

To investigate future augmentation options, an increase in the storage capacity of Clarrie Hall Dam, and construction of a new storage on Byrrill Creek, were analysed. Increasing the capacity of Bray Park Weir was investigated. Different combination of storage capacities of CHD and BCD were investigated to meet future demands with the implementation of both the 95% environmental flow requirements along with the new contingency storage security criteria. Results are given in Table 3.

Table 3: Augmentation Options

Population	Commandable Storage Capacity (ML)		Total Commandable Storage Capacity (ML)	Demand (ML/a)
	CHD	BCD		
67,300	15,000	-	15,000	10,100
125,000	35,000	-	35,000	18,000
125,000	15,000	15,000	30,000	18,125
155,000	45,000	-	45,000	22,000
175,000	15,000	35,000	50,000	24,500

A commandable storage capacity of approximately 30,000 ML is required to service a population of 125,000. A commandable storage capacity of approximately 50,000 ML will be required to meet the potential full development demand for a population of 175,000.

Although increasing the capacity of Bray Park Weir to 720 ML makes little impact on the reliability of the town water supply, the number of restrictions to be applied is reduced. As well, this increase in capacity, resulting from raising the weir crest level by 200 mm, protects the weir pool from salt water ingress during periods of king tides and corresponding low river flows.

For planning future improvements in system operations, flow monitoring at key locations is recommended to determine:

- The most efficient system operation
- Required environmental flow releases
- The quantity of in-stream losses and thus the need for a pipeline to carry water from Clarrie Hall Dam to Bray Park Weir.

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GLOSSARY OF TERMS

Allocation – The annual volume of water in megalitres (ML) required by a regulated user.

Catchment Rainfall – The estimated depth of rain in millimetres (mm) that falls over the entire catchment, usually based upon a weighted average of point (or gauge) rainfall.

Contingency Storage – The reserve storage to be used to supply high priority water during extreme drought condition.

Daily Flow Time Series – The daily record of flow data, listed sequentially with respect to time.

Diversion – The annual volume of water in ML/a, supplied to a regulated user.

Environmental Flow – Minimum flow to be releases to maintain the stream health, the 95% flow means that flow equals or lowers of 95% probability of exceedance of natural flow.

Flow Duration Curves – The plot of flow data, ranked from highest to lowest, against their ranking. This plot shows the proportion of time the flows are within a particular range.

Gauging Station – The site on a river where the flow in the river is continuously measured, using height records and rating curves, relating height to discharge.

Hydrograph – A plot of a streamflow event, showing discharge vs time. The hydrograph consists of the rising limb, showing how fast the event occurs; the peak, showing the maximum discharge of the event, and the recession limb, showing the tailing off of the event.

IQQM – An Integrated Quantity and Quality Model used to simulate both regulated and unregulated water allocations, and is operated on a continuous basis with a daily time-step.

***Lake Evaporation* -** The volume of water (in ML) lost from a storage due to evaporation, determined from Class ‘A’ pan measurements in mm.

Pan Factors – Used with pan measurements and determined from energy considerations (sun, wind, etc) of a particular site, to calculate lake evaporation.

Mean Flow – The average daily, monthly or annual flow volume in ML that is recorded at a particular site along the river.

Model Calibration – The method used, by tuning a number of parameters applied to input rainfall data, to achieve an acceptable fit to recorded streamflow data.

Model Verification – Using the calibration parameters and another period of input rainfall, determine if the output streamflow data replicates to the recorded flows for that period.

x Percentile Flow Values – The monthly flow volume that has an x% chance of being exceeded over the period of record.

Point Rainfall – The recorded depth of rain in mm that falls at a particular point in the catchment.

Potential Evapotranspiration Factors (PET) – The depth of water loss which will occur if at no time, there is a deficiency of water in the soil for use by the vegetation.

Recession Curves – The portion of the streamflow hydrograph, after the peak, that shows the rate of runoff from the catchment, and the behaviour of the baseflow component of the hydrograph.

Residual Flows – The daily volumes of water which come off the catchment between two adjacent sites along the river, eg. between two gauging stations.

Restrictions – The pre-determined percentage to which the annual supply will be reduced, once a storage falls to a set level, in order to conserve water.

Sacramento Model – A soil moisture accounting model used to generate long-term daily streamflow, based on the calibration of recorded streamflow and rainfall data, and the synthesis of flows using the calibrated model parameters and long-term daily rainfall data.

Historical No Failure Yield (HNFY) – The annual volume of water (in ML/a) that can be supplied, without failure for every year of the analysis.

Yield with Restrictions – The annual volume of water (in ML/a) that can be supplied for most of the time, but which is reduced to a fixed proportion of that volume when the storage falls below a pre-determined level.

Staff-read gauge – The original method of recording streamflow, where a designated person measured the height of the river at a set time once each day.

Stand-Alone Storage – A single storage, not supplying or receiving water from any other storage in the system.

Streamflow – Recorded or estimated volumes of water in ML, which flow past a particular point in the river for a set period of time, usually 1 day.

Storage Behaviour Plot **–** A graph of storage volume against time, showing the behaviour of the storage over the period of analysis.

LIST OF ABBREVIATIONS

AHD	Australian Height Datum
BCD	Byrrill Creek Dam
BGA	Blue Green Algae
BPW	Bray Park Weir
CHD	Clarrie Hall Dam
CRCCH-RRL	Cooperative Research Centre for Catchment Hydrology Rainfall Runoff Library
DEUS	Department of Energy, Utilities and Sustainability
EF	Environmental Flow
EL	Elevation
FSL	Full Supply Level
HNFY	Historical No Failure Yield
IQQM	Integrated Quantity and Quality Model
ML/a	Annual demand in megalitres
POE	Probability of Exceedance
SILO	Daily climate database for use with simulation model (See Department of Natural Resources, Mines and Water, Queensland website for more information)
TSC	Tweed Shire Council
TWS	Town Water Supply

INTRODUCTION

Tweed Shire Council, located in far north-eastern New South Wales (Australia), commissioned SunWater to undertake a review of options to meet future demand from the Tweed District Water Supply System. There are no significant irrigation areas in the Tweed River catchment, and the water is mainly required for the urban town centres within Tweed Shire. Clarrie Hall Dam on Doon Doon Creek, and a pumping pool at Bray Park Weir on the Tweed River, are the main regulated structures. Bray Park Weir was built in 1960, both as a pumping pool for the water treatment plant, and as a tidal barrage. Clarrie Hall Dam was constructed in 1983 to supplement flows into the weir. The townships of Uki and Tyalgum in the upper catchment extract their demands directly from the streams. The catchment map is provided in Appendix A.

Tweed Shire Council is completing its Integrated Water Cycle Management study, which outlines the future strategic direction for the water, wastewater and stormwater systems within the Tweed catchment (Hunter Water Australia Pty Ltd, 2006). The study outlines a shortfall in water supply yield compared to forecasted demands. Some of the options, such as demand management and demand substitution, effluent reuse, and augmentation, were proposed to meet the shortfalls in supply.

At this stage, due to the high growth rates in the Tweed Shire, it is expected that supply augmentation may be required as early as 2012. Meantime, Clarrie Hall Dam requires a spillway upgrade to satisfy dam safety requirements and Tweed Shire Council would like to explore the option of augmenting the storage capacity at the same time. This study focused on developing and calibrating catchment hydrological models for testing the various scenarios proposed by Tweed Shire Council.

In 1980, Department of Public Works, NSW (1980) carried out the yield and flood hydrology investigations in connection with the design of Clarrie Hall Dam as part of the augmentation to the Tweed District Water Supply Scheme at that time. In this analysis, a monthly water balance method was used and historical no failure yield was estimated as 27,500 ML/a for a storage similar to the current storage of Clarrie Hall Dam.

In 2002, SunWater (2002) carried out the preliminary system yield study for Tweed Shire Council on the Tweed District Water Supply Management Works. This was based on analysis of long-term daily flows into Clarrie Hall Dam and Bray Park Weir, together with extractions for town water supply and irrigation. Environmental flow requirements were taken into account. The study used the Integrated Quantity Quality Model (IQQM) with the recorded flows for Oxley River at Eungella and Tweed River at Uki extended back to 1887 using the Sacramento Model and Murwillumbah rainfall. The IQQM was set up to model the two storage system, and annual yields were determined for a range of conditions and operating processes over the period 1887 to 2001. This review builds of the previous body of work presented in the Preliminary Report of July 2002.

As the previous study used the commandable volume for Clarrie Hall Dam, due to data limitations, the same volumes were used in this study. To determine the full supply volume for the storage, it is necessary to add the dead storage volume of 1,000 ML to the commandable volumes.

The failure of the wet season in 2002 brought Clarrie Hall Dam down to its lowest level of 35% capacity. If the wet season failed for two years in a row, the current operating strategies would not be able to maintain sufficient water for the Tweed Shire. This current study updates and improves the 2002 model further and tests more scenarios. The first part of this report discusses the model development, data availability, model calibration and model verification. The significant issues noted during the model development and calibration are also discussed. The second part of this report discusses the scenario modelling and the results.

1.0 SCOPE OF WORK

This study was focused on four key tasks:

- Update the IQQM of the Tweed River Water Supply System
- Re-assess the existing supply system with various demand scenarios and performance criteria
- Re-assess the impacts of likely future environmental flow requirements
- Assess the viability of future supply augmentation options.

To meet the scope of the work, the following tasks were carried out:

- update available data
- develop and calibrate Sacramento Models for all available gauging stations within the catchment
- generate long-term flows by extending the recorded flow series using the Sacramento model flows
- determine streamflow proportions in residual catchments
- develop and calibrate the IQQM
- run scenarios using the calibrated IQQM

The system performances were assessed for the following scenarios:

- historic no failure yield (without restrictions or a contingency storage)
- system yield with full application of the Department of Energy, Utilities and Sustainability (DEUS) 5/10/20 criteria
- system yields with restrictions or/and a contingency storage
- system yields after allowing for future environmental flow impacts
- system yields resulting from supply augmentation

2.0 AVAILABLE DATA

2.1 RAINFALL

Rainfall data for the period 1890 to date was obtained from the Department of Natural Resources, Mines and Water, Queensland using their SILO Data Drill. The data was obtained at 0.05 degree intervals covering the catchment as a 5 x 5 grid covering Latitude of $28^0 18'$-$28^0 30'$ and Longitude of $153^0 09'$-$153^0 21'$. This data was then used to determine sub-catchment rainfalls for the relevant sites within the catchment, which are shown in Table 2.1 under ‘2006 Study.’

These catchment rainfalls were compared with the point rainfall used in the 2002 study (SunWater, 2002), also shown in Table 2.1. Both estimates were of similar magnitude. As several rainfall stations are considered in the SILO data drill process to estimate catchment rainfalls, SILO data was considered more reliable than point rainfall data. Therefore, the catchment rainfall data was used in the current study.

Table 2.1: Estimated Mean Daily Catchment Rainfalls

Catchment	2002 Study		2006 Study	
	Mean Daily Rainfall (mm)	Mean Annual Rainfall (mm)	Mean Daily Rainfall (mm)	Mean Annual Rainfall (mm)
Tweed River at Uki	4.63[1]	1691	4.64	1696
Oxley Creek at Eungella	4.27	1560	4.49	1639
Doon Doon Creek at Lower Doon Doon	3.96[2]	1446	4.54	1661
Byrrill Creek at Glen Warning	3.96[2]	1446	4.65	1699
Rolands Creek at Uki	4.63[1]	1691	5.08	1858

[1] Murwillumbah
[2] Kunghur

2.2 STREAMFLOW

The NSW Department of Natural Resources, formerly the Department of Land and Water Conservation, supplied flow data at gauging stations within the catchment, as listed in Table 2.2. There were significant periods of missing records at most of the sites. Gauging sites at Eungella and Uki are still in operation. Historical data was available from four other sites. Flow data at Braeside and Uki were combined to get a long-term flow series at Uki.

Table 2.2: Stream Gauging Stations

Station No	River/Creek	Site	Catchment Area (km^2)	Period of Record	Remarks
201001	Oxley River	Eungella	213	5/1947 - Date	Recorded height & flow, Missing about 2% of data
201003	Tweed River	Braeside	298	9/1951 – 12/1968	Staff gauges only, Recorded daily readings
201900	Tweed River	Uki	275	6/1967 - Date	Recorded height & flow, Missing about 26% of data
201009	Rolands Creek	Uki	36	5/1969 – 12/1981	Bristol Recorders, Recorded continuous stage. Flows were manually computed with mean daily flow values.* Only available mean daily flow digitally for the given period.
201010	Byrrill Creek	Glen Warning	74	5/1969 – 12/1981	
201011	Doon Doon Creek	Lower Doon Doon	54	5/1969 – 12/1981	
201004	Tweed River	Kunghur	49	8/1954 – 12/1981	

* The degree of accuracy for the manual computation is unknown, so some uncertainty exists for this data.

2.3 EVAPORATION

There was one long-term evaporation station within the catchment at Tyalgum, and another to the south at Alstonville. No nearby station had wind and sunshine data to provide the pan to lake factors required. The most compatible site was deemed to be Nambour, so the pan factors from Nambour were used in the model. Table 2.3 lists the station data, while Table 2.4 shows the evaporation and pan factors used.

Alstonville had evaporation data from 1963 to the present (with some missing record), while Tyalgum had data up to 1992. For the common period at these two sites, a relationship was developed and used to extend the evaporation data for the Tweed catchment from 1971 to 2004 (Figure 2.1). For the period from 1890 to 1971, and for periods of missing record, the average monthly evaporation values at Tyalgum were used.

Table 2.3: Evaporation Stations

Station No	Station Name	Latitude	Longitude	Period of Record
058057	Tyalgum (Coodgee St)	28.36	153.21	1971 – 1992
040282	Nambour DPI	26.65	152.94	1952 – Date
058131	Alstonville (Tropical Fruit Research Centre)	28.85	153.46	1963 – Date

Table 2.4: Evaporation Data

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tyalgum (Average Evap mm)	134	100	88	68	50	45	53	70	94	115	127	147
Nambour (Pan to Lake factors)	0.70	0.71	0.71	0.66	0.59	0.54	0.55	0.65	0.76	0.77	0.79	0.71
Nambour (Pan to PET factors)	0.84	0.65	0.66	0.83	0.80	0.80	0.66	0.91	1.04	0.97	0.97	0.85

Source: DNR (1997)
(PET = Potential Evapotranspiration)

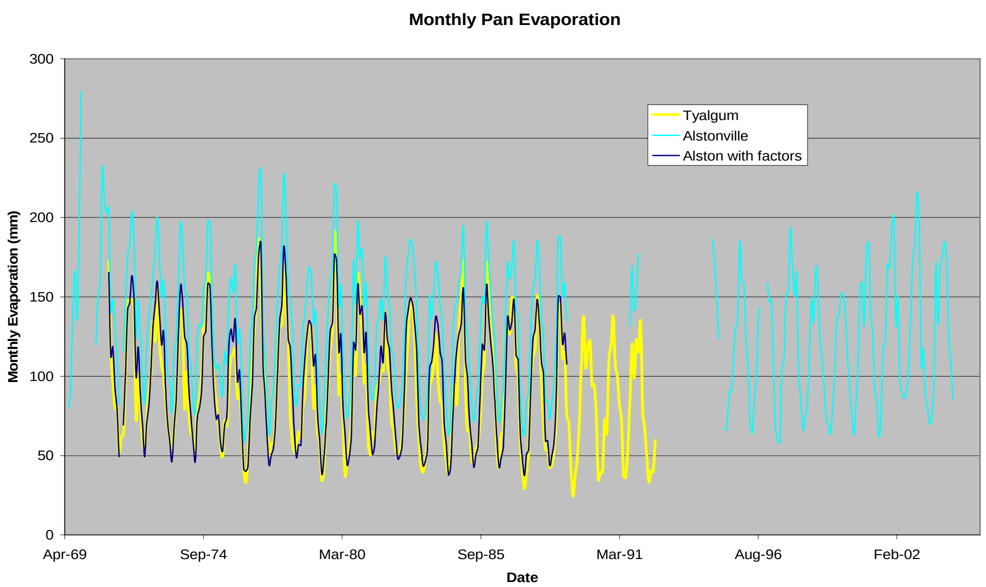

Figure 2.1: Pan Evaporation Relationships

2.4 USAGE DATA

Tweed Shire Council (TSC) provided daily extraction data from the Bray Park pumping station from 1991 to date. For the model calibration, daily data was used. The calculated monthly usage data is shown below in Table 2.5 for presentation purposes.

Table 2.5: Murwillumbah Water Usage

Year	Monthly Town Water Use (ML)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991	936	664	755	792	671	634	704	924	1094	872	919	795	**9760**
1992	918	656	606	595	655	613	673	792	834	1004	802	857	**9005**
1993	947	669	681	657	631	629	590	729	663	741	700	892	**8528**
1994	897	560	625	568	641	611	647	695	780	875	886	838	**8623**
1995	820	671	686	661	584	573	739	752	797	860	771	817	**8730**
1996	793	733	682	829	665	653	797	799	892	929	796	848	**9415**
1997	889	810	883	852	651	646	663	783	825	834	775	935	**9546**
1998	968	844	983	717	704	700	676	672	674	917	804	884	**9543**
1999	857	660	728	705	694	660	678	719	725	742	732	867	**8766**
2000	856	777	755	718	715	701	782	801	1074	930	745	961	**9816**
2001	1039	782	824	749	791	773	816	883	892	1023	902	1052	**10525**
2002	1181	871	936	787	817	758	887	854	833	923	790	789	**10425**
2003	824	618	697	705	703	679	721	772	949	788	873	917	**9247**
2004	918	878	826	796	831	800	865	943	899	1032	900	902	**10590**
Average	**917**	**728**	**762**	**724**	**697**	**674**	**731**	**794**	**852**	**891**	**814**	**882**	**9466**

2.5 STORAGE DATA

The characteristics of the three storages in the catchment are shown below in Table 2.6. The data for Bray Park Weir and Tyalgum Weir were determined by SunWater, based on the information provided by Tweed Shire Council.

Table 2.6: Storage Characteristics

	Clarrie Hall Dam	Bray Park Weir	Tyalgum Weir
Stream	Doon Doon Creek	Tweed River	Tyalgum Creek
Catchment Area (km^2)	60.2	565	38.5
Capacity (ML)	16,000	839	9
Dead Storage (ML)	1,000	191	1.48
Commandable Storage (ML)	15,000	648	7.52
Maximum Surface Area (ha)	220	35.5	N/A
Minimum Operating Volume (ML)	1000	600	N/A

(N/A = Not available)

The commandable volume used in this study for Clarrie Hall Dam is 15,000 ML, which is the full supply volume of 16,000 ML minus the allowed dead storage of 1,000 ML.

3.0 SACRAMENTO MODELLING

The Sacramento rainfall-runoff model was developed in the United States and is freely available from the Cooperative Research Centre for Catchment Hydrology Rainfall Runoff Library (CRCCH-RRL, 2005). The CRCCH-RRL model was used in this study.

As more detailed information on sub-catchment inflows was required for this study, streamflow records at six sites were initially analysed. Recorded daily flow data was used to calibrate and verify the rainfall-runoff models and flow series were extended using these models. As these gauging stations were not at the required sites of interest, these flows were distributed, according to catchment area proportions, to give the data required for the assessment.

The Sacramento models were developed and calibrated for the streamflow gauges at:

- Combined flow series of the Tweed River at Braeside (1951-1968) and Tweed River at Uki (1969-2004),
- Oxley River at Eungella (1947-2004),
- Doon Doon Creek at Lower Doon Doon (1969-1981)
- Byrrill Creek at Glen Warning (1969-1981),
- Tweed River at Kunghur (1954-1981)
- Rolands Creek at Uki (1969-1982)

To calibrate the Sacramento models, three data files (i.e. daily rainfall, evaporation and streamflow) were generally required.

3.1 MODEL CALIBRATION AND VERIFICATION

Although six catchments were initially calibrated by comparing the recorded and computed flows characteristics, two catchments were later excluded due to either poor calibration or inadequate data. Therefore, only the four catchments selected for this study are discussed.

The calibration process involved matching the daily flow statistics and peak flow discharges in the observed and calculated flow sequences. However, more weight was given for the simulation of low and medium flows. During the calibration, parameter adjustments were made on the basis of comparison of the recorded and estimated daily flows and the flow duration curves.

After calibration, the selected parameters were used to simulate flows for another period. This was done to verify that the parameters could be used for other periods, and give a similar level of accuracy. The selected calibration and verification periods for each gauging station are shown in Table 3.1.

The data for the Byrrill catchment was used only for calibration, as there was not sufficient record for verification. The parameters that gave the best results for the calibration period for the four catchments are presented in Table 3.2.

Table 3.1: Selected Calibration and Verification Periods

Gauging Station	Calibration	Verification
Uki	1/09/1951-31/12/1981	15/09/1996-31/12/2004
Eungella	22/05/1947-31/12/1994	1/01/1995-31/12/2004
Lower Doon Doon	15/05/1969-31/12/1980	1/01/1981-31/12/1981
Byrrill	12/05/1969-31/12/1982	-

Table 3.2: Calibrated Sacramento Model Parameters

Parameters	Gauging Station			
	Uki	Eungella	Doon Doon	Byrrill
ADIMP	0.15	0.0	0.0	0.08
LZFPM	120	102	51	192
LZFSM	115	76	179	137
LZPK	0.012	0.012	0.011	0.009
LZSK	0.073	0.102	0.057	0.243
LZTWM	220	146	412	274
PCTIM	0.011	0.01	0.014	0.010
PFREE	0.40	0.03	0.60	0.40
REXP	3.0	3.0	3.0	3.0
RSERV	0.30	0.30	0.30	0.30
SARVA	0.001	0.001	0.003	0.007
SIDE	0.01	0.001	0.30	0.04
SSOUT	0.0025	0.001	0.0075	0.0035
UZFWM	91	40	131	144
UZK	0.575	0.65	0.835	0.775
UZTWM	80	217	143	200
ZPERC	35	63	85	35
RFADJ	0.88	0.88	1.0	0.85

Model performances of the calibration and verification calculated for different flow regimes (i.e. low, medium and high flow ranges) are shown in Table 3.3. These three flow regimes were arbitrarily defined according to the Probability of Exceedance (POE) values also in Table 3.3.

Overall model performances were within the range of 0.3 – 13% except for the Doon Doon gauge. The results of this gauge showed high overall verification error. Significant errors were in the simulation of low and high flows. However, for medium flows, the simulated flows overestimated by 6% which was acceptable.

The plots of daily flow data of each gauge for both periods are shown in Appendix B. These plots show that generally, the simulated flow series match well with the recorded flow series.

The calibration and verification for each gauge are discussed separately in the following subsections.

Table 3.3: Model Performance (Volume Difference as %)

Flow Range (POE %)	Assessment for	Gauging Station			
		Uki	Eungella	Doon Doon	Byrrill
Low Flow (99-70%)	Calibration	-0.4	-16.6	-20.5	-0.6
	Verification	-3.9	-4.0	-63.9	-
Medium Flow (69-30%)	Calibration	22.8	18.6	46.7	7.6
	Verification	38.6	29.2	-6.5	-
High Flow (29-1%)	Calibration	50.7	58.0	122.9	13.0
	Verification	14.8	66.6	23.4	-
Overall	Calibration	2.0	-12.6	-16.6	0.3
	Verification	3.0	0.8	-57.6	-

Volume Difference, % = [(simulated flow volume – observed flow volume) / observed flow volume)] × 100

3.1.1 Uki Gauging Station

Tables 3.4 and 3.5 present the calibration flow statistics for the Uki gauge site. The mean daily and monthly flows were simulated reasonably well. The recorded maximum peak flow was underestimated in the Sacramento model for the calibration period, while the mean daily and monthly flows were slightly overestimated in the verification period. As indicated in Table 3.3, low flows were simulated accurately (0.4 – 3.9%), but errors increased in the medium to high flows. Overall, the model simulated flows accurately, giving a calibration error of 2% and verification error of 3%.

Figures 3.1 and 3.2 present the daily flow duration curves for the Uki gauge site. The curves matched reasonably well for the calibration period, but slightly overestimated for the verification period. In this catchment, the flow data for the calibration period was from the pre-Clarrie Hall Dam period, and for the verification period, from the post-dam period. Therefore, this difference might be due to Clarrie Hall Dam's storage effects and special releases from the storage.

Table 3.4: Calibration Statistics for Uki (5/1951 to 12/1981)

Statistic	Recorded	Sacramento
Daily Mean (ML)	541	554
Daily Standard Deviation (ML)	2870	1913
Daily Skew	26.7	10.6
Monthly Mean (ML)	16442	16824
Monthly Standard Deviation (ML)	31344	25657
Maximum Peak Value (ML/day)	153646	53371

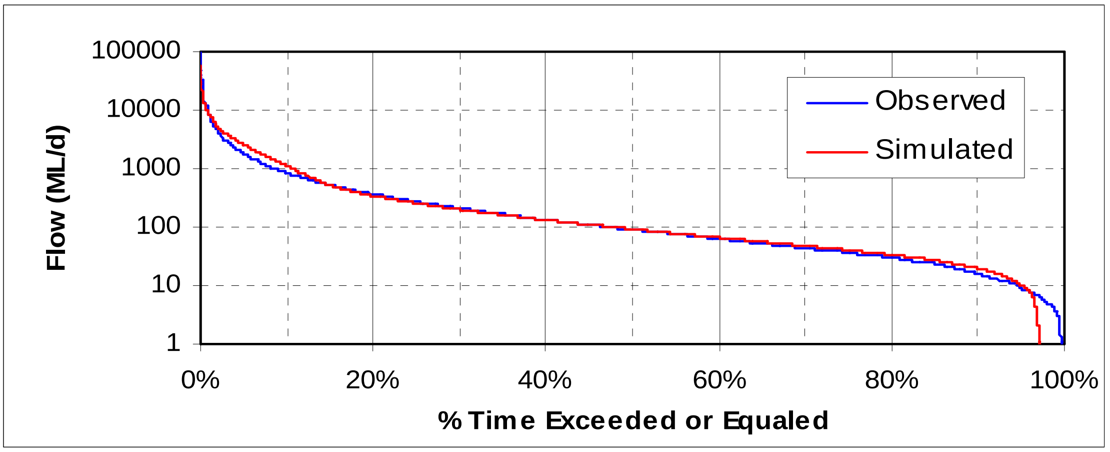

Figure 3.1: Daily Flow Duration Curves for Uki for the Calibration Period

Table 3.5: Verification Statistics for Uki (1/1987 to 12/2004)

Statistic	Recorded	Sacramento
Daily Mean (ML)	351	373
Daily Standard Deviation (ML)	1776	1407
Daily Skew	16.2	12.8
Monthly Mean (ML)	10705	11361
Monthly Standard Deviation (ML)	23047	19550
Maximum Peak Value (ML/day)	60710	47454

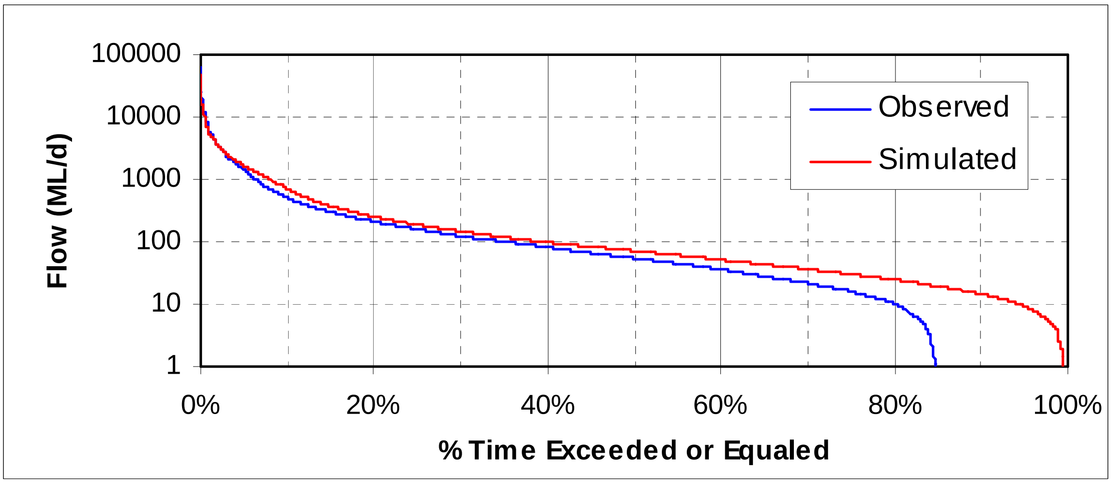

Figure 3.2: Daily Flow Duration Curves for Uki for the Verification Period

3.1.2 Eungella Catchment

Tables 3.6 and 3.7 present the flow statistics for the Eungella gauge site. The mean daily and monthly flows and the maximum peak flow were simulated reasonably well for both the calibration and verification periods. As indicated in Table 3.3, low flows were simulated to a reasonable accuracy (4.0 – 16.6%) but errors increased from the medium to high flows. Overall, the flows were accurately modelled, giving a calibration error of 12.6% and verification error of 0.8%.

Figures 3.3 and 3.4 present the daily flow duration curves for the calibration and verification periods for the Eungella gauge site. Flow duration curves also matched reasonably well for the calibration and verification periods.

Table 3.6: Calibration Statistics for Eungella (5/1947 to 12/1994)

Statistic	Recorded	Sacramento
Daily Mean (ML)	455	398
Daily Standard Deviation (ML)	2070	1601
Daily Skew	15.2	15.0
Monthly Mean (ML)	13792	12005
Monthly Standard Deviation (ML)	25978	21035
Maximum Peak Value (ML/day)	68587	63232

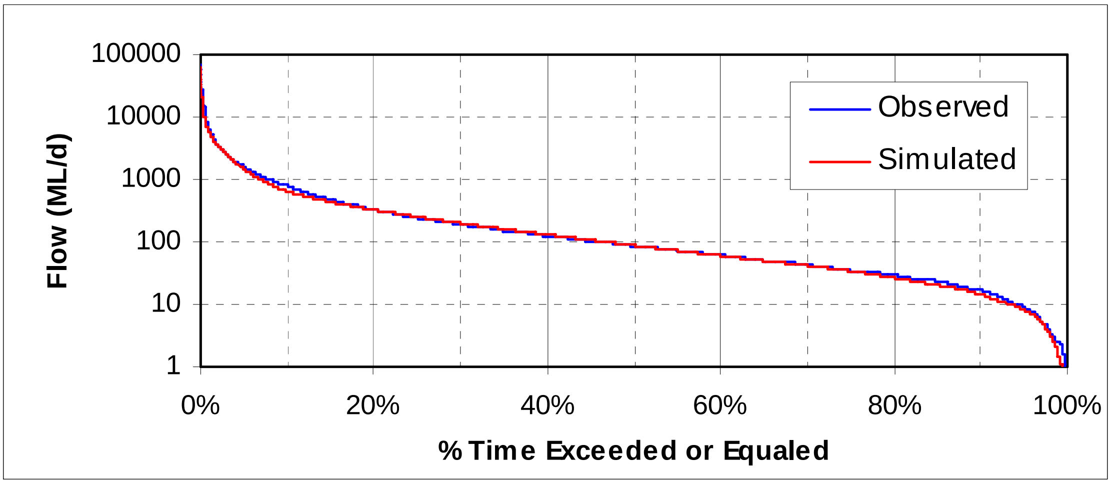

Figure 3.3: Daily Flow Duration Curves for Eungella for the Calibration Period

Table 3.7: Verification Statistics for Eungella (1/1995 to 12/2004)

Statistic	Recorded	Sacramento
Daily Mean (ML)	259	271
Daily Standard Deviation (ML)	1285	1267
Daily Skew	16.8	16.6
Monthly Mean (ML)	7,677	7,997
Monthly Standard Deviation (ML)	15,131	16,081
Maximum Peak Value (ML/day)	35,160	33,811

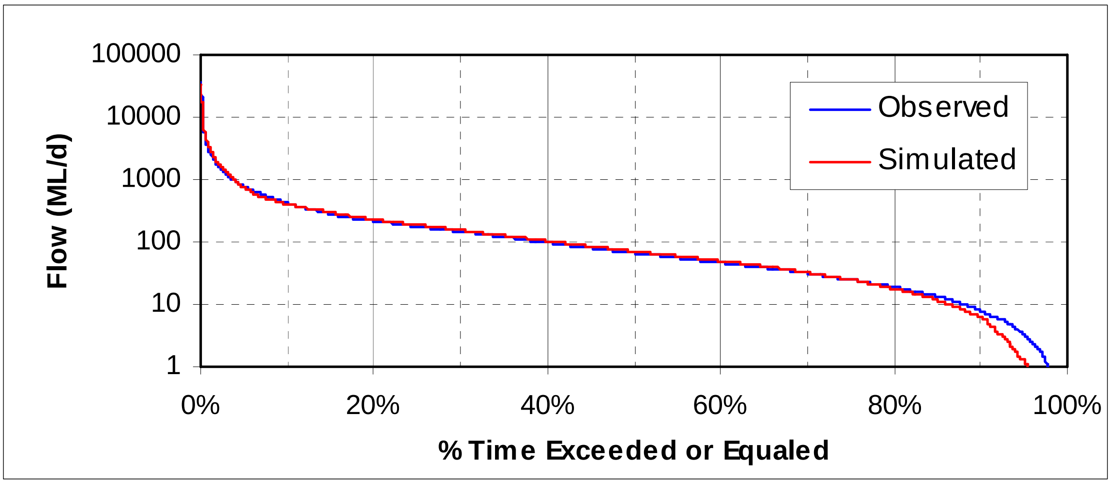

Figure 3.4: Daily Flow Duration Curves for Eungella for the Verification Period

3.1.3 Lower Doon Doon Catchment

Tables 3.8 and 3.9 present the flow statistics for the Lower Doon Doon gauge site. The mean daily and monthly flows were simulated reasonably well for the calibration period, but the maximum peak flow was underestimated. For the verification period, the mean daily and monthly flows, and the maximum peak flow were significantly underestimated. As only one year of data was used for the verification period, this might not reflect the full picture.

As indicated in Table 3.3, low flows were simulated with significant error (20.5 – 63.9%) and errors decreased from the low to medium flows. Overall, the model simulated flows with reasonable accuracy for the calibration period (16.6%) but gave a high error (57.6%) in the verification. At this gauge, the recorded flows were manually computed, giving only mean daily flow figures, not total volumes. Therefore, the recorded data was not accurate, especially in high flows.

Figures 3.5 and 3.6 show the daily flow duration curves for the calibration and verification periods for the Eungella gauge site, which matched reasonably well.

Table 3.8: Calibration Statistics for Lower Doon Doon (5/1969 to 12/1980)

Statistic	Recorded	Sacramento
Daily Mean (ML)	161	136
Daily Standard Deviation (ML)	873	509
Daily Skew	15.8	9.0
Monthly Mean (ML)	4896	4142
Monthly Standard Deviation (ML)	9503	6774
Maximum Peak Value (ML/day)	28625	11369

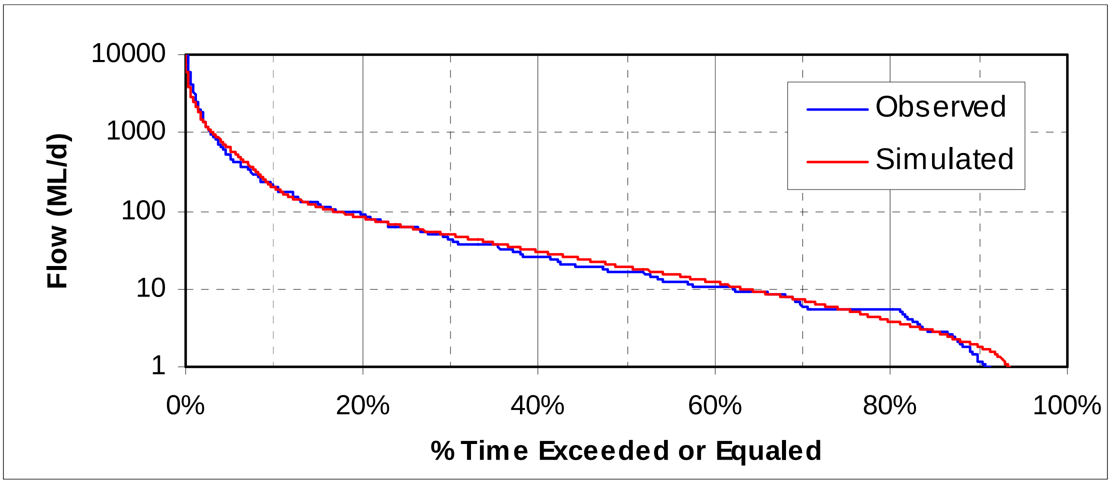

Figure 3.5: Daily Flow Duration Curves for Lower Doon Doon for the Calibration Period

Table 3.9: Verification Statistics for Lower Doon Doon (1/1981 to 12/1981)

Statistic	Recorded	Sacramento
Daily Mean (ML)	99	62
Daily Standard Deviation (ML)	324	168
Daily Skew	7.1	5.4
Monthly Mean (ML)	3009	1893
Monthly Standard Deviation (ML)	4704	2504
Maximum Peak Value (ML/day)	3568	1515

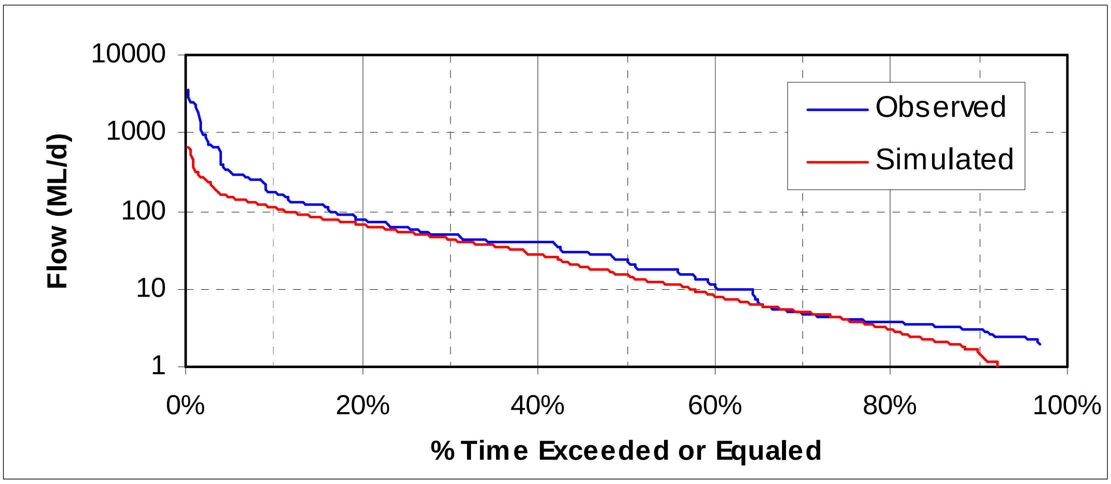

Figure 3.6: Daily Flow Duration Curves for Lower Doon Doon for the Verification Period

3.1.4 Byrrill Catchment

Table 3.10 presents the flow statistics for the Byrrill Creek gauge site. The mean daily and monthly flows were simulated reasonably well for the calibration period but the maximum peak flow was slightly underestimated.

As indicated in Table 3.3, flows for all three flow regimes were simulated accurately (0.6 – 13%). Overall, the model simulated flows accurately, giving a calibration error of 0.3%. Flow data was not sufficient to do verification for this catchment.

Figure 3.7 shows the daily flow duration curves for the calibration period.

Table 3.10: Calibration Statistics for Byrrill (1/1969 to 12/1982)

Statistic	Recorded	Sacramento
Daily Mean (ML)	118	121
Daily Standard Deviation (ML)	567	468
Daily Skew	15.0	10.2
Monthly Mean (ML)	3608	3674
Monthly Standard Deviation (ML)	6539	6377
Maximum Peak Value (ML/day)	15500	10685

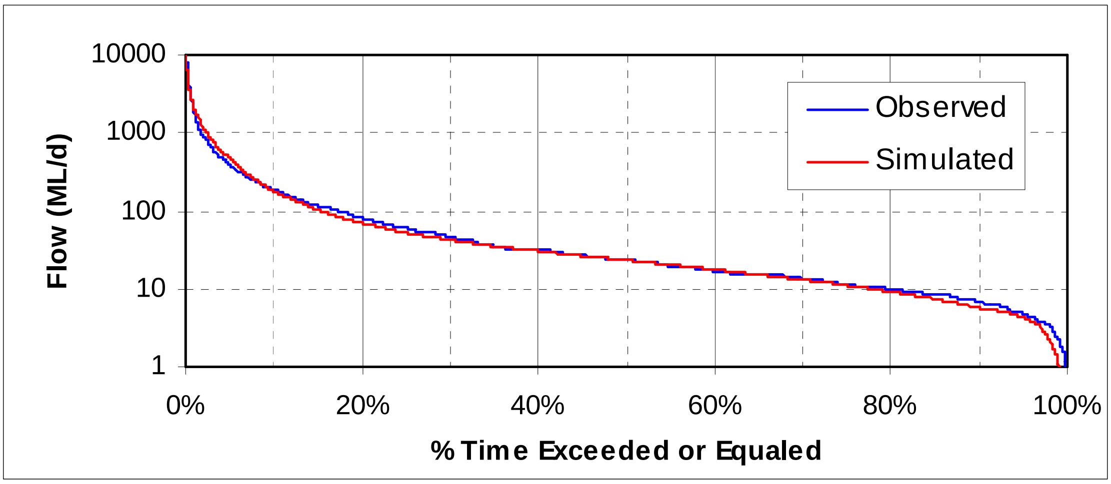

Figure 3.7: Daily Flow Duration Curves for Byrrill for the Calibration Period

3.2 STREAMFLOW EXTENSION

The Sacramento model was run with the calibration parameters and the appropriate rainfall and evaporation data, to obtain long-term daily flows of the four catchments for the simulation period (01/01/1890 – 31/12/2004). The simulated stream flows were used wherever recorded data did not exist within the simulation period, as indicated in Table 3.11.

Table 3.11: Streamflow Data Used in Simulation

Catchment	Sacramento Data		Recorded Data	
	From	To	From	To
Uki	01/01/1890	28/06/1967	29/06/1967	09/11/1976
	10/11/1976	1/12/1976	02/12/1976	19/11/1980
	20/11/1980	18/12/1980	19/12/1980	17/07/1983
	18/07/1983	31/08/1983	01/09/1983	14/08/1984
	15/08/1984	17/10/1984	18/10/1984	27/05/1986
	28/05/1986	17/07/1995	18/07/1995	09/01/2003
	10/01/2003	23/01/2003	24/01/2003	31/12/2004
Eungella	01/01/1890	21/05/1947	22/05/1947	07/04/1957
	8/04/1957	30/06/1957	01/07/1957	25/03/1963
	26/03/1963	17/05/1963	18/05/1963	14/11/1963
	15/11/1963	20/11/1963	21/11/1963	16/03/1985
	17/03/1985	27/03/1985	28/03/1985	03/05/1985
	04/05/1985	27/05/1985	28/05/1985	16/02/1994
	17/02/1994	22/02/1994	23/02/1994	08/02/1995
	09/02/1995	31/12/2004		
Lower Doon Doon	01/01/1890	14/05/1969	15/05/1969	01/01/1982
	02/01/1982	31/12/2004		
Byrrill	01/01/1890	11/05/1969	12/05/1969	01/01/1982
	02/01/1982	31/12/2004		

3.3 SUMMARY OF SACRAMENTO MODEL CALIBRATION

Rainfall-runoff models (Sacramento models) for four gauging stations (Uki, Eungella, Lower Doon Doon and Byrrill) were developed and calibrated. The catchment rainfall was estimated from the SILO database, which was considered more accurate than the estimates from point rainfall used in the 2002 study. Long-term evaporation data was obtained from a combination of recorded data and the average monthly evaporation, although the data used for the calibration and verification periods was recorded data.

The simulated flow volumes were compared with the recorded flow volumes for the calibration and verification periods. The flows of Uki, Eungella and Byrrill gauges produced acceptable results, with volume differences for these gauges between 0.8 – 12.6%.

The flows of Doon Doon gauge, although giving acceptable results for the calibration period of 11 years, produced model errors for the verification period (57% under-estimated). Medium flows were simulated accurately, but significant errors occurred in high flow simulations. At this gauge, the recorded flows were manually computed to give mean daily flow figures. Therefore, the recorded data was less accurate, especially in high flows.

Inflows into Clarrie Hall Dam from 1991 to 2005 were also calculated using a water balance. The calculated inflow series were compared with the simulated one and produced some differences. However, the uncertainty in release estimates and inaccuracies in storage heights indicated that these values were no more accurate than the Sacramento flows, so the Sacramento inflows to Clarrie Hall Dam series were used in the analysis.

The flows developed in this study were more accurate than those developed in the 2002 study, as, in the 2002 study, daily flows were developed for two gauging stations (Uki and Eungella) and distributed throughout the catchments using area proportions.

In the current study, four gauges were used for the calibration and the relevant model parameters were used for the corresponding sub-catchments. Recorded evaporation was used for the calibration, but in the previous study, average evaporation was used.

4.0 IQQM SETUP

The Integrated Quantity Quality Model (IQQM) Version 7.49.0 (GUI) (DLWC, 2004) was initially used to provide a daily simulation model of the catchment, but the model proved to have some programming errors. Therefore, the reliable 'DOS version' of the model (Version 6.73.004) was used.

The IQQM was set up according to information provided by the Tweed Shire Council. This included the method of operating the system, whereby Clarrie Hall Dam only releases water downstream to Bray Park Weir when the weir drops below a certain level. Restrictions would be imposed as indicated in Table 6.4. Clarrie Hall Dam would be used to maintain the weir at a certain level, but would not be used to supplement the fish ladder releases.

The fish ladder on Bray Park Weir operates whenever the storage is high enough, and this was modelled with a flow control table based on volume of the weir against discharge from the fish ladder. Actual releases from the fish ladder were not recorded. This was a significant drawback in the model calibration.

The system Node Diagram is shown in Appendix C, together with the IQQM system file.

4.1 IQQM CALIBRATION DATA

4.1.1 Streamflows

From the extended flow series at the gauge sites, flows were then distributed according to catchment area proportions to get the flow series at inflow points of the IQQM. The summary of this flow derivation is given in Table 4.1.

Table 4.1: Inflow Derivation for IQQM

Inflow Point	Gauge Site Used for the Derivation	Relationship or Method Used
Upstream of Clarrie Hall Dam (CHD)	Lower Doon Doon (GS 201011)	CHD inflow = 1.11 × GS 201011 flow
Upstream of proposed Byrrill Creek Dam (BCD)	Byrrill Creek (GS 201010)	BCD inflow = 0.70 × GS 201010 flow
Upstream of Tyalgum	Eungella (GS 201001)	Tyalgum inflow = 0.18 × GS 201001 flow (Flows less than 1 ML were set to zero)
Residual flow at Eungella	Eungella (GS 201001)	Residual inflow = 0.82 × GS 201001 flow
Residual flow from the area excluding the catchments of CHD and BCD up to the confluence point of Byrrill Creek and Tweed River	Uki (GS 201900)	Residual inflow = 0.54 × (GS 201900 flow – CHD inflow – BCD inflow); negative flows replaced by zeros
Residual flow from the area between downstream of the confluence point of Byrrill Creek and Tweed River to Uki gauge	Uki (GS 201900)	Residual inflow = 0.46 × (GS 201900 flow – CHD inflow – BCD inflow); negative flows replaced by zeros
Residual flow from the area covering downstream of Uki and Eungella gauges up to Bray Park Weir	Uki (GS 201900) & Eungella (GS 201001)	Residual inflow = 0.13 × (GS 201900 flow + GS 201001flow)

For the calculation of the residual flow upstream of the Uki gauge, the flow series was adjusted for the releases from Clarrie Hall Dam for the post-dam period (1986–date). For this period, total residual flows were calculated by subtracting Clarrie Hall Dam releases and Byrrill Creek Dam simulated inflows from the recorded flows at Uki.

4.1.2 Long-Term Evaporation Data

As the evaporation record used for this analysis extended only from 1971 to 2004, the average evaporation and Nambour potential factors given in Table 2.4 were applied to cover the remainder of the full simulation period (01/01/1890 – 31/12/2004).

4.1.3 System Demands

The known demands on the system are tabulated below in Table 4.2. Recorded usage data from the Bray Park Weir pumping station were available and have already been summarised in Section 2.5. The daily usage of Uki and Tyalgum townships, and irrigators upstream of Bray Park Weir, were not recorded but are small. However, an allowance was made for these small extractions by modelling them as constant demands over the year (Table 4.2).

Generally, Bray Park Weir was operated reasonably full (about 100 mm from FSL of the weir). However, during the recent dry period (2001-2003), the storage was allowed to drop below the invert level of the fish ladder, at which point irrigation was banned. The bans were independent of the low flows at Uki and Eungella.

Table 4.2: System Demands for Model Calibration

Site	Demand	Pattern	Restrictions
Uki TWS	60 ML/a	Constant	No restriction
Tyalgum TWS	50 ML/a	Constant	No restriction
Tweed District WS	Recorded usage data (Table 2.5)	Actual daily usage	No restriction
Irrigators from Bray Park Weir pool	730 ML/a	Constant	No diversions allowed when BPW level less than 405 ML

4.1.4 Blue-Green Algae (BGA) Releases

According to the data provided by Tweed Shire Council, two releases from Clarrie Hall Dam to flush BGA from Bray Park Weir were recorded in 1996 and 2001. The volumes of these flushing releases were approximately 1,400 ML and 3,300 ML respectively. These releases were also added to the regular releases from Clarrie Hall Dam.

4.1.5 Environmental Flow Requirements

The current environmental flow requirements are shown in Table 4.3.

Table 4.3: Environmental Flow Requirements

Clarrie Hall Dam	Bray Park Weir	Tyalgum Weir
Lesser of inflow to dam and 1.1 ML/day Sep to Apr 0.8 ML/day May to Aug	Releases through fish ladder, as defined (i.e. vary from 0 to 25ML/d when storage increases from 405 ML to Full	Not considered

4.2 IQQM MODEL CALIBRATION

The model was calibrated using recorded streamflows and recorded usage from the various sites. Streamflow data was obtained from the Department of Infrastructure Planning and Natural Resources (DIPNR) and actual usage and release data from Tweed Shire Council.

4.2.1 Calibration of Inflows to Clarrie Hall Dam

Inflow series generated from the Sacramento model matched reasonably well with flows calculated from the water balance based on recorded data at Clarrie Hall Dam. This was a sanity check for the accuracy of the Sacramento flow series. Therefore, the Sacramento inflow series was selected for the rest of the calibration.

4.2.2 Calibration Upstream of Uki

Residual catchment flows were calculated using the area proportion method, which can produce some inconsistencies. To maintain the water balance in the system, a loss node was included in the reach above Uki. This node was calibrated using the recorded Uki gauging flows together with the estimated inflows upstream of the gauge, and the releases from Clarrie Hall Dam, through matching the Uki simulated flow duration curve to the recorded one. The final calibration curves are shown in Figure 4.1., and match well except for very small flows. The calibrated loss values are shown in Table 4.4.

It is worth noting that these loss values do not reflect the actual transmission losses, as all errors in inflow data and outflow measurements of Clarrie Hall Dam are also compensated for at this loss node. Therefore, this information should not be used for making any decision regarding the possible transmission losses between Clarrie Hall Dam and Bray Park Weir.

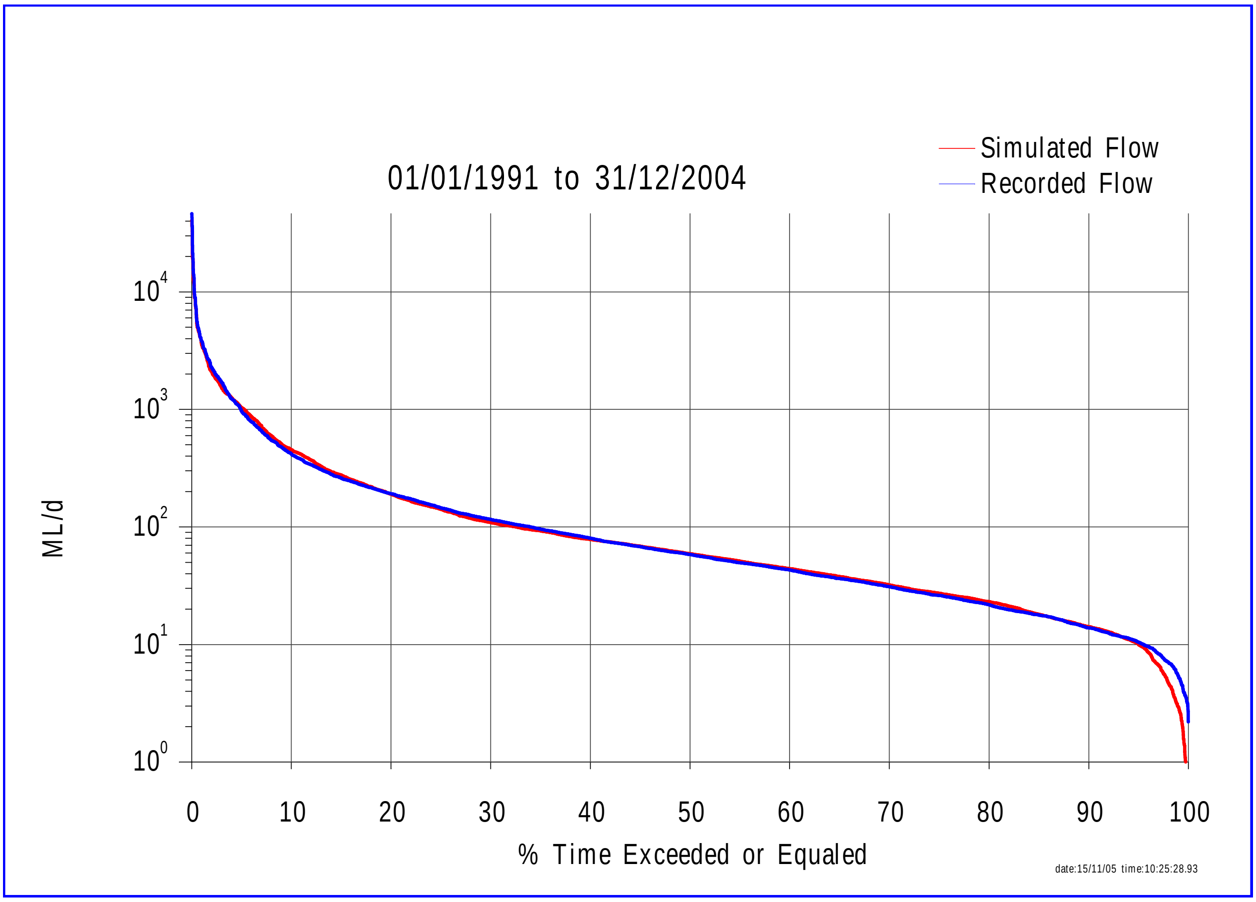

Figure 4.1: Uki Flow Duration Curves with a Loss Node

Table 4.4: Loss Model Upstream of Uki

River Flow (ML/d)	Loss (ML/d)
0	0
10	0
42	10
116	15
530	100
> 530	100

4.2.3 Calibration Downstream of Uki

To maintain the water balance in the system, a loss node was included in the reach downstream of Uki. The losses were calibrated using the recorded Uki and Eungella flows, the estimated residual flow upstream of Bray Park Weir, and recorded usage data, assumed fish ladder operation and irrigation usages. Evaporation loss and rainfall at Bray Park Weir were also considered. The visual inspection of Bray Park Weir during its current rehabilitation suggested minimal leakage through the structure.

The simulated storage volumes for the period of 14/09/2003 to 31/12/2004 were compared with the recorded storage levels. Adjustments to the loss values and routing parameters in the reach were made to get the best fit of these two curves. The final loss calibration plots are shown in Figure 4.2.

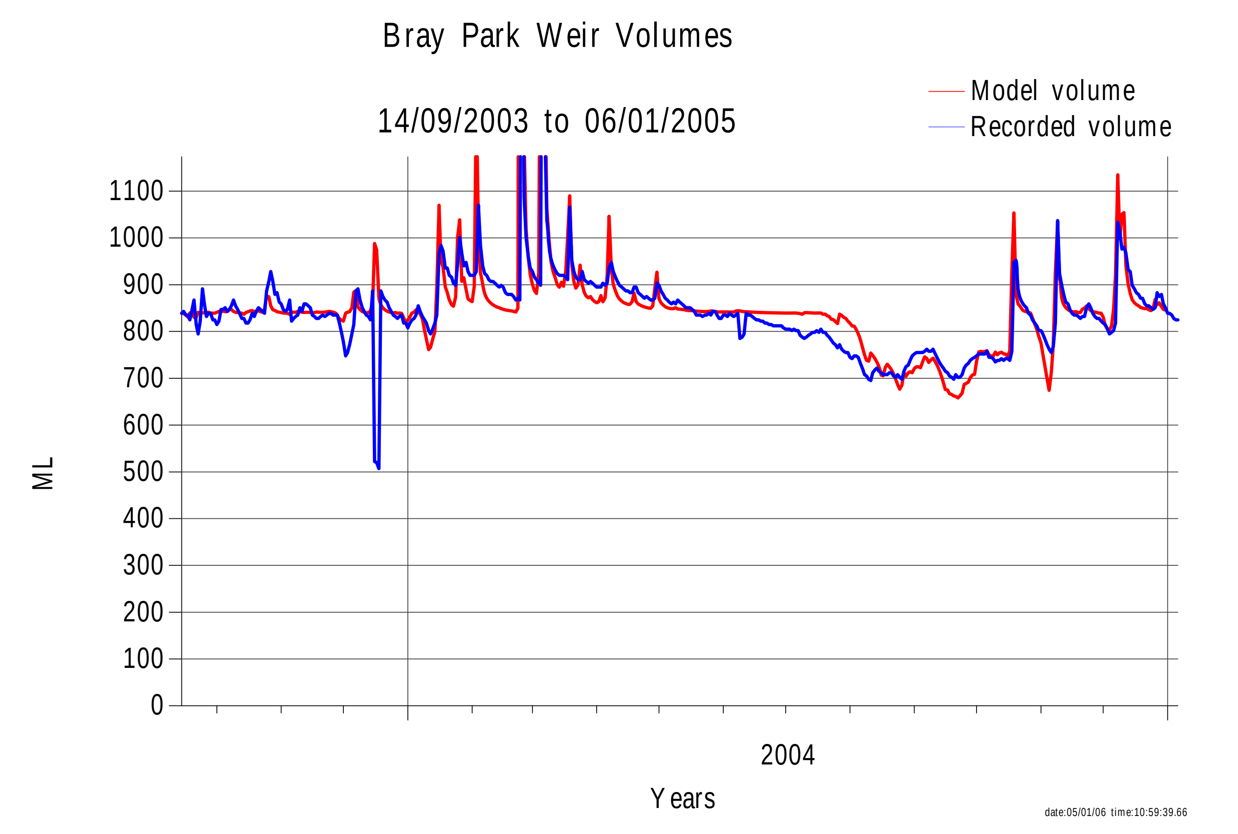

Figure 4.2: Simulated and Calibrated Storage at Bray Park Weir

In this plot, the volumes matched reasonably well, and the recession curves fitted. The calibrated loss values are shown in Table 4.5. The lag time of 0.25 days provided the best fit with no flood routing.

Table 4.5: Loss Model Downstream of Uki

River Flow (ML/d)	Loss (ML/d)
0	0
50	10
100	20
>100	30

According to the available data, there is no reliable method to estimate the actual transmission losses between the reach of Uki gauge and Bray Park Weir unless actual flow measurements are carried out. The calibrated loss values do not reflect the actual transmission losses, as all the errors in inflow data series and outflow measurements of Bray Park Weir are also compensated for at these loss nodes.

4.2.4 Calibration of IQQM for Whole System

The IQQM was set up for the whole system, incorporating the loss nodes and lag time obtained from the calibrations described in the previous sections. The recorded Tweed District water supply was included as an extraction node. The system was run for the period from 01 January 1991 to 31 December 2004.

The recorded storage behaviour of Clarrie Hall Dam, especially during the recent drought period between 2001 and 2003, was used for the calibration of the model. During this period, the operation of the system was not undertaken in a uniform and consistent manner, which made calibration of the model difficult. As only uniform behaviour of the system could be modelled, the following factors were varied until an optimal system operation was achieved.

- Bray Park Weir storage levels maintained from Clarrie Hall Dam releases
- Fish ladder operations of Bray Park Weir

The optimal values are shown in Table 4.6 and the corresponding plot is shown in Figure 4.3.

Table 4.6: Optimum Calibrated Operational Parameters

<table>
<tr><th>Operational Parameter</th><th colspan="2">Value</th></tr>
<tr><td>Bray Park Weir maintained level</td><td colspan="2">405 ML</td></tr>
<tr><td rowspan="4">Fish ladder discharge curve</td><td>BPW Commandable Storage Level (ML)</td><td>Fish Ladder Discharge (ML/d)</td></tr>
<tr><td>0</td><td>0</td></tr>
<tr><td>405</td><td>0</td></tr>
<tr><td>648</td><td>25</td></tr>
</table>

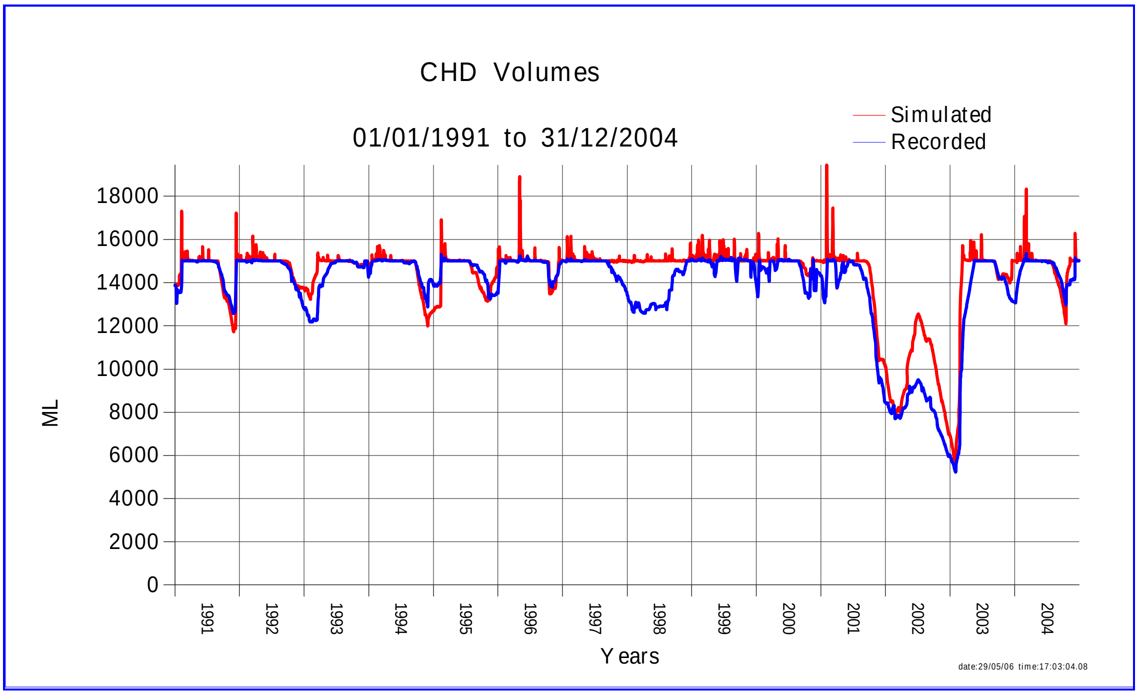

Figure 4.3: Simulated and Calibrated Storage Volume of Clarrie Hall Dam

4.3 SUMMARY OF IQQM MODEL CALIBRATION

The system simulation model (IQQM) was calibrated using the simulated flow series, evaporation data, system data, recorded streamflow data, and recorded releases and storage levels, although there was reasonable doubt about the accuracy of the release estimates.

Water balance loss nodes upstream of Uki gauge and Bray Park Weir were incorporated to ensure the flows at Uki and the storage levels of Bray Park Weir respectively simulated the recorded data.

The IQQM was calibrated using the recorded storage levels of Clarrie Hall Dam. Investigations were carried out to see whether the model could mimic the historical behaviour of Clarrie Hall Dam, particularly over the recent drought, by adjusting the releases and operating strategies.

The incorporation of two abnormal releases of water to flush a blue-green algal bloom out of Bray Park Weir in 1996 and 2001 significantly improved the calibration. The Clarrie Hall Dam calibration plot was not as definitive as expected, but the system had not been operated in an efficient fashion in the past.

The drop in the storage level of Clarrie Hall Dam in 1998 could not be replicated. Recorded rainfall at the time resulted in the Sacramento model providing a significant inflow, which was not reflected in the storage.

Given the accuracy of the available data and uncertainty in some input parameters in the model, the calibration of the IQQM was considered satisfactory.

5.0 DISCUSSION ON CALIBRATION ISSUES

These models were developed with available data, but there were some uncertainties in this data and in the operational procedure of the system. The major issues and limitations of these models are:

- In the rainfall-runoff model calibration, rainfall and evaporation data may not be representative of the corresponding catchments. It is recommended that further evaporation and rainfall data be collected, and used to refine the calibration.
- It was identified that there were some errors in the measured streamflows. In some locations, streamflow data was not available (i.e. downstream of Clarrie Hall Dam, confluence of Byrrill Creek and Doon Doon Creek, and upstream of Bray Park Weir). At these sites, extrapolated data from other sites, according to catchment area, was used. In the future, if gauging stations are placed at these points, the data should be used for further model calibration.
- Storage releases and the operation of the fish ladder were not recorded for the calibration period. Therefore, best estimates only were used. It is recommended that the fish ladder releases and detailed information on storage operations are recorded, allowing better calibration in the future.
- Recorded usage data was not available for the Uki TWS, Tyalgum TWS and irrigators. A uniform usage pattern was used in the calibration. It is recommended that information be collected and the model recalibrated with the recorded daily usage data at these sites.
- The calibrated loss values do not reflect the actual transmission losses, as all the errors in inflow data series and outflow measurements of Clarrie Hall Dam are compensated for at these loss node values. Therefore, no conclusions about the transmission loss between Clarrie Hall Dam and Bray Park Weir should be drawn from this study.
- Only uniform behaviour of the system was modelled, as operational inconsistencies cannot be modelled accurately using IQQM.

6.0 DATA FOR SCENARIO MODELLING

The scenario analyses used streamflow, rainfall and evaporation data generated in IQQM for the full simulation period (1890 – 2004). However, additional information was required to undertake the scenario modelling, such as:

- Demands within the system
  - Current Demands
  - Future Demands
  - Pattern of Demand
- Restrictions to be imposed on these demands
- Determination of contingency storages
- Future operation of Bray Park Weir
- Updated storage curves for existing and proposed storages

6.1 SYSTEM DEMANDS

6.1.1 Current Demands

The system demands are shown in Table 6.1, together with the monthly demand pattern applied to each demand.

Table 6.1: System Demands

Site	Demand (ML/a)	Pattern
Uki TWS	60	Constant
Tyalgum TWS	50	Constant
Tweed District WS	10,900 (Present) 24,500 (Full development)	See Table 6.2
Irrigators from ponded area of Bray Park Weir	730	Constant

6.1.2 Future Demands

Future fixed demand was calculated by Tweed Shire Council using the following procedure:

1. Extract recorded use data from 1991 – 2005
2. Calculate per capita usage for each year
3. Calculate maximum, average and minimum usages from the recorded period
4. Plot per capita usage against the population to identify the trend.
5. Adjust the average per capita usage to incorporate the trend identified with increase of population.
6. Estimate the fixed demand according to forecasted population

The resultant annual fixed demands for various population sizes are shown in Table 6.2.

Table 6.2: Estimated Murwillumbah Urban Demand

Projection	Population	Estimated Usage (KL/year/person)	Annual Fixed Demand (ML)
Current	71,394 (current)	152.3	10,871 (Say 10,900)
Near Future	75,000	150.0	11,250
Medium Term (10 to 15 years)	125,000*	145.0	18,125
Long Term (> 30 years)	175,000*	140.0	24,500

Source: Tweed Shire Council

6.1.3 Pattern of Demand

6.1.3.1 Average Pattern

Tweed Shire Council provided daily extraction data from 1991 to 2005. Using this data, an average monthly pattern of use was derived, shown in Table 6.3. This pattern of demand was used for all scenarios.

Table 6.3: Water Usage Pattern

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Average Use (ML)	917	728	762	724	697	674	731	794	852	891	814	882	9466
Monthly Pattern	9.7	7.7	8.0	7.6	7.4	7.1	7.7	8.4	9.0	9.4	8.6	9.4	100.0

Monthly factors were computed according to the average monthly usage from the recorded usage data from 1991 to 2004. Therefore, the historic average annual usage (9466 ML) is different to the current annual usage of 10,900 ML.

6.1.3.2 Climatic Pattern of Demand

The Water Services Association of Australia guidelines (WSAA, 2005), recommend that seasonal variations in demands should be modelled, as urban demands often exhibit a high seasonal variation. Therefore, as well as using a fixed annual demand from the system, demands that varied according to the climate were also investigated. To determine such variable demands, a relationship between demand and climate factors based on rainfall, evaporation and temperature were defined.

To find suitable correlations between demand and evaporation, rainfall, or temperature, statistical analyses were carried out. The rainfall data extracted from the SILO database for the period from 1890 to 2004 was first classified into wet, medium and dry periods. The wet, medium and dry periods were defined according to the probability of exceedance (POE) of < 30%, 30% - 70% and > 70% for each month. The corresponding values for this categorisation are shown in Table 6.4.

Table 6.4: Rainfall Statistics & Categorisation (1890 -2004 SILO data)

Month	Monthly Rainfall (mm)			Dry (> 70% POE)	Medium (70 - 30% POE)		Wet (<30% POE)
	Max	Average	Min	<	From	To	>
January	940	213	21	115	116	160	161
February	935	232	8	123	124	244	245
March	948	242	18	124	125	249	250
April	888	151	9	70	71	160	161
May	760	135	0	68	69	158	159
June	867	109	0	34	35	131	132
July	504	84	1	32	33	87	88
August	280	61	0	23	24	74	75
September	177	55	0	25	26	72	73
October	593	97	1	53	54	108	109
November	457	118	17	61	62	144	145
December	604	166	17	95	96	192	193
Annual	**2993**	**1664**	**789**	**1382**	**1383**	**1877**	**1878**

As an initial estimate, annual data was used to see if there were relationships between usage data and rainfall, evaporation, or temperature. It was found that there was a very poor correlation between each of these relationships.

The same analysis was extended to a monthly basis. In this case although some months showed reasonable correlations, most of the monthly relationships were poor. Additionally, during some months, it was found maximum and minimum usage occurred during the same rainfall or temperature.

Two methods for use estimation were also tested with the available data set. The first method was to estimate the usage from the regression equations of usage and rainfall for each month. The second method was to estimate the usage according to the rainfall categorisation (based on the values given in Table 6.3). The following factors were used for the estimation.

- usage for dry months = 110% of the average usage
- usage for medium months = 100% of the average usage
- usage for wet months = 95% of the average usage

Prediction errors for these two methods were compared for the available usage data set. Related plots for this analysis are shown in Appendix D. It was concluded that neither of the tested methods were accurate enough to estimate the climatic demand.

This could be the result of any of the following:

- The available data set may be considered too small to achieve any valid relationship, with recorded water use only being available from 1991 to 2004.
- Variation in water use may not show during a monthly time step, and perhaps daily time steps (if the data is available) may show better results.
- The climate variability in the Tweed River catchment may not be significant over the period of recorded data.

Therefore, until more data is available, or a better statistical analysis is possible, it was not possible to continue this investigation into climatic variability of demand.

6.2 RESTRICTIONS

Restrictions to the Tweed District water supply were to be based solely on the storage level of Clarrie Hall Dam (Table 6.5).

Table 6.5: Demand Restriction Policy

Restriction Level	Target Reduction in Consumption (%)	Imposed at Commandable Storage Volume of CHD (%)
Level 1	10	50
Level 2	15	45
Level 3	20	35

Note: In the 2002 study, 20% reduction for storage below 50% was assumed.

The restriction rule is applied to the commandable volume or the usable volume of the storage, which is defined as the total storage volume minus the minimum operating volume.

6.3 CONTINGENCY STORAGE

The Water Services Association of Australia (WSAA, 2005) paper states that:

> *The volume of water should be reserved in a storage to take account of unprecedented climatic fluctuations and growth in demand. This storage provides a "buffer" or contingency if actual drought conditions are more severe than design drought conditions. The size of the contingency storage depends on the consequence of a community running out of water and the additional cost associated with reserving this volume. Each water utility will have different level of service objectives commensurate with this risk. Gold Coast Water and South East Queensland Water, for instance, have opted to adopt very high level of service standards because it is extremely difficult to put in place emergency supply options for major urban centres within an appropriate timeframe.*

Tweed Shire Council recommended the use of 80% of the annual town supply demand as a contingency storage. In this situation, the net inflow into the CHD was assumed as zero. This assumption was checked with the analysis of inflow series and losses from CHD for a base case, and it was found that net inflows in to the dam was always greater than zero (i.e. Minimum net annual inflow was 1600 ML) Therefore 80% of the demand assumption for contingency storage is reasonable.

When a restriction rule is applied, the commandable storage is first calculated by deducting the contingency storage from the total storage volume. Then, the first restriction rule is applied when the commandable storage drops to 50% and lower.

6.4 FUTURE ENVIRONMENTAL FLOW REQUIREMENTS

Advice from Tweed Shire Council was that new environmental flow requirements may be introduced in New South Wales in the near future. This involves the requirement of the 80% and 95% Probability of Exceedance (POE) flows to be passed through the system.

These monthly flow values were calculated from the simulated inflow series for Clarrie Hall Dam (CHD), Byrrill Creek Dam (BCD) and Bray Park Weir (BPW). The environmental flow requirements from Bray Park Weir were calculated from the simulated inflow series corresponding to the pre-development situation (i.e. without Clarrie Hall Dam upstream). Monthly environmental flow requirements from the storages corresponding to the 80% and 95% POE are given in Tables 6.6 and 6.7.

Table 6.6: 80% POE Environmental Flows (ML/d)

Storage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Clarrie Hall Dam	2	10	29	23	16	11	7	5	3	2	1	1
Byrrill Creek Dam	4	7	15	16	17	15	12	10	8	6	5	4
Bray Park Weir	34	65	175	156	121	86	69	53	40	31	31	32

Table 6.7: 95% POE Environmental Flows (ML/d)

Storage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Clarrie Hall Dam	0	1	6	5	7	5	3	2	1	0	0	0
Byrrill Creek Dam	1	4	3	4	7	6	6	5	4	3	2	1
Bray Park Weir	12	20	35	40	55	48	38	30	17	15	12	13

6.5 FUTURE OPERATION OF BRAY PARK WEIR

Bray Park Weir is to operate such that only natural inflows into the weir are available for release through the fish ladder. Clarrie Hall Dam will only release water to Bray Park Weir to maintain a level 10 cm below the fish ladder outlet.

Irrigation and environmental flow releases from Bray Park Weir were based on the storage level of the weir as shown in Table 6.8.

Table 6.8: Restrictions on Bray Park Weir Users

Bray Park Weir Level (ML)	Releases for Irrigation (%)	Releases from Fish Ladder (ML/d)
0	0	0
405	0	0
406	100	0
450	100	5
≥648	100	25

6.6 STORAGE CURVES

A number of scenarios were proposed for either raising the existing storages, building an additional storage or both. Details of these proposed storage curves are listed below and corresponding storage curves are attached in Appendix E.

6.6.1 Revised Clarrie Hall Dam

Clarrie Hall Dam's storage curve was linearly extended from the current FSV of 16,000 ML up to 45,000 ML using the original curve in the Operation and Maintenance Manual of Tweed Shire Council (1984).

6.6.2 Revised Bray Park Weir

For the increased capacity of Bray Park Weir, the storage curve given in Plan Number 218541 was used.

6.6.3 New Byrrill Creek Dam

Digital 2.5 m contours were used for the derivation of storage curve for the proposed Byrrill Creek Dam. This curve was extended up to 58,000 ML (130 m AHD).

7.0 SYSTEM MODELLING

The calibrated IQQM was used for a range of scenarios to evaluate system performance for three major areas of concerns:

- The existing system under different management scenarios
- Future environmental flow impacts
- Supply augmentation options

The first two points are discussed in this section and the third is discussed in Chapter 8. The system node diagram and system file for the full development case are given in Appendix F. All scenarios with associated variables and results are summarised in the table in Appendix I.

7.1 DEFINITIONS OF SECURITY CRITERIA

Hunter Water Australia has provided comments on the various performance criteria used in this water supply security review. These comments are attached in Appendix G. The following points briefly describe the different performance criteria.

7.1.1 Historic No Failure Yield

The Historic No Failure Yield (HNFY) is the maximum annual volume of water that could be extracted from the system each and every year of the analysis, without failure of supply. Water could be extracted down to the minimum operating volume of the storages.

7.1.2 System Yield with Restrictions

The system yield with restrictions is the volume of water that could be supplied from the system for the majority of years of the analysis. Whenever the dominant storage falls below a chosen level, the annual demand is restricted to a pre-determined percentage of the full demand, until the storage increased back to the chosen level. This yield would be larger than the HNFY.

7.1.3 Monthly Reliability

The monthly reliability is the percentage of months out of the total simulation period that the restricted or unrestricted demand can be fully met. If the water level drops below the minimum operating level and takes a reasonable time to recover, it will be counted as a failure. Therefore, the system reliability of the HNFY cases will be 100%.

7.1.4 Number of Restrictions

The number of restrictions is the number of occasions that the full demand cannot be met. This can be estimated by counting the number of occasions where the storage is below the upper restriction level.

7.2 EXISTING SYSTEM PERFORMANCE

The existing system was analysed under a range of demand and operational conditions, including different restriction levels and contingency storages. Conditions which stayed constant throughout the scenarios, included:

- The fish ladder was operated to release up to 25 ML/d of flow when Bray Park Weir storage was greater than 405 ML.
- The 730 ML/a irrigation demand was supplied from Bray Park Weir when its storage was greater than 405 ML.
- The existing commandable capacity of Clarrie Hall Dam (15,000 ML) was assumed in the simulations.

The scenarios to be considered for the existing system are:

1. Historic No Failure Yield
2. System yield with restrictions
3. System yield with DEUS criteria
4. System yield with restrictions and contingency storage
5. System performance for current and future of demands

7.2.1 Historic No Failure Yield Scenario Analysis

The current system was analysed without any restrictions applied to the town water supply and without a contingency storage.

The historic no failure yield highlighted that, while no failure occurred, it almost happened during the 2002/03 drought. Storage levels were dangerously low (ie almost 0%), which in reality, would not be acceptable. This analysis produced a historic no failure yield of 16,200 ML/a. When the current model was run for the same period as the 2002 study (1890 to 2001), the HNFY was 16,600 ML/a.

In the 2002 study, the critical period influencing the results was the 1902/03 drought, while in the current study, it was the drought of 2002/03. The major improvements in the current model compared to the 2002 model include:

- Derivation of a more accurate inflow series for Clarrie Hall Dam, rather than based on area proportion of the inflow data at Uki gauge.
- Incorporation of loss nodes to simulate recorded flow at the Uki gauge and storage behaviour of Bray Park Weir.

The storage plot of Clarrie Hall Dam corresponding to this case is shown in Figure 7.1, which highlights the most critical period of the 2002/03 drought.

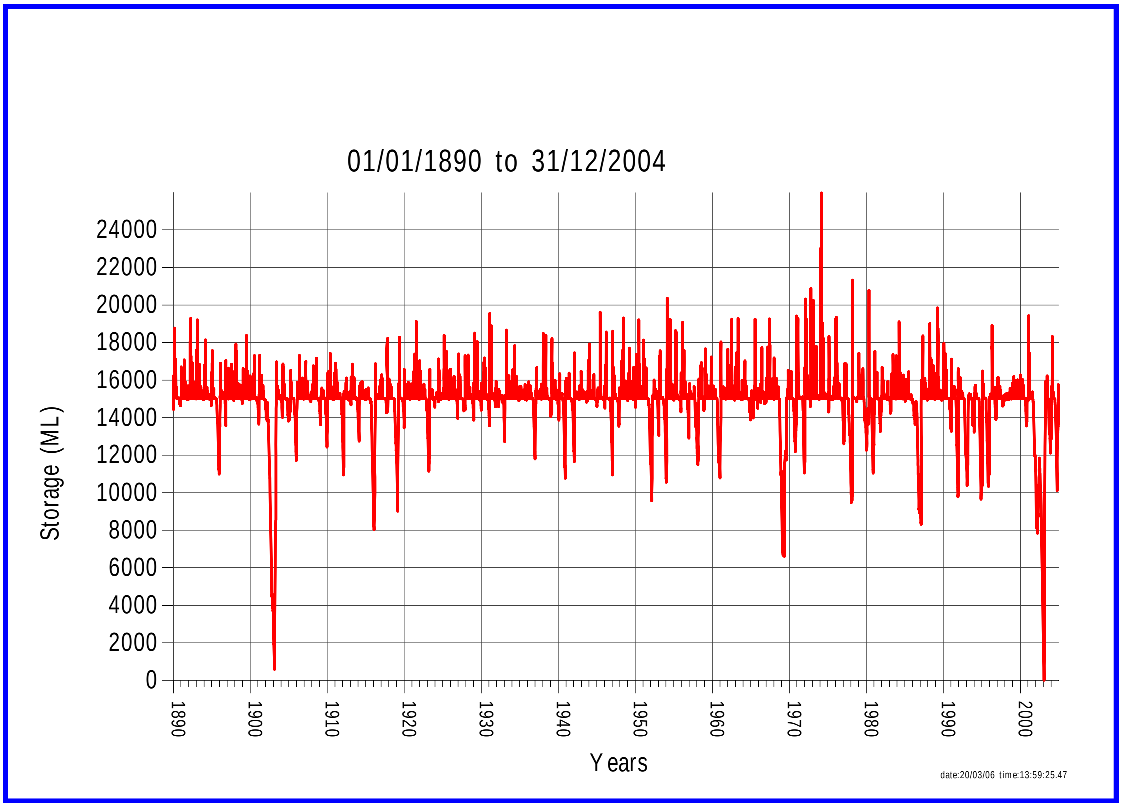

Figure 7.1: Clarrie Hall Dam - HNFY, No Restrictions, No Contingency Storage

7.2.2 System Yield with Restrictions

The restriction levels shown in Table 6.5 were applied to the Tweed District water supply, based on Clarrie Hall Dam levels. Water could be extracted down to the minimum operating volume of Clarrie Hall Dam. The simulation resulted in a yield of 17,150 ML/a, compared to 18,500 ML/a in the 2002 study. The corresponding storage plot of Clarrie Hall Dam is given in Figure 7.2. This figure again shows that the most critical year was the 2002/03 drought.

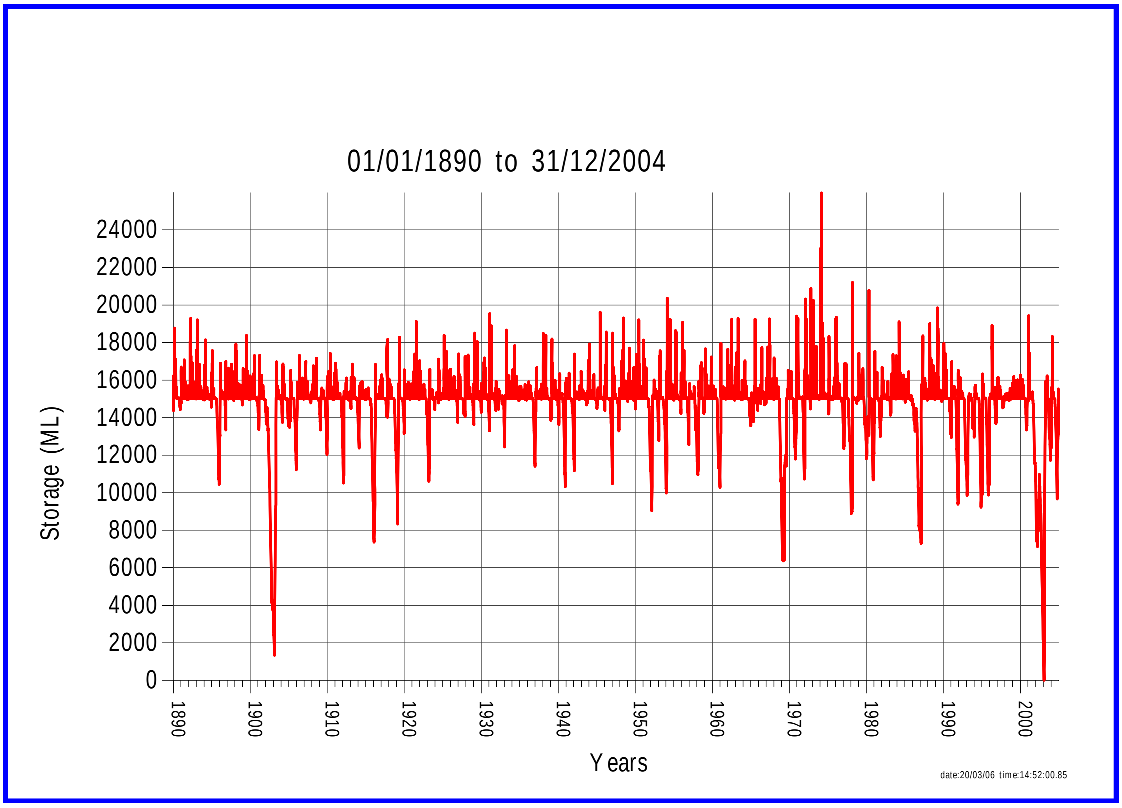

Figure 7.2: Clarrie Hall Dam - With Restrictions, No Contingency Storage

7.2.3 System Yield with DEUS - 5/10/20 Criteria

The Department of Energy, Utilities and Sustainability (DEUS) criteria specify that the yield (with restrictions) must be such that the yield can still be obtainable if the worst drought is in action. The criteria, commonly referred to as the “5/10/20” rule, are defined as follows:

- restrictions no more than 5% of the time
- restrictions to have a frequency of no more than 1 in 10 years, on average
- a 20% reduction in consumption to be assumed
- 80% of full demand must be deliverable even if the storage is at the contingency level when the worst recorded drought commences.

The difference between Tweed Shire Council and DEUS restriction criteria was the application of restrictions. TSC restriction criteria assumed three levels of restriction (i.e. 90%, 85% and 80% of the demand) when the storage level of Clarrie Hall Dam was below 50% full of the defined commandable storage (Table 6.5). DEUS assumed restrictions of 80% of the demand all the time when the storage level of Clarrie Hall Dam was below a determined percentage of the commandable storage. See Appendix H for more information.

The yield from this scenario was determined through iterative runs of the model. A demand of 16,900 ML/a could be supplied from the system under the DEUS criteria, with restrictions commencing when the storage fell below 60% (10,000 ML) of the commandable volume. If the 95% POE environmental flow releases are required downstream of Bray Park Weir, the yield falls to 13,750 ML/a.

The Clarrie Hall Dam's storage, ranked storage volume and ranked diversion of Tweed District Water Supply are shown in Figures 7.3 – 7.5. These figures show that the selected demand is within the DEUS criteria. The 20% reduction in consumption criteria used by DUES was applied as an immediate reduction to the monthly demands used in the model.

Both restriction criteria did not consider the climatic conditions prevailing at the time and also what is referred to as "demand hardening". Demand hardening is a term used to describe how restrictions have lessening effect as water use per person is reduced due to the conservation education of consumers.

As a result, the yield with restrictions derived from the use of this criterion are less likely to be achieved.

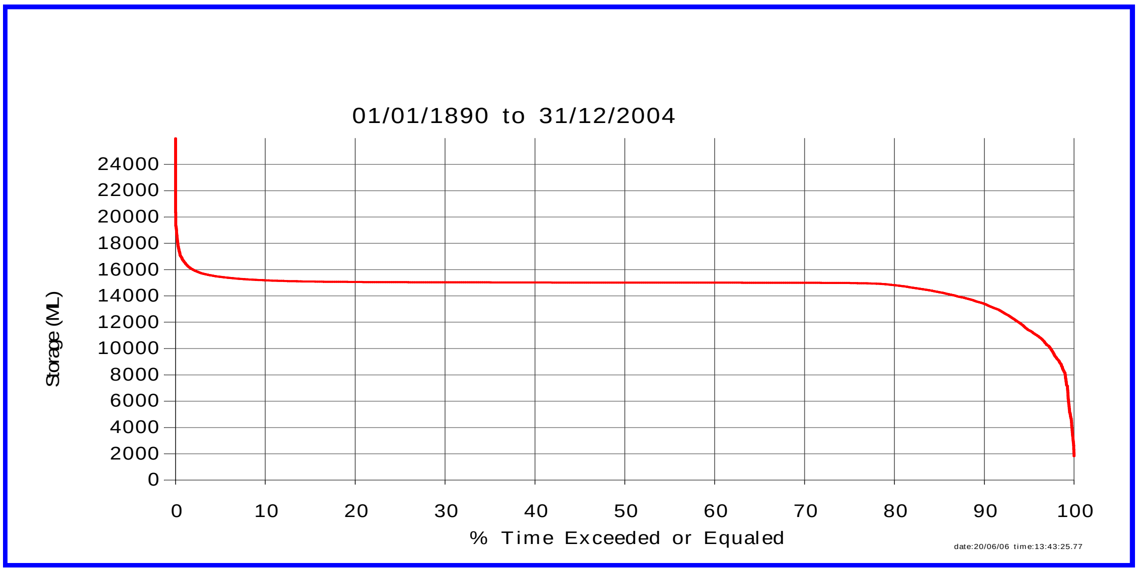

Figure 7.3: Ranked Volume of Clarrie Hall Dam under DEUS Criteria (5% of time)

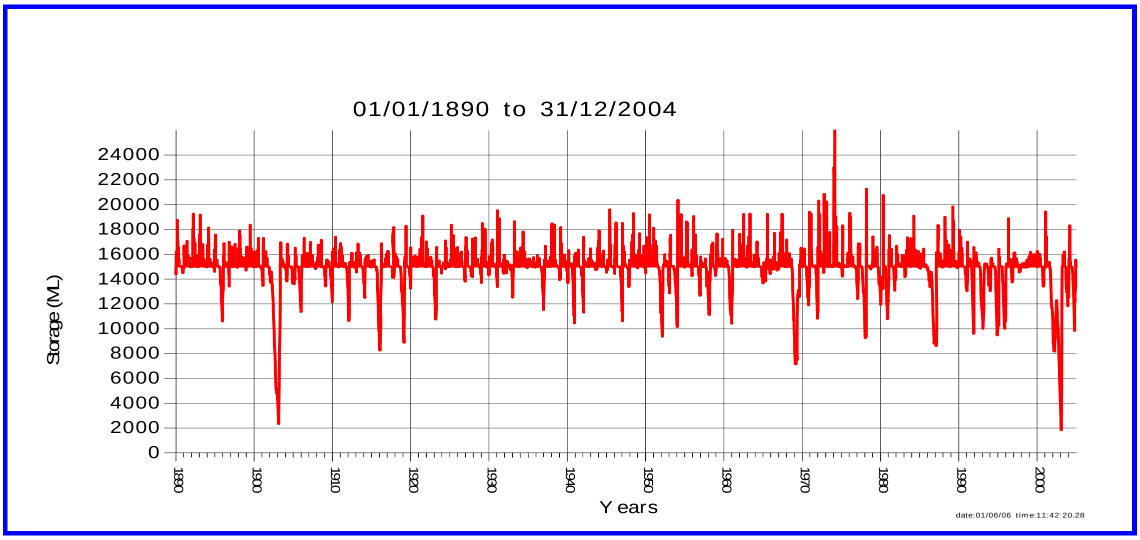

Figure 7.4: Clarrie Hall Dam under DEUS Criteria (1 in 10 freq)

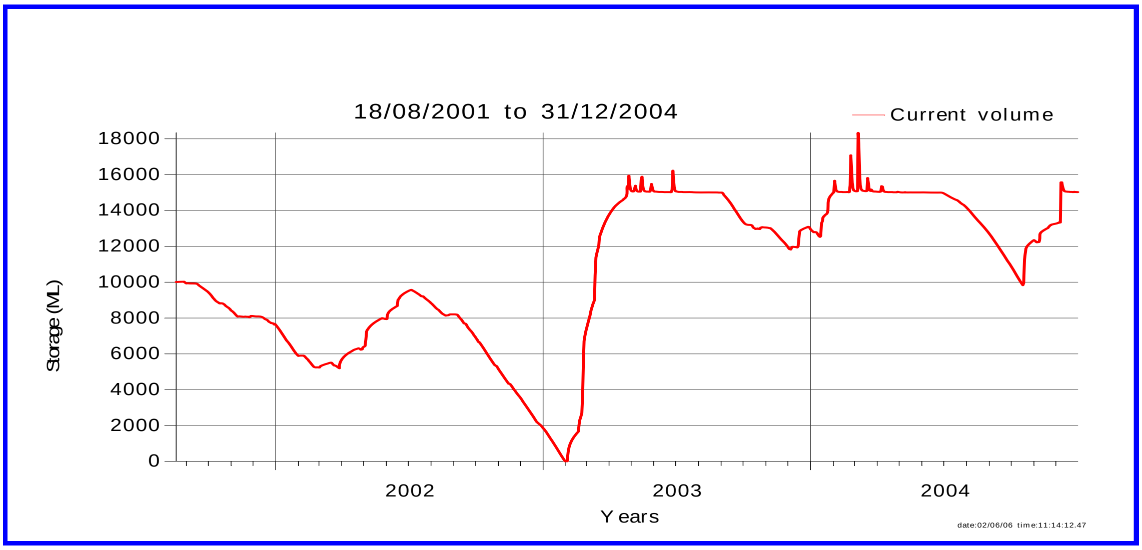

Figure 7.5: Plot using DEUS Criteria (20% restriction in worst drought)

7.2.4 System Yield with Restrictions and a Contingency Storage

Instead of the minimum storage being defined as the minimum operating volume, a contingency storage of 8,400 ML (= 80% of current demand) was used as the storage below which no water could be extracted. This allowed for a drought worse than any experienced in the historic period. The resultant yield with restrictions for this case was 10,500 ML/a. The corresponding storage plot of Clarrie Hall Dam is shown in Figure 7.6.

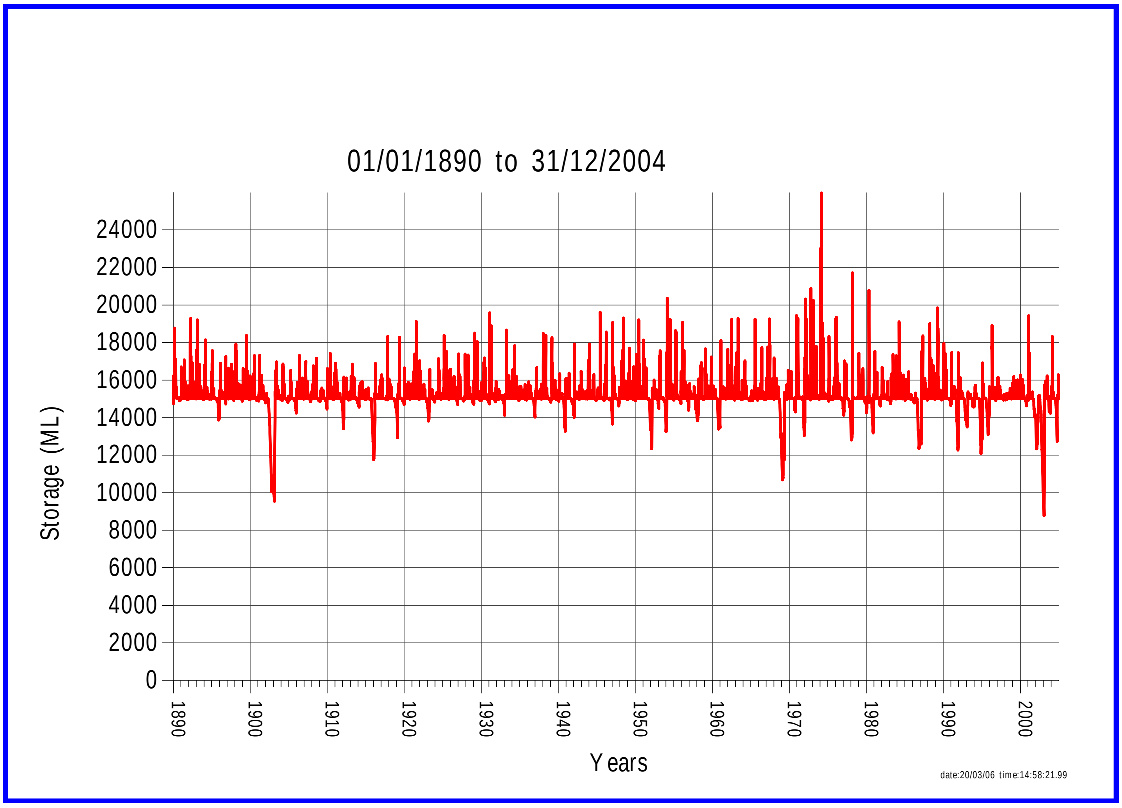

Figure 7.6: Clarrie Hall Dam - With Restrictions, and a Contingency Storage

7.2.5 System Yield with Restrictions, a Contingency Storage and 95% EF d/s of BPW

As well as a contingency storage in Clarrie Hall Dam, a release of the 95th percentile natural inflow to Bray Park Weir was included to meet environmental requirements. The release was used instead of the fish ladder operation. The resultant yield with restrictions for this case was 10,100 ML/a, a reduction of only 400 ML/a from the scenario with no additional environmental flow requirement.

7.2.6 Summary of Current Demand Scenarios

Table 7.1 summarises the system yields obtainable under a range of operating conditions.

Table 7.1: Yields under Different Security Criteria

Case	Method	Yield (ML/a)	Population	Commandable Restriction Level (ML)	Restrictions	
					% time	Frequency (1:_ yr)
A	2002 Study HNFY	18,000	124,000	N/A	N/A	N/A
B	2006 Study HNFY	16,200	111,000	N/A	N/A	N/A
C	DEUS yield under existing EF d/s of CHD & BPW[1]	16,900	116,000	10,000	2.6%	10
D	DEUS yield under existing EF d/s of CHD & 95% flow d/s of BPW	13,750	90,000	9,000	1.8%	16
E	Yield under existing EF d/s of CHD & BPW, TSC Restrictions and a contingency storage[2]	10,500	70,000	11,700	< 1%	29
F	Yield under existing EF d/s of CHD & 95% flow d/s of BPW, TSC Restrictions and a contingency storage[3]	10,100	67,300	11,540	< 1%	13

[1] Current regulatory regime (existing EF rules d/s CHD and BPW: for CHD, lesser of inflow to dam and 1.1 ML/day Sep to Apr 0.8 ML/day May to Aug; for BPW, releases through fish ladder, flow vary from 0 to 25 ML/d when storage > 405 ML
[2] Contingency storage equals to 80% of demand (= 8,400 ML)
[3] Contingency storage equals to 80% of demand (= 8,080 ML)

By applying the DUES 5/10/20 criteria, a yield of 16,900 ML/a, (300 ML/a greater than the HNFY), was obtained when applying current environmental release rules (Case C). This was due to the application of 20% restrictions whenever Clarrie Hall Dam fell below a defined level.

The historic no failure yield was considered to have an unacceptable security of supply, so the security of any yield greater than that would be more compromised, with restrictions imposed at the maximum permitted frequency (1 in 10 years) whenever Clarrie Hall Dam fell below 60% full. A lower yield of 13,750 ML/a, based on future environmental flow conditions (Case D), also imposed restrictions more frequently than 1 in 20 years.

Table 7.1 highlights that Case F offers the greatest security of supply for the Tweed Shire Council. When the application of a contingency storage is used in addition to restrictions, the system yield drops to 10,500 ML/a. However, the ability of the system to supply this yield in future drought conditions is greatly enhanced. Restrictions are imposed for less than 1% of the time, and the frequency of restrictions decreases to slightly less than 1 in 30 years. The imposition of the upgraded environmental release rules does not significantly decrease the available system yield, reducing it by 400 ML/a to 10,100 ML/a. It also allows for a significant buffer storage, able to cater for future more severe droughts.

The HNFY from the 2006 study is 1,800 ML/a less than that determined from the 2002 study. This is due to the following factors\:

1. The 2006 study included the 2002/2003 drought, which was the most severe on record.

2. The estimation of inflows to Clarrie Hall Dam in the 2006 study relied on recorded flows in Doon Doon Creek, not just recorded flows at Uki aerially proportioned for Doon Doon, as in the 2002 study.

3. The IQQM set up in 2006 more accurately represented the catchment, being based on recorded storage operations at Clarrie Hall Dam and Bray Park weir.

7.2.7 System Performance with Current and Future Demands

Using the preferred methodology of system yield with restrictions and a contingency storage, the system was analysed to determine if it could meet existing and future demands. These demand conditions represent the water needed for existing and future populations. The system performances for each demand condition are given in Table 7.2. The corresponding storage plots of Clarrie Hall Dam are shown in Figures 7.7 to 7.10, but does not include the scenario for a full development population of 175,000, where the contingency volume is greater than the full commandable volume of Clarrie Hall Dam.

Table 7.2: Existing System Performance for Current and Future Demands

Demand (ML/a)	Population	Restrictions		Contingency Volume (ML)	< Cont'y Volume		Minimum Storage (ML)	Criteria Pass/ Fail
		% time	Frequency (1:_ yr)		% time	Frequency (1:_ yr)		
10,100 (HNFY)	67,300	0	> 115	8,080	0	> 115	8,100	Pass
10,900 (Current)	71,500	2.8	7.0	8,720	0.3	58	7,400	Fail
11,250	75,000	3.4	6.4	9,000	0.5	58	7,000	Fail
18,125	125,000	25.4	1.1	14,500	22.0	1.1	0	Fail
24,500	175,000	100	<1.0	19,600*	100	< 1	0	Fail

* Greater than CHD Full Supply Volume

The demands used in this study represented the total per person-use and did not include any reductions resulting from Integrated Water Cycle Management's initiatives including the substitution of source water with effluent and or storm water, or the specific use of rain water tanks. However, they did include the continuing downward trend in per person-use based on public education.

Table 7.2 highlights that with a change in system management from the historic no failure yield to one with restrictions and a contingency storage, Tweed Shire Council may not meet the existing demands in the water supply system, Therefore, in addition to these changes, Tweed Shire Council may need to increase the storage capacity of the water supply system. Chapter 8 investigates some options available to the council.

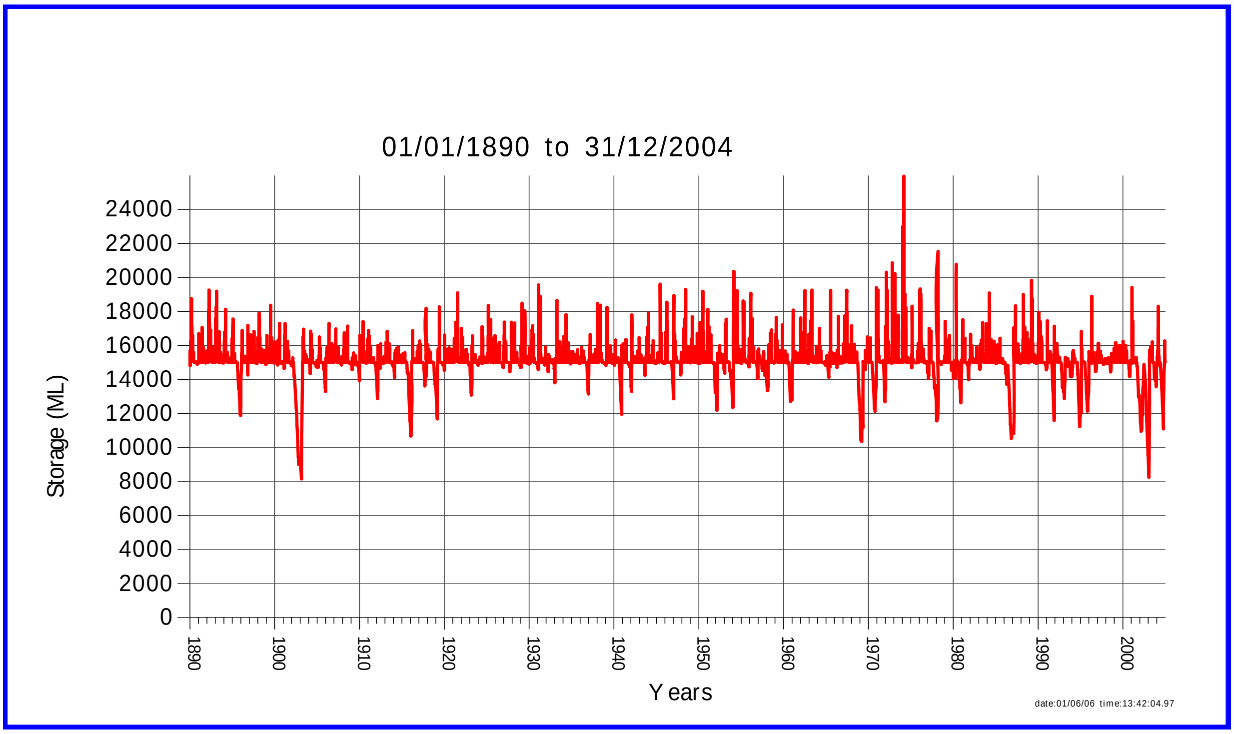

Figure 7.7: CHD Storage Plot for the HNFY with a Contingency Storage

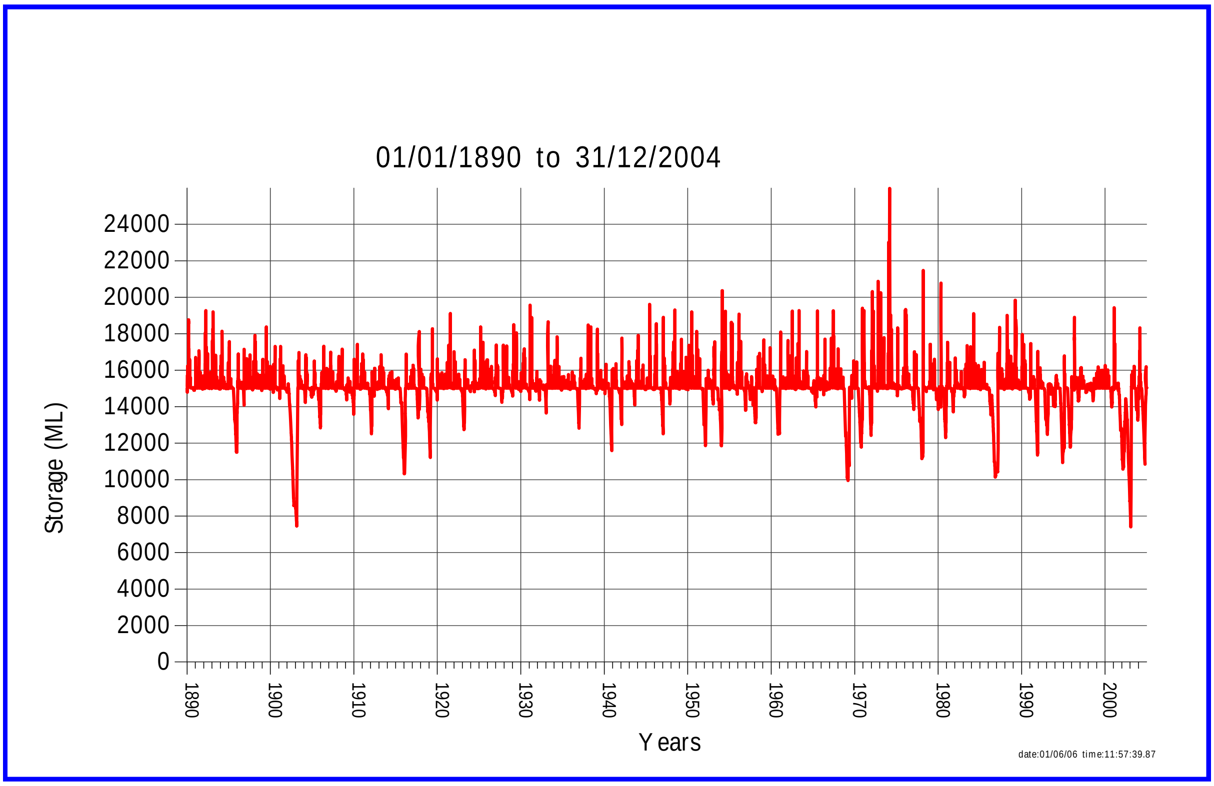

Figure 7.8: CHD for Current Demand (71,500 people) with a Contingency Storage

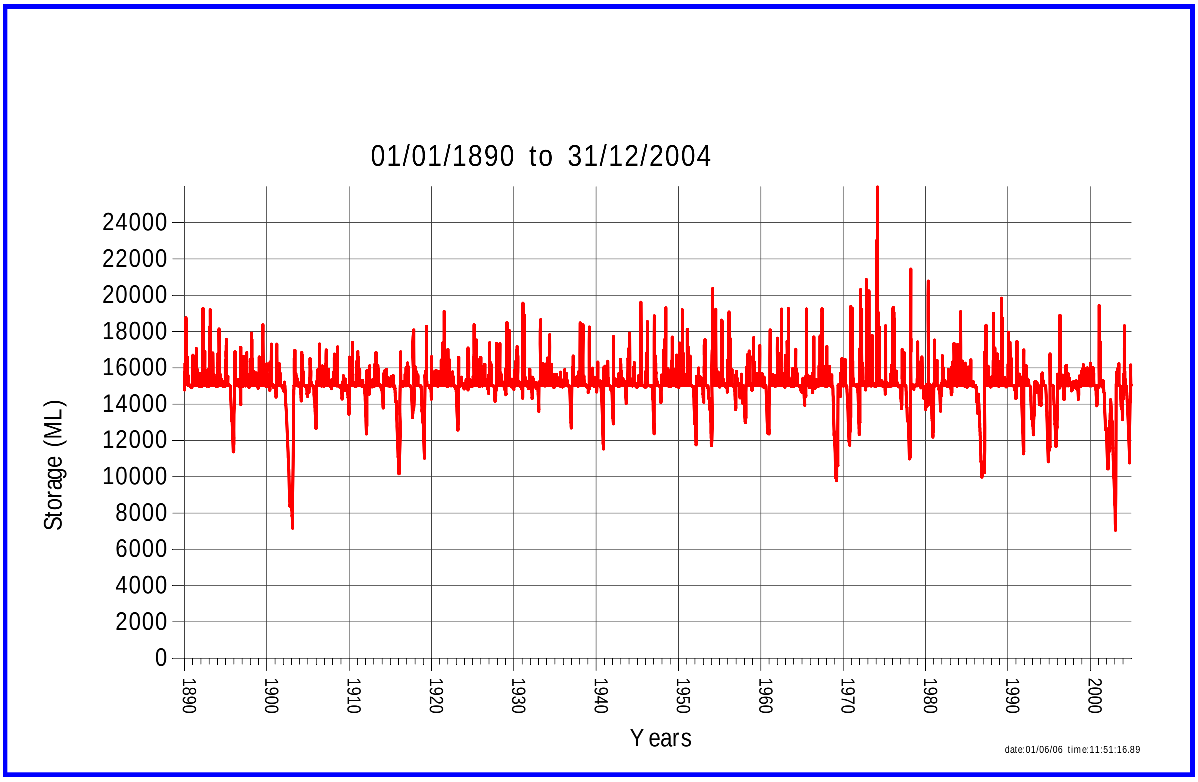

Figure 7.9: CHD for Demand for 75,000 People with a Contingency Storage

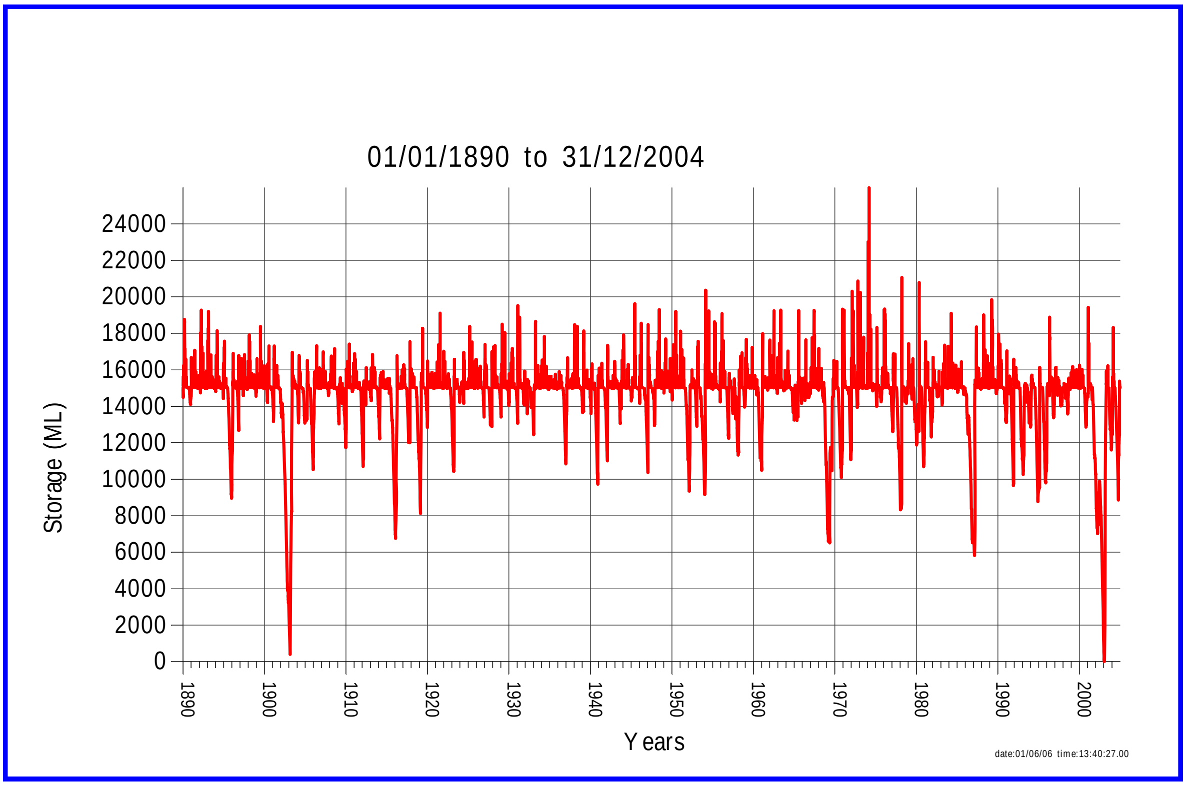

Figure 7.10: CHD for Demand for 125,000 People with a Contingency Storage

7.3 ASSESSMENT OF FUTURE ENVIRONMENTAL FLOWS IMPACT

7.3.1 Effect of Future Environmental Flow Requirements

Scenario runs were carried out to determine the effect of different environmental release rules on system yields. The considered environmental flow scenarios and the resultant system yields for each scenario are given in Table 7.3. Figure 7.11 compares the effect of the rules downstream of Bray Park Weir.

For these scenario runs, no consideration was given to the physical feasibility of such releases from any of the structures. Infrastructure constraints, such as the capacity of outlet works, may be significant deterrents to the release of such volumes in real life.

Table 7.3: Yield with Contingency Storage and Different EF Releases

EF Release Scenario	Storage Releases		Yield (ML/a)
	Clarrie Hall Dam	Bray Park Weir	
Current releases at CHD & BPW	Lesser of inflow to dam or 1.1 ML/d Sep to Apr, 0.8 ML/d May to Aug	Up to 25 ML/d through the fish ladder, when weir > 405 ML	10,500
Current releases at CHD & 95% POE flow at BPW	Lesser of inflow to dam or 1.1 ML/d Sep to Apr, 0.8 ML/d May to Aug	95% POE natural inflow of weir	10,100
Current releases at CHD & 80% POE flow at BPW	Lesser of inflow to dam or 1.1 ML/d Sep to Apr, 0.8 ML/d May to Aug	80% POE natural inflow of weir	7,000

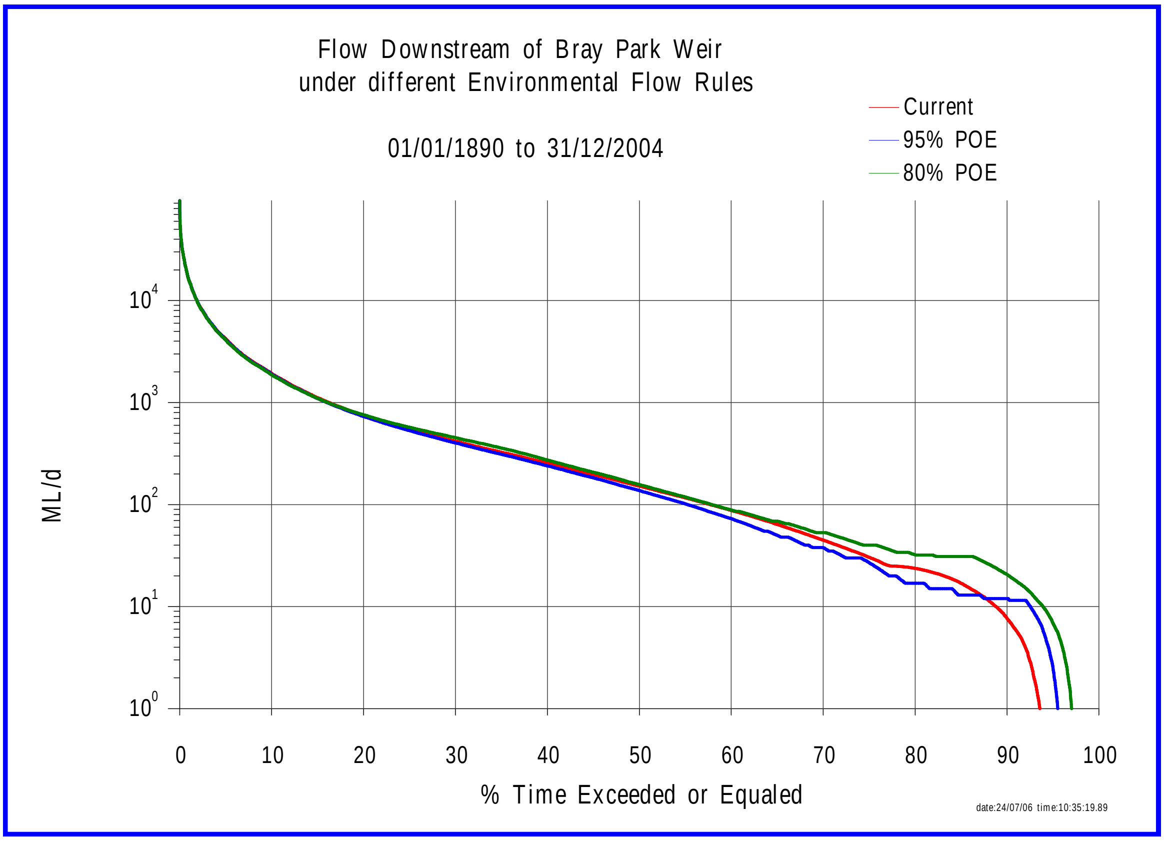

Figure 7.11: Flow d/s of BPW for Different EF Release Conditions

Results highlighted that the environmental flow releases have a very significant impact on the system yield, depending on where they are imposed. However, if the environmental flow releases from Clarrie Hall Dam are changed from the current release rules to 95% flows, the effect is negligible, as the environmental flows are very similar to the current releases.

When the environmental flow release criteria of Bray Park Weir was changed from the current system to 95% POE criteria, the system HNFY dropped from 16,200 ML/a to 14,000 ML/a. However, once the additional security criteria of contingency storages and restrictions were introduced, the effect of the changed environmental flow was only minimal, with the system yield dropping from 10,500 ML/a to 10,100 ML/a.

When the 80% POE criteria was adopted, the HNFY dropped to 9,900 ML/a, and the yield under the additional security criteria dropped to 7,000 ML/a. The 80% POE rules reduce the system yields by approximately 30%, while the 95% POE rules reduce the yield by 4%.

The 2002 study results for the historic no failure yield for the 95%ile flow was 14,900 ML/a, (similar to this study) and the 80%ile yield as 13,200 ML/a (higher than this study). The method of determining the required releases varied between the two studies, with the latest version being the method now accepted by DLWC.

7.3.2 Environmental Flow Monitoring

Tweed Shire Council requested a practical method of determining daily flow into Bray Park Weir, in order to calculate the environmental flow to be released, should such a release be required. To determine the environmental flow releases, it is highly recommended that a rating curve for the existing automated gauge at Bray Park Weir be developed and used to record daily flows and releases from the weir.

The following relationship, derived using the Uki and Eungella flow gauges, should be used until such a curve is developed. The low and high flows recorded at the gauges of this catchment supported the area proportion assumption for most of flow events. . In applying the equation, the travel time (obtained from local experience) from the gauge locations to Bray Park Weir should be taken into account.

BPW inflow = 0.58 (Uki recorded flow + Eungella recorded flow – CHD estimated releases)

Natural inflows into the weir up to but not exceeding the daily environmental flow shown in Table 7.4 below, must be released downstream to satisfy the environmental flow requirements.

Table 7.4: Bray Park Weir 95% POE Flows

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily Flow (ML/d)	12	20	35	40	55	48	38	30	17	15	12	13

8.0 ASSESSMENT OF SUPPLY AUGMENTATION

Various options have been proposed to increase the system yield for Tweed Shire Council. These options are as follows:

- Upgrade Clarrie Hall Dam storage capacity)
- Build a new dam on Byrrill Creek
- Combination of Clarrie Hall Dam Upgrade and Byrrill Creek Dam
- Increase the Bray Park Weir capacity.

8.1 CONDITIONS OF OPERATION

In the modelling, both Clarrie Hall Dam and Byrrill Creek Dam were assumed to operate in harmony, i.e., to supply the demand, both storages would supply the same percentages of their available commandable storages for each release. However, operational strategies should be determined to minimise the storage losses and optimise the system efficiencies.

In this study, the 95% flow was assumed as the environmental flow releases downstream of Bray Park Weir and the existing environmental flow releases were used for Clarrie Hall Dam. If Byrrill Creek Dam is included, then the 95% flow will be required downstream of this storage. Additionally, the 730 ML/a irrigation demand was supplied from Bray Park Weir when its storage is greater than 405 ML. A contingency storage equivalent to 80% of the demand was assumed for each scenario. The TSC restrictions were applied to the town water supply demand.

8.2 CLARRIE HALL STORAGE UPGRADE

The analysis involved increasing the storage capacity of Clarrie Hall Dam up to the highest practical level. As the yields obtained were system yields and depended on unregulated streamflows as well as storage volumes, the hydrologic limit of the storage was not considered as the limiting factor. However, the capacity of Clarrie Hall Dam was limited by the physical constraints of the site to an upper limit of about 45,000 ML.

At this capacity, the spillway would be required at approximately EL 72 m AHD, and the PMF level would be some 6 m to 8 m above that. The current storage-area curve for Clarrie Hall Dam was extended to this level (see Section 6.5). The structural feasibility of a dam of this size is yet to be determined.

The system yields for different Clarrie Hall Dam capacities were calculated and shown in Table 8.1.

Table 8.1: System Yield for Range of Clarrie Hall Dam Capacities

Clarrie Hall Dam Commandable Capacity (ML)	System Yield (ML/a)
15,000	10,100
20,000	12,000
25,000	14,000
35,000	18,000
45,000	22,000

Although the physical limitation of Clarrie Hall Dam imposed a cutoff of 45,000 ML, Figure 8.1 shows that the system hydrologic limit was not reached, as yield is still increasing proportionally with storage capacity. This is due to the considerable unregulated flow coming into Bray Park Weir from the rest of the catchment.

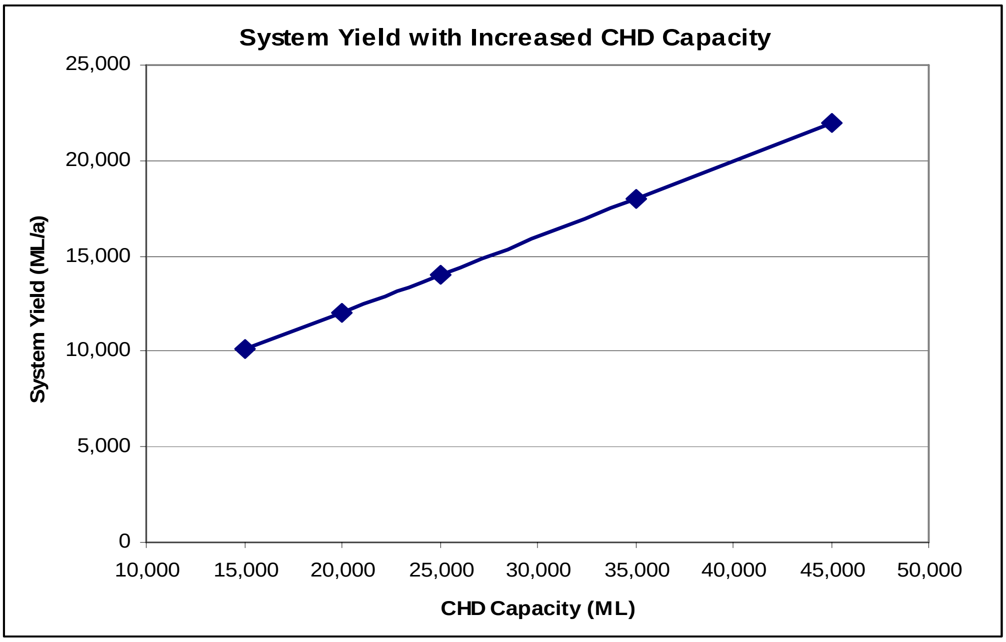

Figure 8.1: System Yields for Range of CHD Capacities

8.3 CONSTRUCTION OF BYRRILL CREEK DAM

A future development option for Tweed Shire Council involved the construction of an additional storage on Byrrill Creek, to the northwest of Doon Doon Creek. The upper limit of the spillway of this storage was at EL 130 m AHD, owing to topographic constraints. The storage-area curve for the Byrrill Creek Dam site was calculated and showed that approximately 58,000 ML of storage could be created at the upper limit, (Section 6.5). The structural feasibility of a dam of this size is yet to be determined.

The system yields were determined for a range of capacities of Byrrill Creek Dam with Clarrie Hall Dam at its present capacity (15,000 ML of commandable capacity). In these scenarios, the 95% flow was assumed as the environmental flow releases downstream of Byrrill Creek Dam and Bray Park Weir for relevant cases. The existing environmental flow releases were used for Clarrie Hall Dam. The results are summarised in Table 8.2.

Table 8.2: System Yield for Different Byrrill Creek Dam Capacities

Clarrie Hall Dam Commandable Capacity (ML)	Byrrill Creek Dam Commandable Capacity (ML)	System Yield (ML/a)
15,000	15,000	18,125
15,000	20,000	19,000
15,000	25,000	21,000
15,000	35,000	24,500

Figure 8.2 shows the relative increase in yields for a range of capacities for Byrrill Creek Dam. Comparison with the yields obtainable from the raising of Clarrie Hall Dam shows an increase in yields from the two-dam system. As the storages drain separate catchments, the dry periods are managed individually.

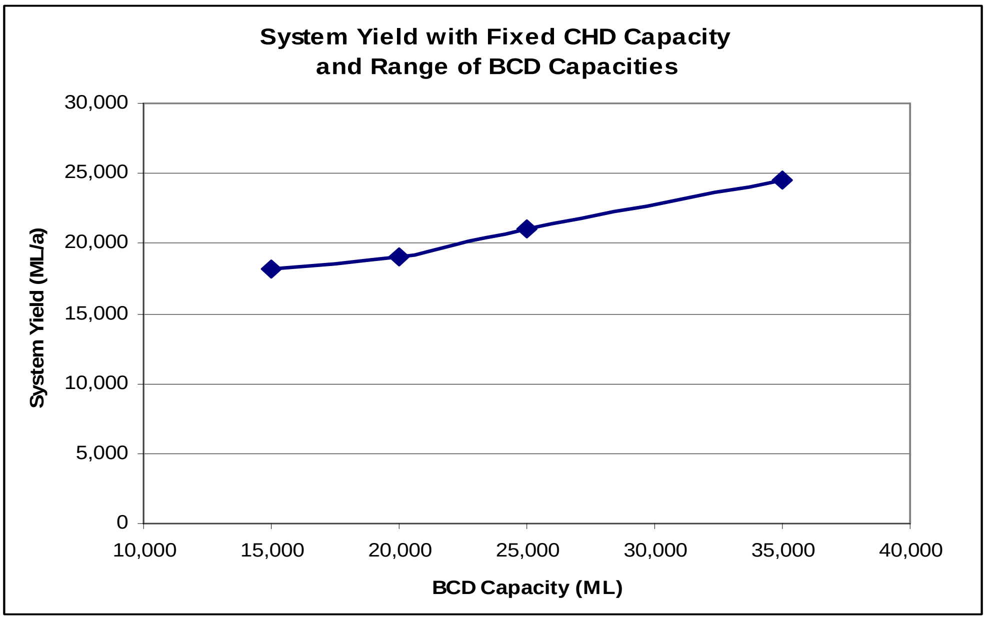

Figure 8.2: System Yields for Range of BCD Capacities (fixed CHD)

8.4 COMPARISON OF STORAGES

Historic No Failure Yields for various commandable storage capacities of Clarrie Hall or Byrrill Creek Dams as stand-alone storages, suggested that both storages produced approximately the same yield up to 25,000 ML capacity while Clarrie Hall Dam performed better beyond this capacity. Details are given in Appendix I.

Both storages have similar yields for similar storage capacities. Several model runs were undertaken to determine the best combination of storage upgrades to meet current and future demands of the region. The demands were based on future population figures up to 175,000 people. The results for each scenario are summarised in Table 8.3.

Table 8.3: Augmentation Options

Population	Commandable Storage Capacity (ML)		Total Commandable Storage Capacity (ML)	Demand (ML/a)
	CHD	BCD		
67,300	15,000	-	15,000	10,100
125,000	35,000	-	35,000	18,000
125,000	15,000	15,000	30,000	18,125
155,000	45,000	-	45,000	22,000
175,000	35,000	13,000	48,000	24,500
175,000	15,000	35,000	50,000	24,500

Table 8.3 highlights that, to meet future demands, a second dam is required. Increasing the capacity of Clarrie Hall Dam alone will only supply 22,000 ML/a of the required future demand of 24,500 ML/a. The construction of a second dam at Byrrill Creek will provide the additional storage necessary for future demands.

The construction of the increased storage at Clarrie Hall Dam and/or the new Byrrill Creek Dam can be planned in stages to meet the future population demand.

8.5 INCREASE BRAY PARK WEIR STORAGE CAPACITY

Bray Park Weir capacity was analysed by increasing the storage capacity from its current level of 648 ML up to 720 ML. The investigation included Clarrie Hall Dam with a capacity of 45,000 ML, 95% EF, 730 ML/a irrigation supply from Bray Park Weir, 19,600 ML of contingency storage and restrictions to town water supply and irrigators.

The monthly reliabilities of town water supply corresponding to the two volumes of Bray Park Weir were 99.70% and 99.71% respectively. The improvement in reduction in length of restrictions was 1% and there was a 20% reduction in the number of times that restrictions occurred. Results are summarised in Table 8.4.

The Bray Park Weir storage behaviour for the two cases is shown in Figure 8.3 and corresponding Clarrie Hall Dam storage is shown in Figure 8.4 for the critical period. Based on these figures, there is no hydrologically significant improvement in the system performance to be gained from the raising of Bray Park Weir. However, there may be practical considerations, such as improved weir performance, that may make the project feasible.

Table 8.4: Effects of Bray Park Weir Storage Upgrade

Scenario	Clarrie Hall Dam Commandable Capacity (ML)	Bray Park Weir Capacity (ML)	Results		
			Monthly Reliability (%)	No of Restrictions	Remark
BPW	45,000	648	99.70	10 times	A small reduction in restrictions.
BPW with increased storage	45,000	720	99.71	8 times	

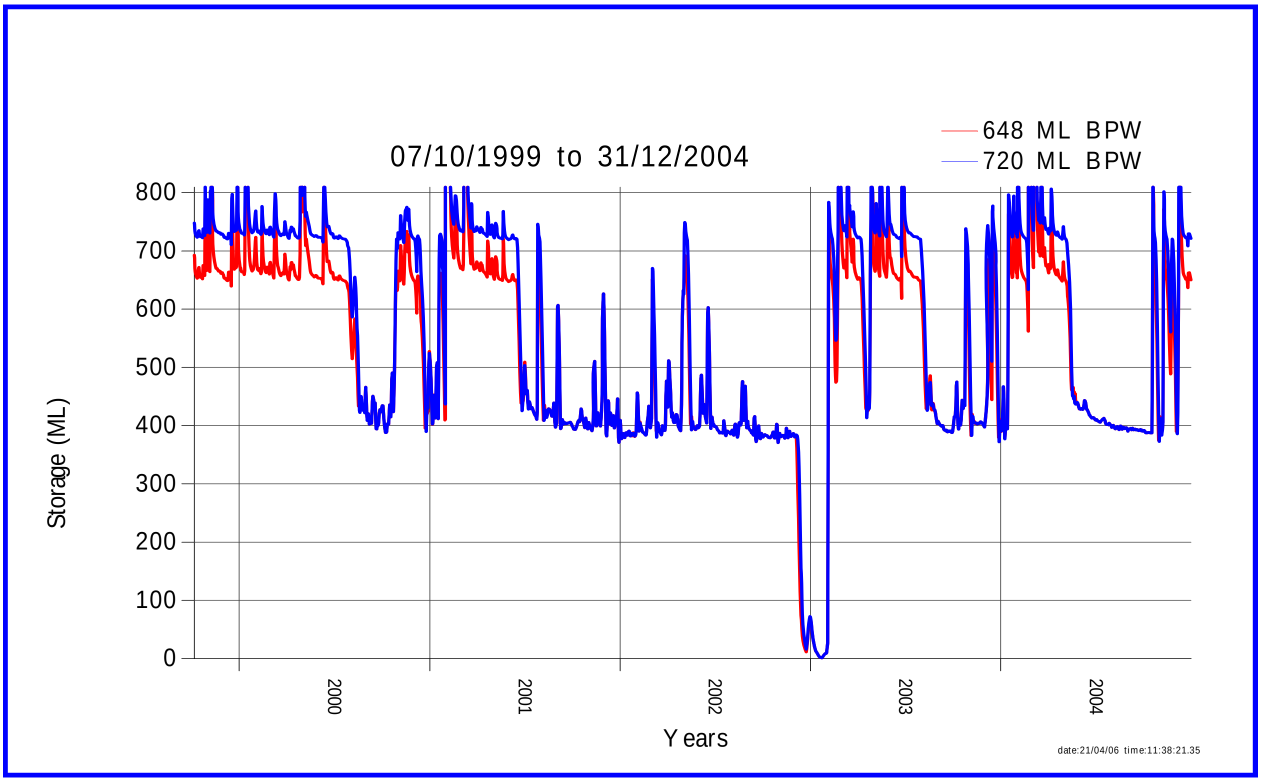

Figure 8.3: Storage of Bray Park Weir for 648 and 720 ML Capacities

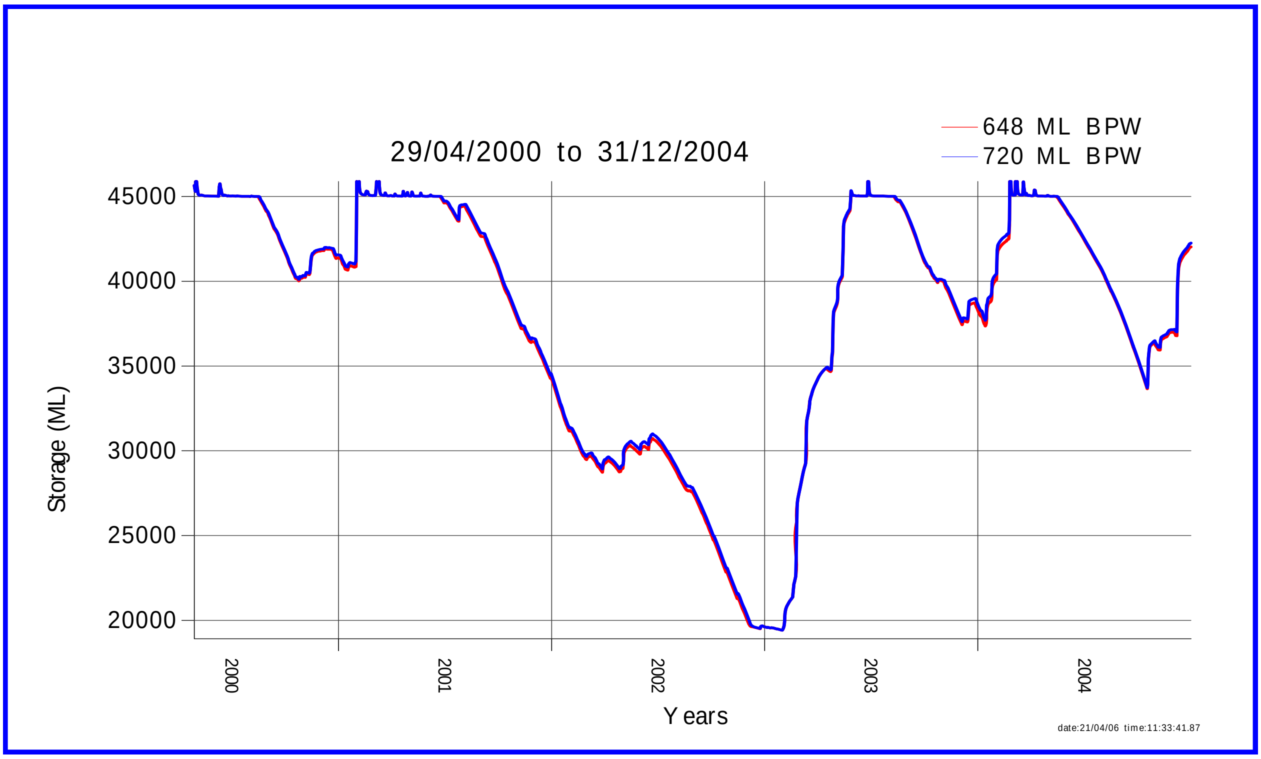

Figure 8.4: Clarrie Hall Dam Storage for 648 and 720 ML of Bray Park Weir Capacities

8.6 ESTIMATING STREAMBED LOSSES

Concern was expressed that releases from Clarrie Hall Dam down to Bray Park Weir might be reduced due to streambed losses. Considering the lack of available data, using the IQQM model to derive losses was not advisable.

Recorded data for the last couple of years was used to investigate if any loss parameters could be determined. Unfortunately, it was not possible to distinguish any losses, due to the coarseness of recorded and estimated storage volumes and downstream releases, overwhelming any small transmission loss decreases in downstream flows. Appendix J contains a brief description of the analyses undertaken. A field measurement method is strongly recommended for the assessment of losses.

The losses in a stream are usually measured by a method known as “inflow and outflow method”. In this method, a long reach of the stream is selected. Discharge observations are taken at the beginning and end of the reach continuously for a number of days. A range of water levels are examined covering the range of normal releases. Gradual increase of the releases provides the opportunity to estimate initial losses. Outlets or pumps if any are completely closed or stopped during the observation period. The difference between the discharge entering the reach and leaving the reach is the loss occurring in the reach.

9.0 RESULTS AND DISCUSSIONS

The calibrated IQQM model was run for the scenario cases for the full period of record from 1890 to 2004, to test different options for improving the security of the supply of town water. In scenario modelling, only the hydrological feasibility of different options was considered and other engineering or environmental issues were not considered.

Scenario options to be investigated were:

1. Reliability of supply from existing system
2. Increasing storage capacity of Clarrie Hall Dam
3. Construction of a new storage on Byrrill Creek
4. Conjunctive use of Clarrie Hall Dam and Byrrill Creek Dam
5. Increase Bray Park Weir storage capacity

9.1 RELIABILITY OF EXISTING SUPPLY

Historical No Failure Yield for the Tweed Water Supply System with no conditions attached, was determined to be 16,200 ML/a. This figure was 1,800 ML/a less than that of the 2002 study, which was 18,000 ML/a. In the 2002 study, the very dry period in 1902/03 had the most significant impact on the behaviour of the system. In this study, the worst dry period was in 2002/03. Apart from the some improvements in the current model, the shifting of the dry period caused in the differences in yields.

The system yield with TSC restrictions was 17,150 ML/a compared to 18,500 ML/a in the 2002 study, although the restriction rule in the 2002 study was not a stepped function. Although there was no major improvement in the yields when the restriction rules were imposed as one dry period over-rode the possible improvements gained throughout the rest of the analysis, there would be other benefits such as reduction in length of restrictions.

Recent droughts across Australia and a heightened awareness of potential impacts of climate change have resulted in a review of drought security criteria. The traditional approach has been to adopt the Historic No Failure Yield (HNFY). In the Tweed Shire Council's case, this represents a probability in the order of 1 in 100 years. The adequacy of this criterion is now being questioned. The DEUS criteria are an accepted method of determining security of supply in New South Wales. Another method analysed in this study is the use of a contingency storage. A contingency storage represents a volume equivalent to 80% of normal consumption (i.e. full restrictions imposed) for a period of time adequate to bring online an emergency supply.

DEUS has defined a set of criteria in order to determine an acceptable system yield, which allows for the application of restrictions and extreme drought, known as the 5/10/20 criteria. (See Appendix H for a full description). Under these criteria, the system yield with current environmental flow releases was determined to be 16,900 ML/a, with restriction applied whenever the storage fell below 60%. The total duration of the restrictions did not exceed 2.6% while the criteria allowed up to 5%. The total number of restriction events was 11 while the criteria allowed up to 12. The scenario with future EF releases was found to be 13,400 ML/a. Two historical droughts (i.e. 1902/03 and 2001/03) did affect the possible yield. However, security of supply was not addressed in depth under these criteria, due to the short duration of the dry periods.

Using the system yield with a contingency storage method, the ability of the system to meet future drought requirements was increased at the cost of lower yield. By providing a contingency storage equivalent to 80% of the annual demand, the frequency of restrictions was reduced to less than 1% (or less than 1 in 29 years). If environmental flows were also taken into account, restrictions would increase to 1 in 13 years.

Therefore, the contingency storage method provides the best security of supply for the Tweed Shire Council. With this level of security, it was found that Tweed Shire Council could not meet existing demands. Therefore, in addition to changing the method of managing the security of supply, Tweed Shire Council will need to increase the available storage in the system.

9.2 INCREASING STORAGE CAPACITY OF CLARRIE HALL DAM

Scenarios were run to determine the yields possible if the storage capacity of Clarrie Hall Dam was increased. Current environmental flow releases from CHD and 95% POE EF releases from Bray Park Weir were applied. A contingency storage was incorporated, as well as the application of restrictions to supply.

For a commandable storage volume of 45,000 ML, the system yield increased to 22,000 ML/a, an improvement of about 12,000 ML/a over the yield with the current storage. This was not the hydrologic limit of the system, but was the physical limit of Clarrie Hall Dam.

As the demand required by a future population of 175,000 people is estimated to be greater than 22,000 ML/a, an increased Clarrie Hall Dam would not be able to supply this population by itself. However, it could supply the medium-term population of 125,000 people, with a demand of 18,250 ML/a, if its commandable capacity were greater than 35,000 ML.

Appendix I contains the HNFY results for Clarrie Hall Dam as a stand-alone storage.

9.3 CONSTRUCTION OF A NEW STORAGE ON BYRRILL CREEK

Another option considered involved the construction of a new storage on Byrrill Creek. This storage could have a maximum capacity of 58,000 ML at EL 130m AHD. For these scenarios, the commandable storage capacity of Clarrie Hall Dam was held constant at 15,000 ML.

To obtain a yield needed for the maximum population of 175,000, a storage at Byrrill Creek would need to have a commandable capacity of 35,000 ML. The system yield, with a contingency storage, environmental flows and restrictions applied, was found to be 24,500 ML/a.

9.4 CONJUNCTIVE USE OF CLARRIE HALL DAM AND BYRRILL CREEK DAM

The study found that additional storage was necessary to meet future demands. System yield analyses were undertaken to provide two potential options. Table 9.1 summarises the yields possible from Clarrie Hall Dam and Byrrill Creek Dam.

Table 9.1: System Performances

Clarrie Hall Dam Commandable Capacity (ML)	Byrrill Creek Dam Commandable Capacity (ML)	System Yield (ML/a)
15,000	-	10,100
35,000	-	18,000
15,000	15,000	18,125
45,000	-	22,000
35,000	13,000	24,500
15,000	35,000	24,500

To obtain the demand necessary for a future population of 175,000, the total commandable storage capacity in the system must be at least 50,000 ML, with at least 15,000 ML at Clarrie Hall Dam. A planning study is recommended to find the best solution for Tweed Shire Council of what combination of options to use.

9.5 INCREASE BRAY PARK WEIR STORAGE CAPACITY

No appreciable increase in system yields or reliability was achieved by increasing the storage capacity of Bray Park Weir by 10% up to 720 ML. However, this increase in capacity resulting from raising the weir crest level by 200 mm protects the weir pool from salt water ingress during periods of king tides and corresponding low river flows.

9.6 ENVIRONMENTAL FLOW RELEASES MONITORING

The environmental flow releases rules are based solely on estimated natural flows into the storages. No consideration was given in this analysis to the possibility of physically being able to make such releases, given the current infrastructure capabilities. Environmental flow releases used in the analysis may also not be consistent with operational strategies.

For future environmental flow monitoring purposes, a flow relationship was developed using the gauge readings of Uki and Eungella. A 95% environmental flow could be released from Bray Park Weir using this relationship, but the travel time between these gauges to Bray Park Weir should be considered. It is recommended that the existing automated gauge at Bray Park Weir have a rating curve developed and it be used for daily monitoring recording of flows and releases from the weir.

9.7 STREAMBED LOSSES

Stream losses for the pipeline could not be modelled accurately with the available data and therefore, loss estimation from a flow monitoring method is recommended.

10.0 CONCLUSIONS

An IQQM was developed for the Tweed River Basin. Long-term streamflows were obtained by calibrating a rainfall runoff model against recorded flow data, and extending the series from 1890 to 2004 using catchment rainfall. The IQQM was calibrated, using short periods of recorded storage levels in Clarrie Hall Dam and Bray Park Weir.

A number of scenarios were then analysed to determine the security of the current supply for Tweed Shire Council, and determine which future development options would best suit future demands. In the scenario modelling, only the hydrological feasibility of different options was considered, not any other engineering or environmental issues.

The following major conclusions are drawn from these analyses:

- The adequacy of the traditional approach (historic no failure yield) to security of supply was found insufficient, given possible future climate change and demand hardening, as indicated in the drought of 2002/03.
- By changing the security of supply methodology from the historic no failure yield to restrictions and a contingency storage approach, the Tweed Shire Council can reduce the frequency of restrictions to less than 1%, or 1 in 29 years.
- The current system falls short of meeting existing demands (10,900 ML/a) with the increased security of supply, (i.e. a new security criterion for contingency storage, equivalent to 80% of annual usage).
- To meet future demands without a very significant reduction in per person usage (of approximately 60%), additional storage will be required. Augmentation of the existing Clarrie Hall dam alone will not meet future demands of 24,500 Ml/a for a population of 175,000.

Other outcomes from the investigations are:

- The study has identified a reduction in the HNFY from 18,000 ML/a (2002 Study) to 16,200 ML/a, mainly attributable to the 2002/03 drought being the worst on record for the Tweed River.
- The implementation of the 95% environmental flow releases, reduces the HNFY of the existing system to 14,000 ML/a, increasing to 15,000ML/a when restrictions are implemented.

- With the introduction of the 95% environmental flow requirement and the contingency storage security criteria, the existing system falls to 10,100 ML/a, a shortfall of 800 ML/a for the current demand.
- The implementation of both the 95% environmental flow requirements and the new contingency storage security criteria results in a required commandable storage capacity of approximately 30,000 ML to service a population of 125,000. A commandable storage capacity of approximately 50,000 ML is required to meet the potential full development demand for a population of 175,000.
- Comparison with the yields obtainable from the raising of Clarrie Hall Dam shows an increase in yields resulting from the two-dam system. The storages drain separate catchments, so the dry periods are managed individually.
- Although increasing the capacity of Bray Park Weir to 720 ML makes little impact on the reliability of the town water supply, the number of restrictions to be applied is reduced. Raising the weir crest level by 200 mm protects the weir pool from salt water ingress during periods of king tides and corresponding low river flows.
- At this stage, it was not possible to identify any significant climate trends in relation to recorded water use. However, any future demand modelling should look into expressing the demand as a function of climate variability, if more recorded data is available.
- In order to accurately manage the system in the future, it will be necessary to impose more stringent monitoring practices throughout the system.

11.0 RECOMMENDATIONS

The following recommendations are made to further improve the management of the Tweed Water Supply in the future.

- The placement of new stream flow gauges at key locations to ensure efficient system operations, and monitor environmental flow releases is recommended. This could be done by continuous recording of the following:
    - Flows at the Byrrill Creek damsite – for future development of the site.
    - Flows in the Tweed River above the junction with Doon Doon Creek – to record flow from the unregulated section of the catchment.
    - Flows immediately downstream of Clarrie Hall Dam – to record all releases (and overflows) – or alternatively by installation of flow metering on the discharge pipe work
    - If possible, all flows into Bray Park Weir from Tweed River and Oxley River – to assist in the determination of environmental flow releases from Bray Park Weir.
    - Storage heights at Clarrie Hall Dam and Bray Park Weir – on a continuous basis, not daily, to near millimetre accuracy.
    - The operation of the fish ladder.
- The above records would also be used to determine the quantum of in-stream losses and the need for a pipeline to carry water from Clarrie Hall Dam to Bray Park Weir.
- Daily or at least monthly usage data of Uki, Tyalgum and irrigation users should be recorded.
- Releases from Clarrie Hall Dam and Bray Park Weir will need to be optimised and operational procedures developed as part of the Water Sharing Plan implementation to achieve the yields identified by this study.
- When accurate inflow data to Bray Park Weir is available, a water balance for Bray Park Weir should be carried out to refine in-stream losses, if any.
- It is recommended that the Tweed Shire Council review their Drought Management Plans, particularly the introduction of restriction levels and contingency measures, for the short-term while the total storage capacity is marginal.

- Once the final operational system is accepted, the Tweed Shire Council will need to develop operational strategies to implement the Water Sharing Plan's objectives, including environmental flow releases.
- A planning study, including a NPV analysis, is recommended to find the best combination for construction of additional storage.
- Regarding such environmental flow releases, further investigation is required to meet the criteria in the best practical way, as the current infrastructure cannot successfully achieve all necessary releases.
- The council should review restriction levels regularly, taking into account such factors as demand hardening, once residents become more water-wise in their everyday activities.

12.0 REFERENCES

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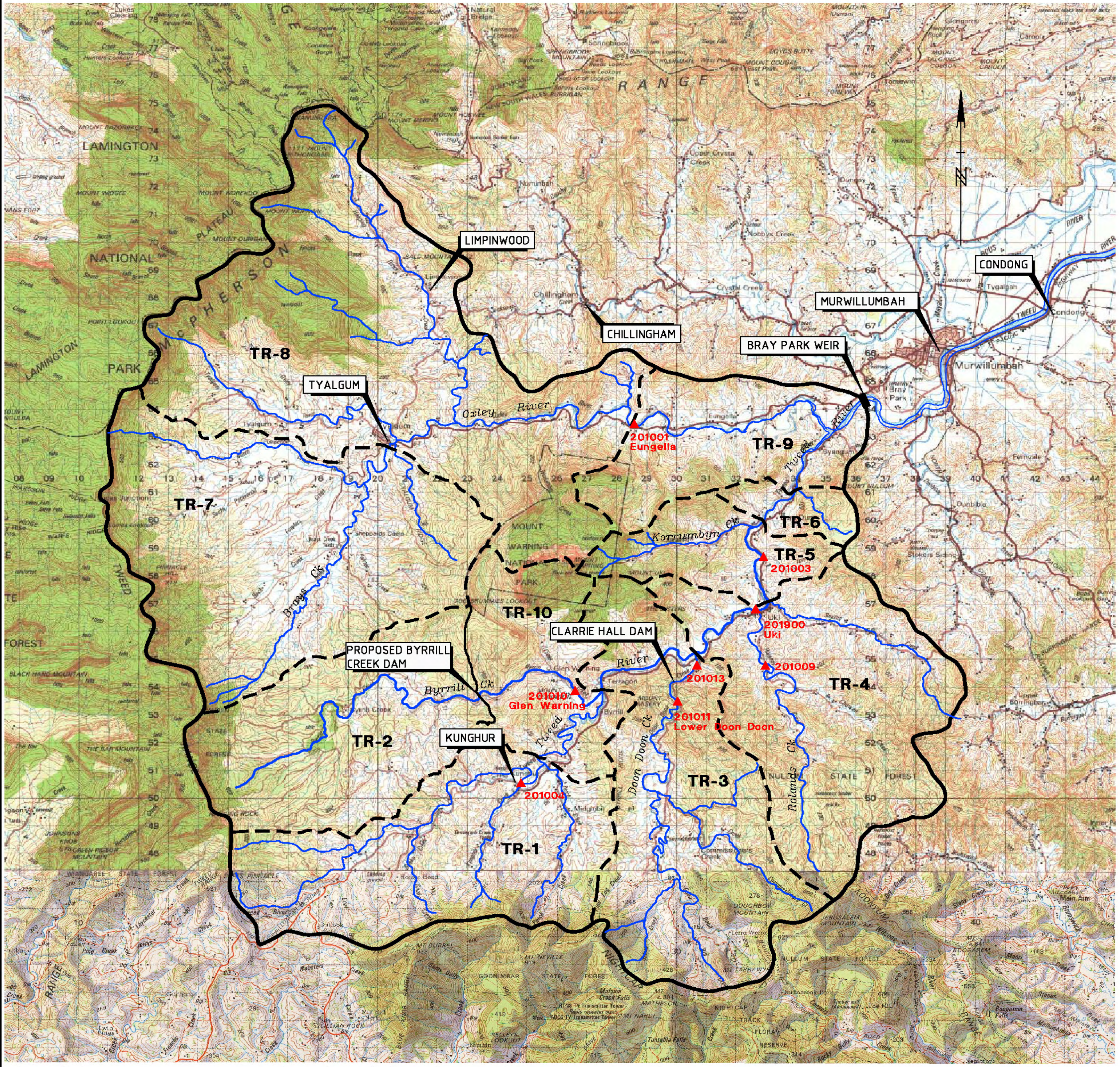
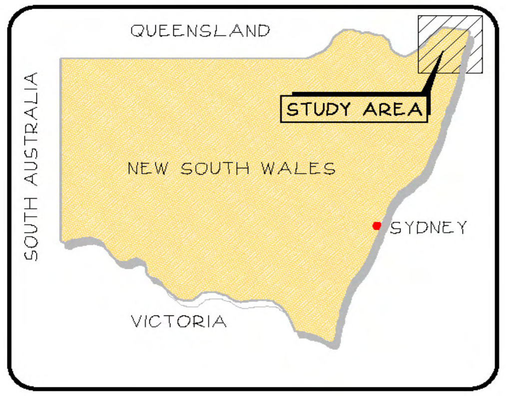
APPENDIX A

CATCHMENT PLAN





LEGEND

(solid line)	CATCHMENT BOUNDARY
(dashed line)	SUBCATCHMENT BOUNDARY
TR-7	SUBCATCHMENT ID
(blue line)	STREAM
▲ 201001 EUNGELLA	GAUGING STATION NUMBER AND NAME

CATCHMENT AREA = 552km²

SCALES

0 2.5 5.0 7.5 KILOMETRES
1 : 150000

COMPILED FROM 1:100000 TOPOGRAPHIC MAP 9541a and 9540

REVISION	DATE	REMARKS	CKD	PSD

REFERENCE DRAWINGS

DRAWN RET | DESIGNED SD
CHECKED | CHECKED
APPROVED
N.Bartlett
for PROJECT MANAGER WATER STUDIES

SunWater
Level 9, 120 Edward Street
Brisbane Qld 4002
Tel: (07) 3120 0000

TWEED RIVER CATCHMENT
YIELD STUDY - 2005
CATCHMENT MAP
IQQM MODEL LAYOUT

CONTRACT NUMBER
DRAWING NUMBER 222653
DATE SEP 2005

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APPENDIX B

DAILY FLOW DATA FOR CALIBRATION AND VERIFICATION PERIODS

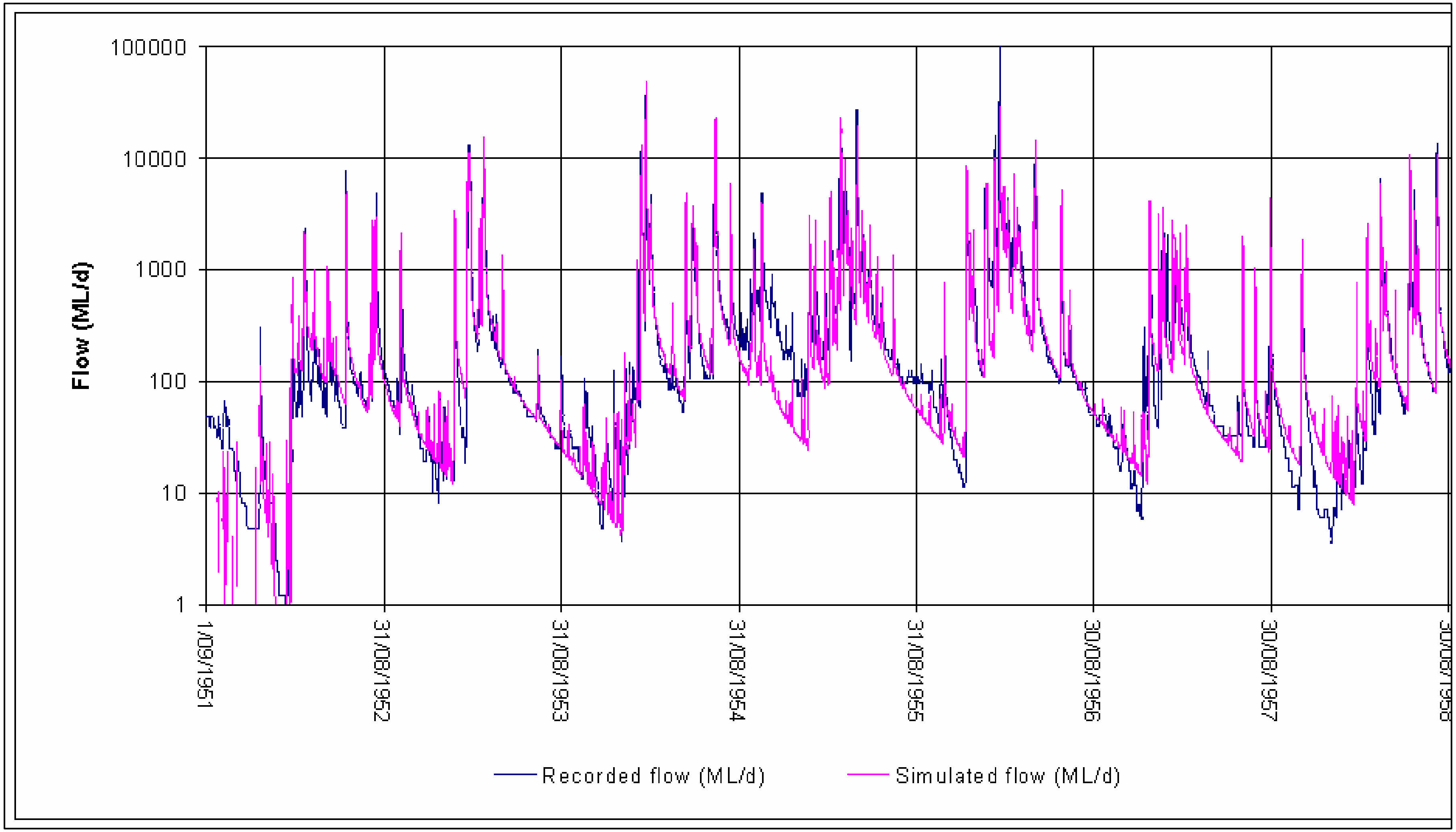


Figure B1-a: Simulated and Recorded Daily Flows for the Calibration Period of Uki Gauge

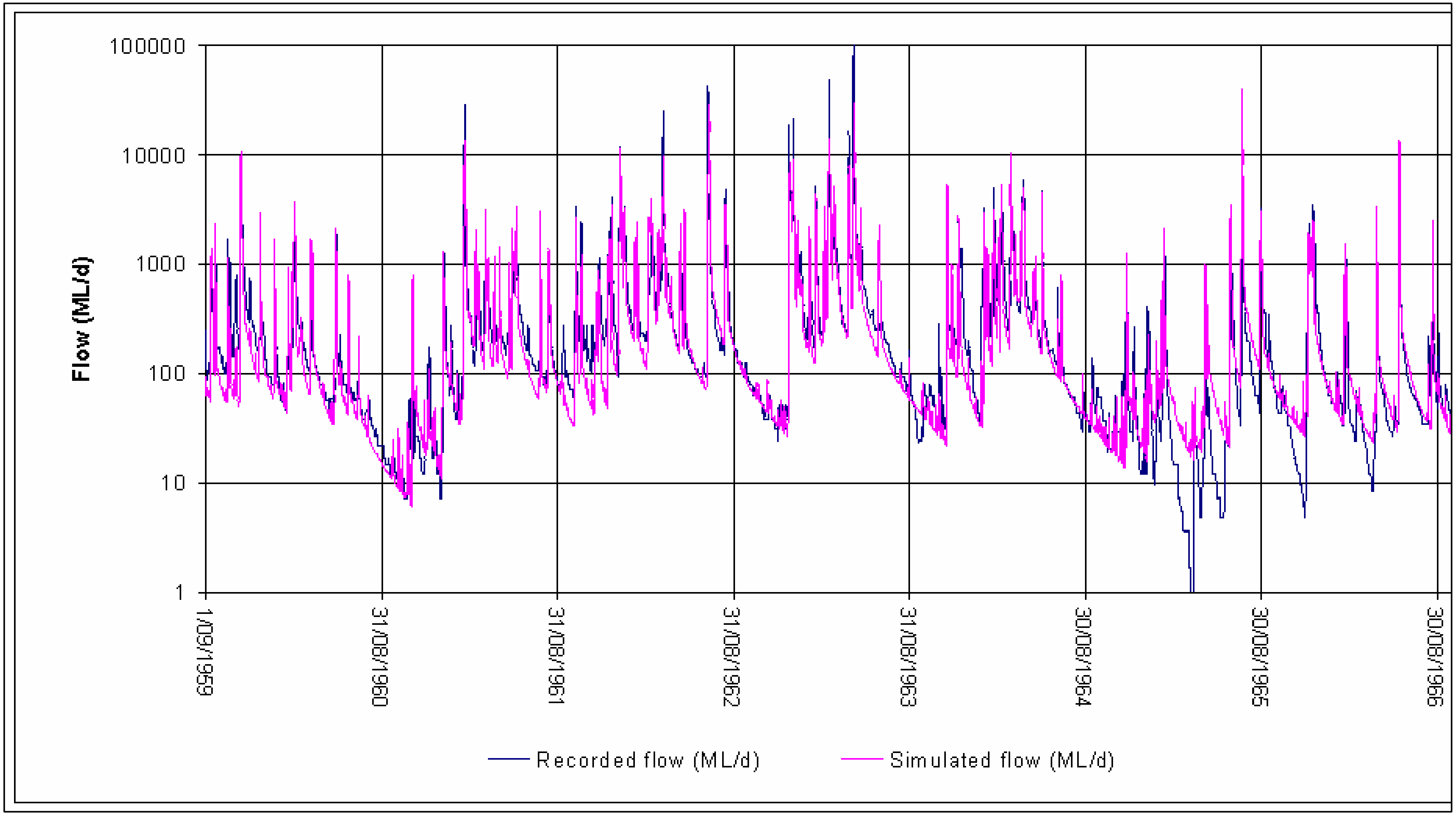


Figure B1-b: Simulated and Recorded Daily Flows for the Calibration Period of Uki Gauge

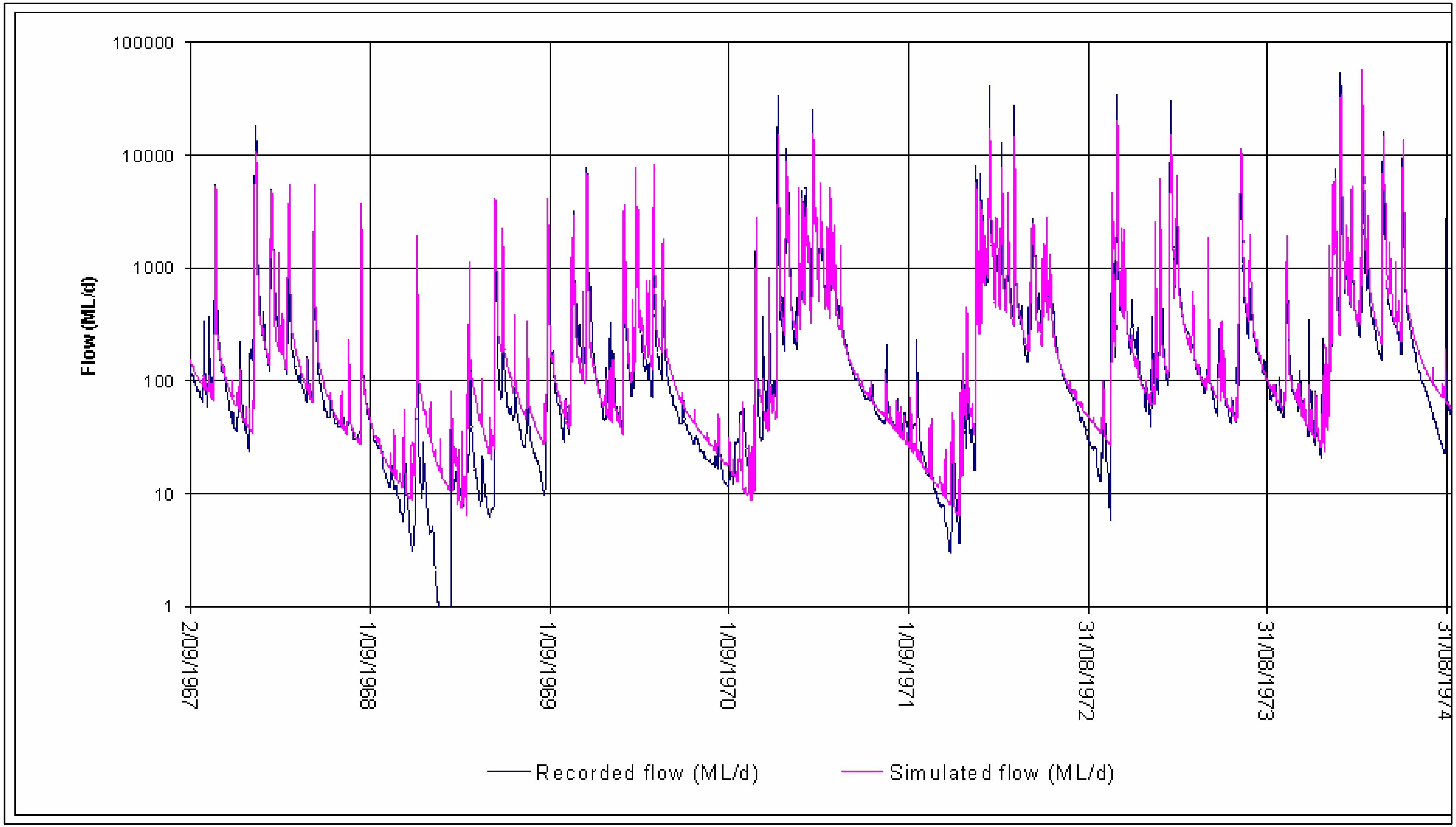


Figure B1-c: Simulated and Recorded Daily Flows for the Calibration Period of Uki Gauge

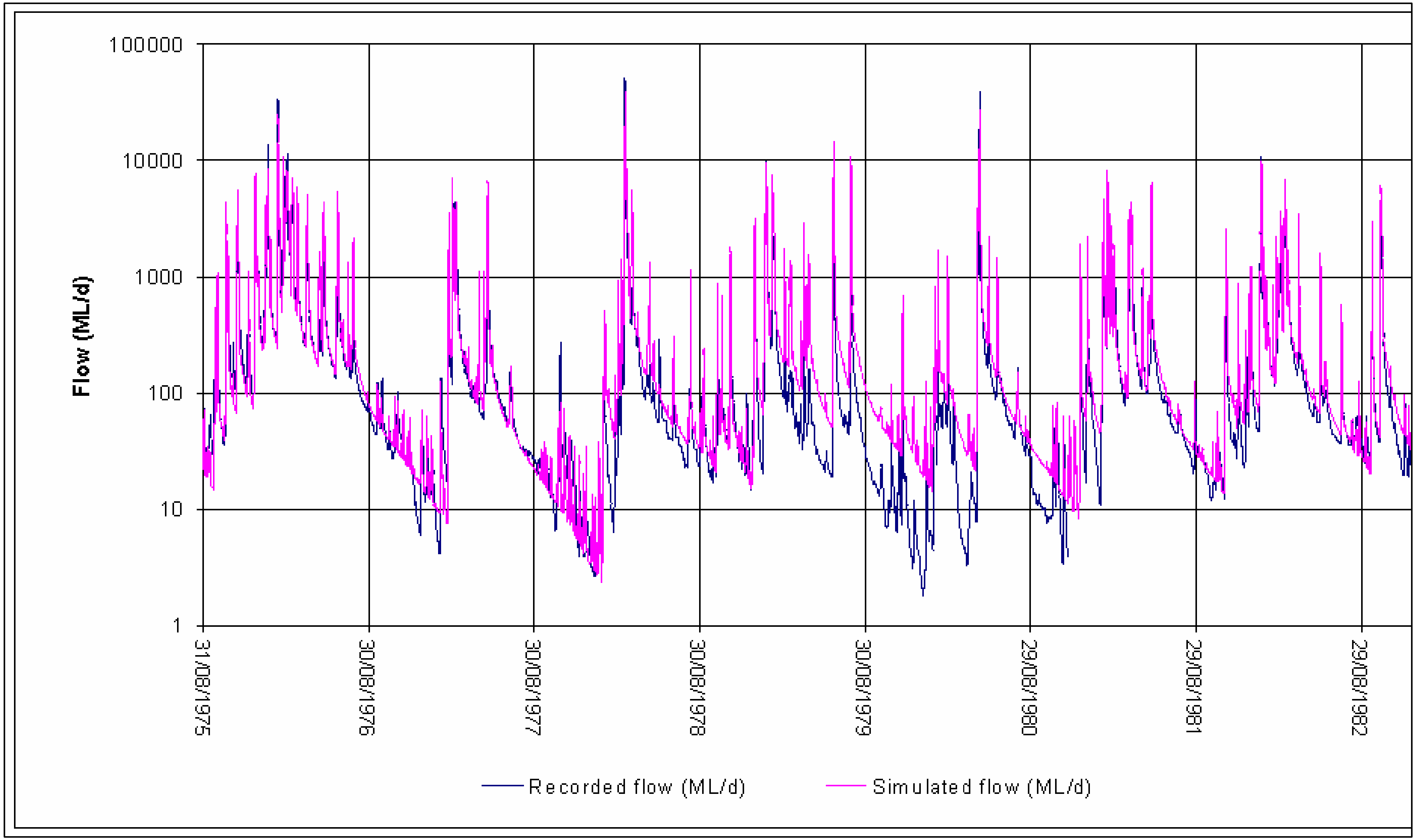


Figure B1-d: Simulated and Recorded Daily Flows for the Calibration Period of Uki Gauge

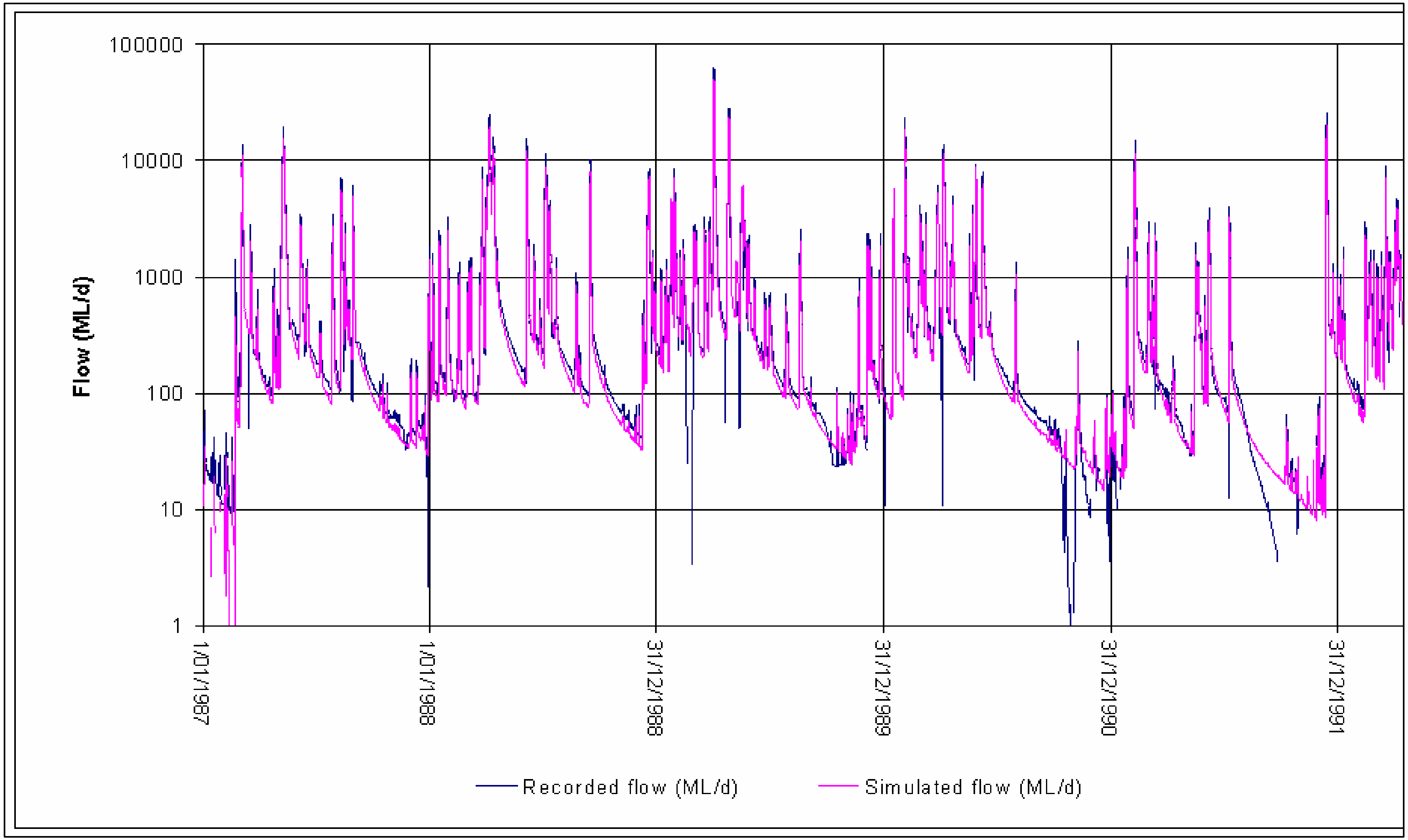


Figure B2-a: Simulated and Recorded Daily Flows for the Verification Period of Uki Gauge

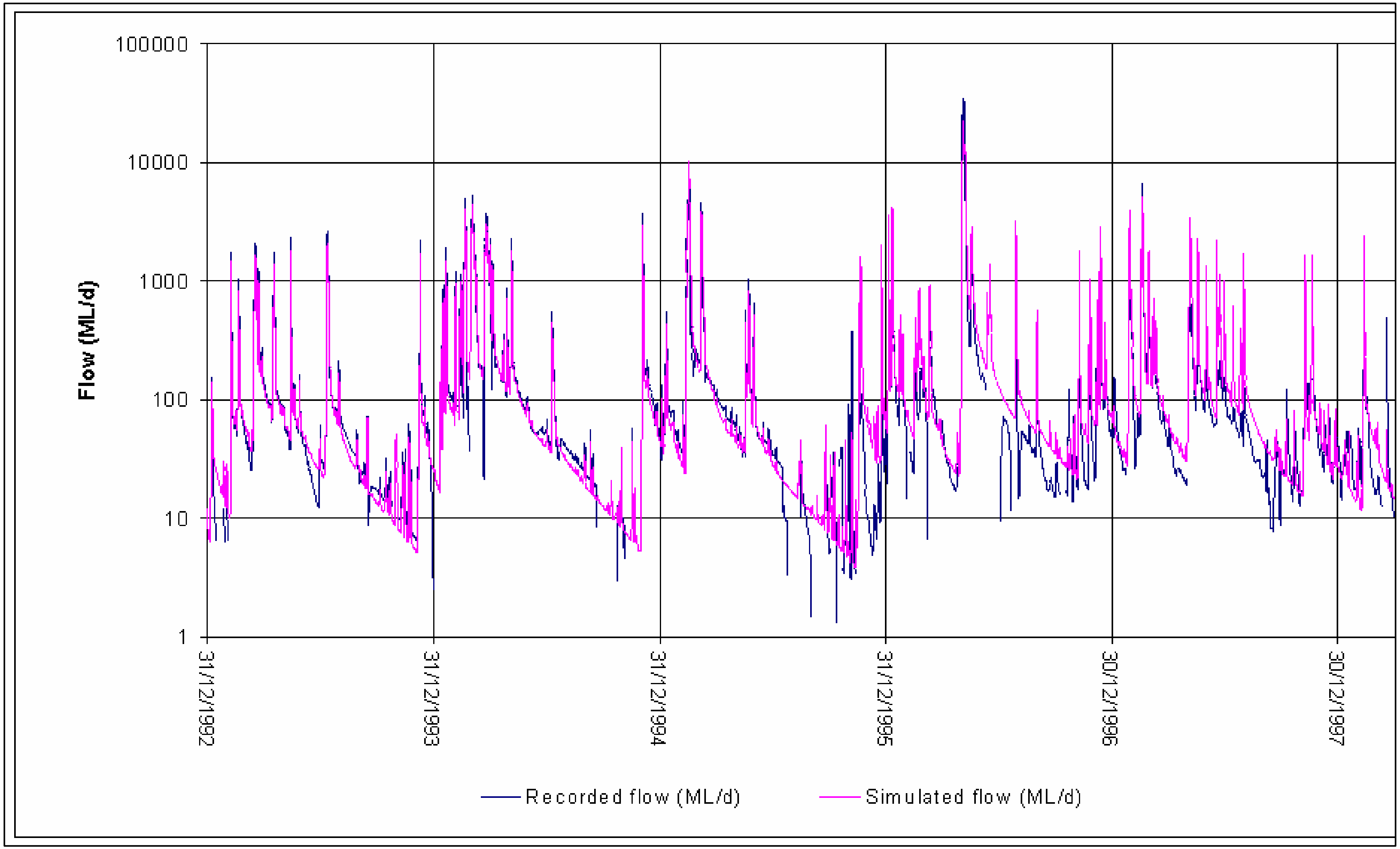


Figure B2-b: Simulated and Recorded Daily Flows for the Verification Period of Uki Gauge

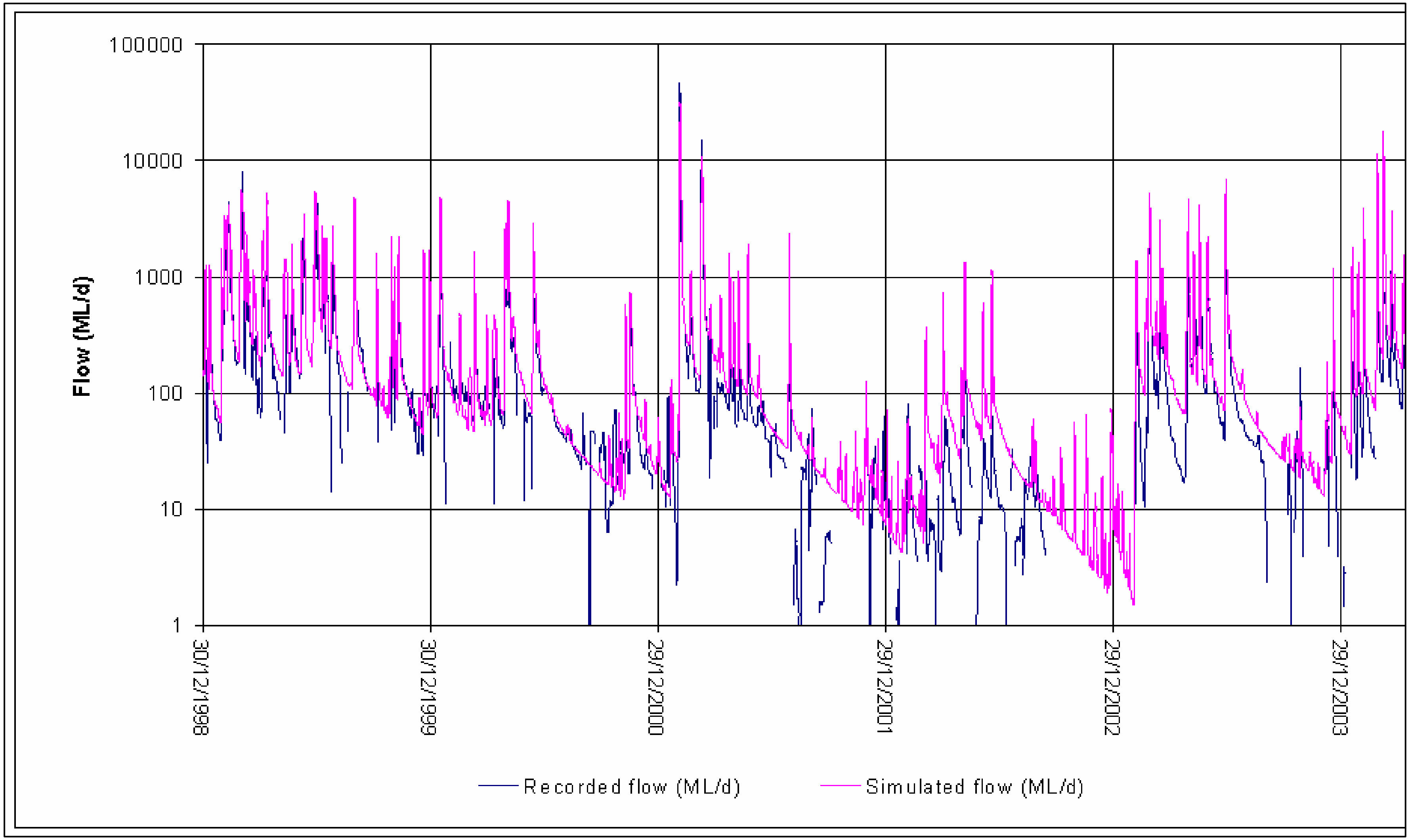


Figure B2-c: Simulated and Recorded Daily Flows for the Verification Period of Uki Gauge

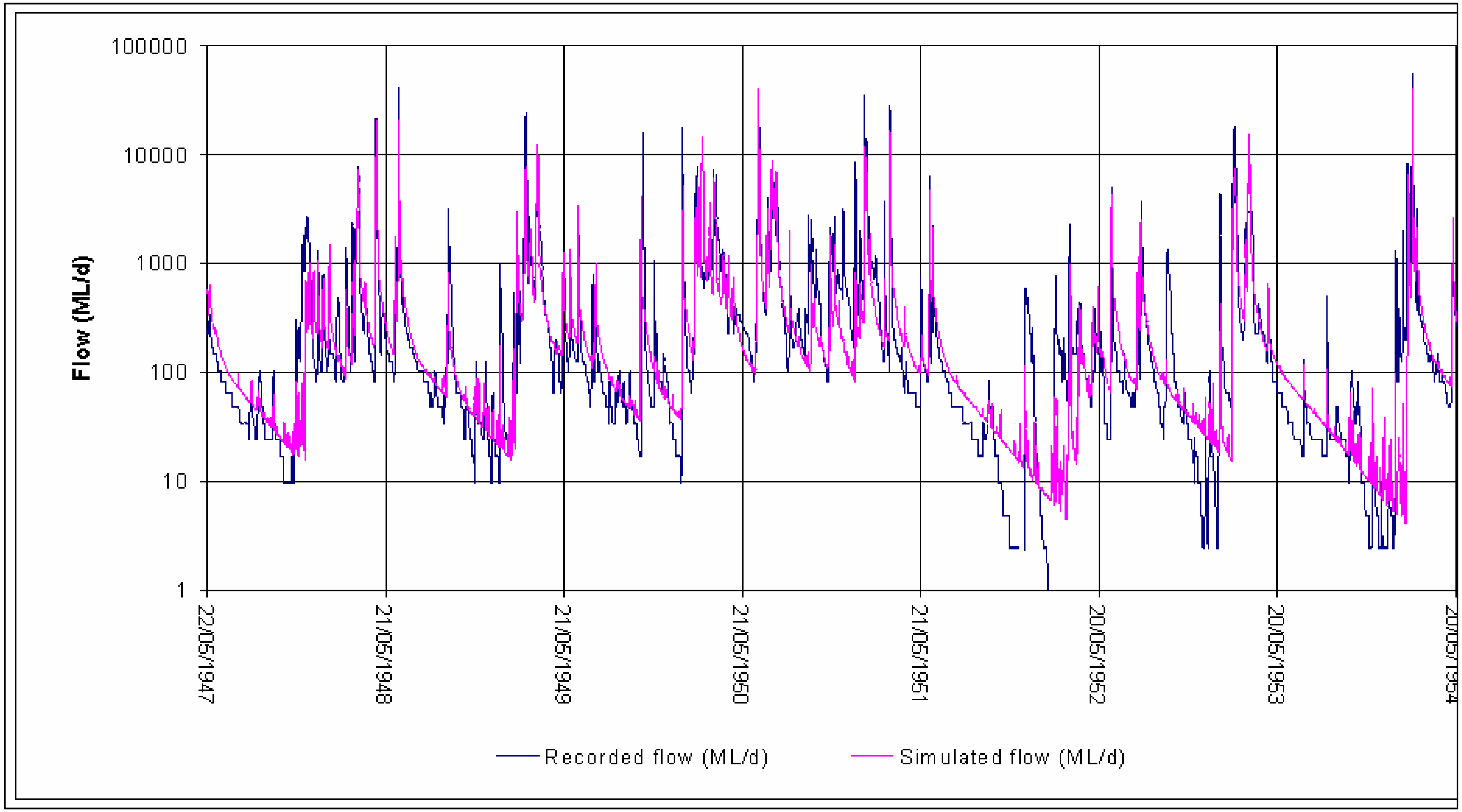


Figure B3-a: Simulated and Recorded Daily Flows for the Calibration Period of Eungella Gauge

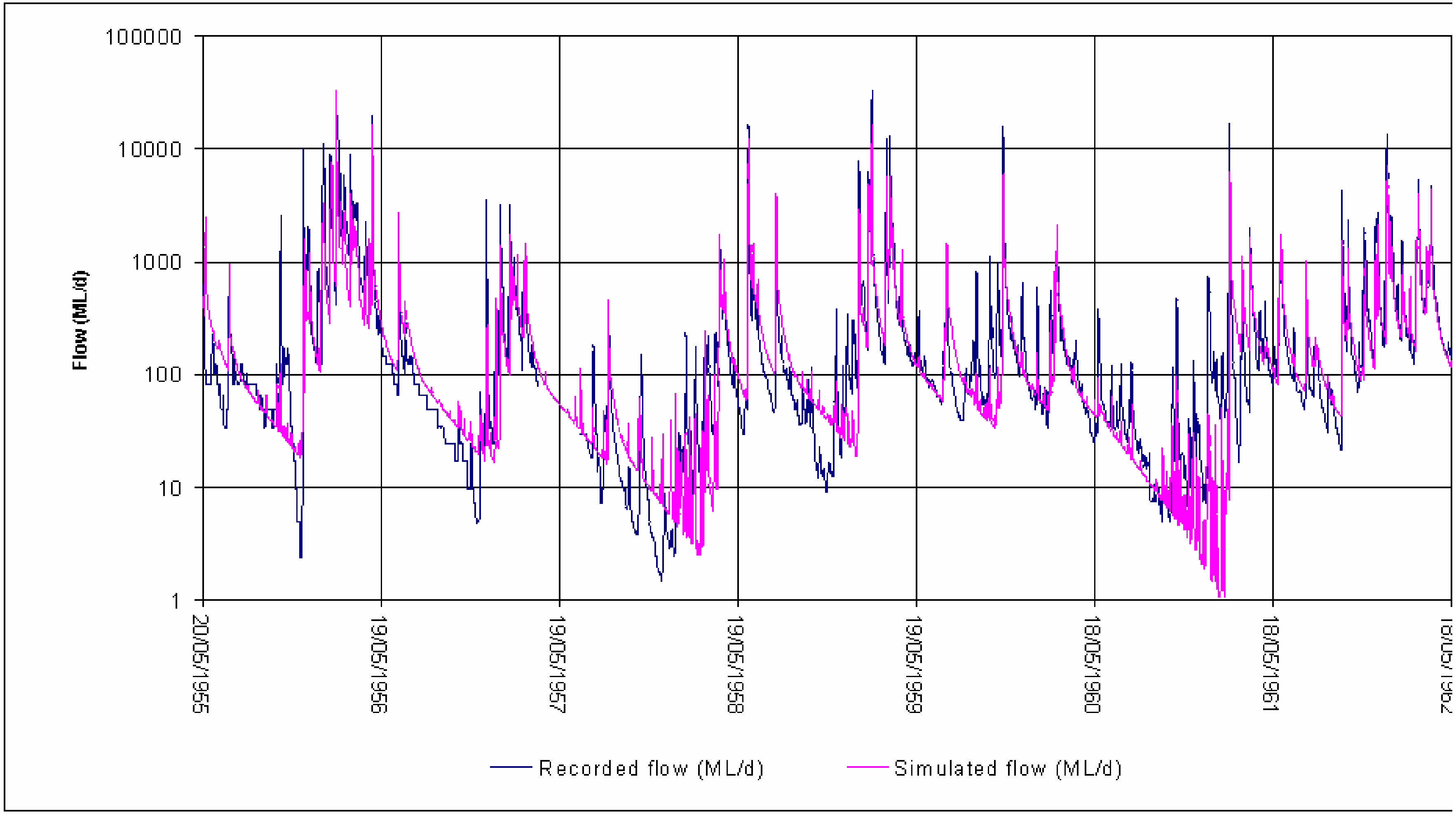


Figure B3-b: Simulated and Recorded Daily Flows for the Calibration Period of Eungella Gauge

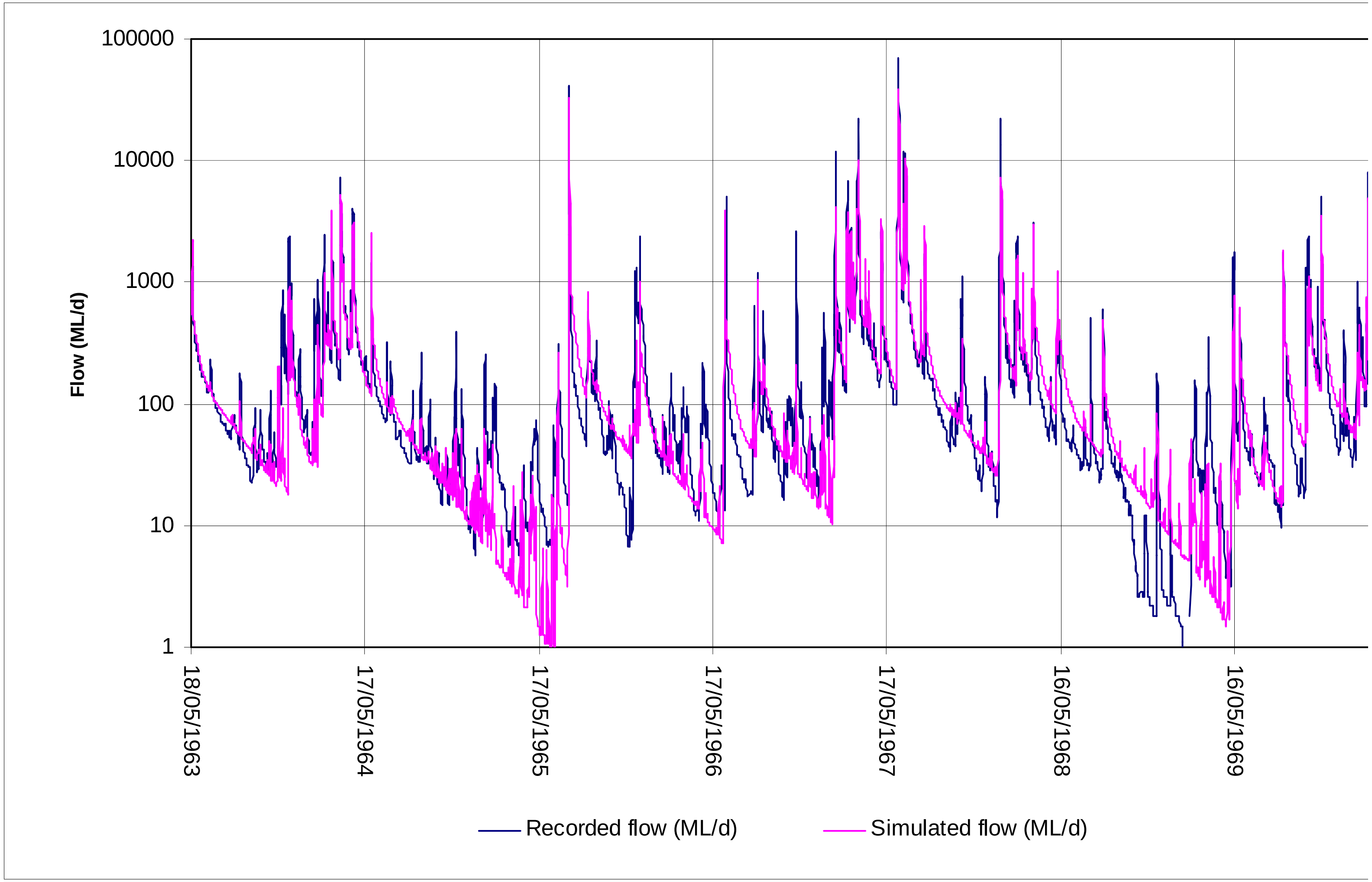


Figure B3-c: Simulated and Recorded Daily Flows for the Calibration Period of Eungella Gauge

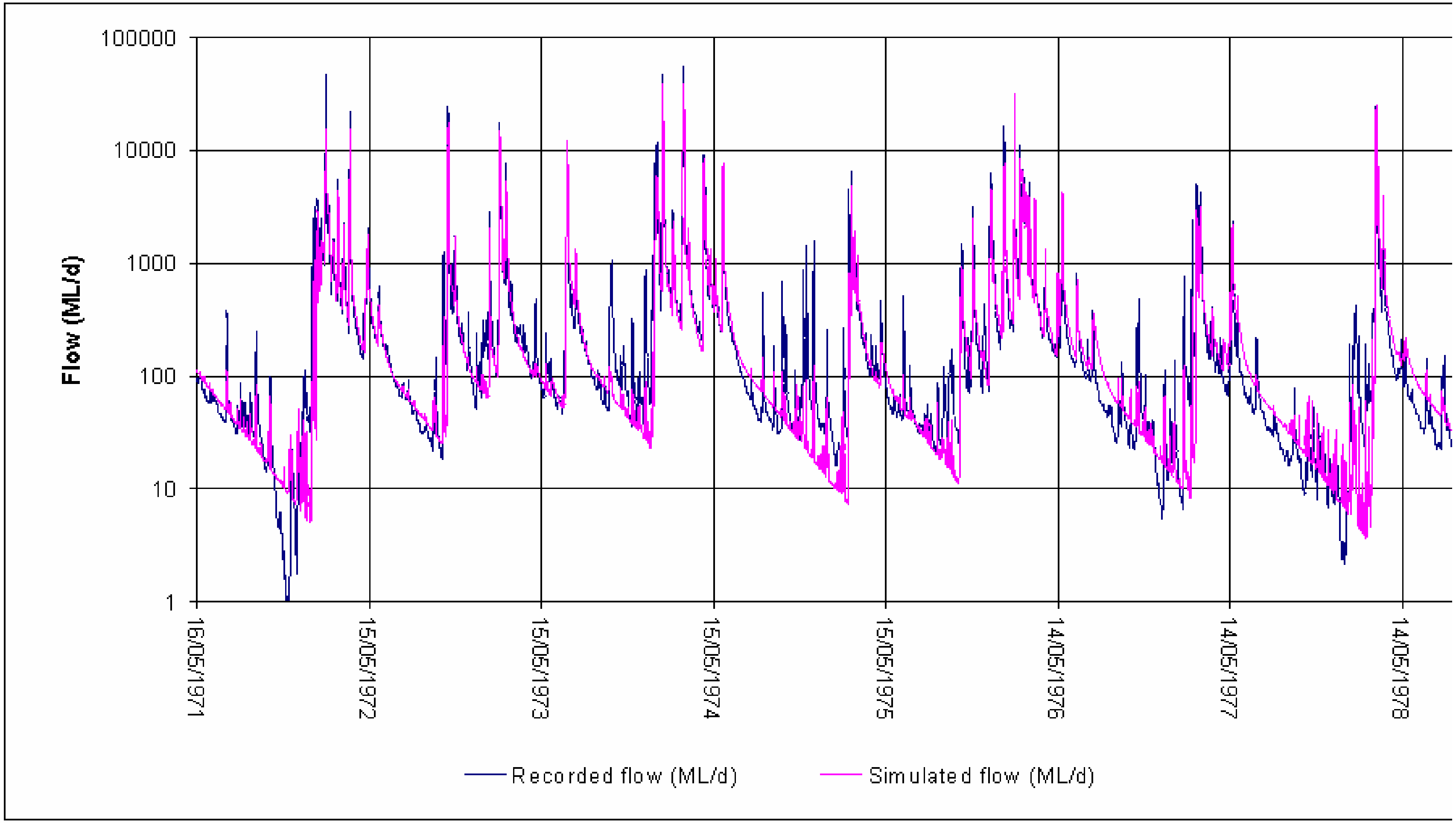


Figure B3-d: Simulated and Recorded Daily Flows for the Calibration Period of Eungella Gauge

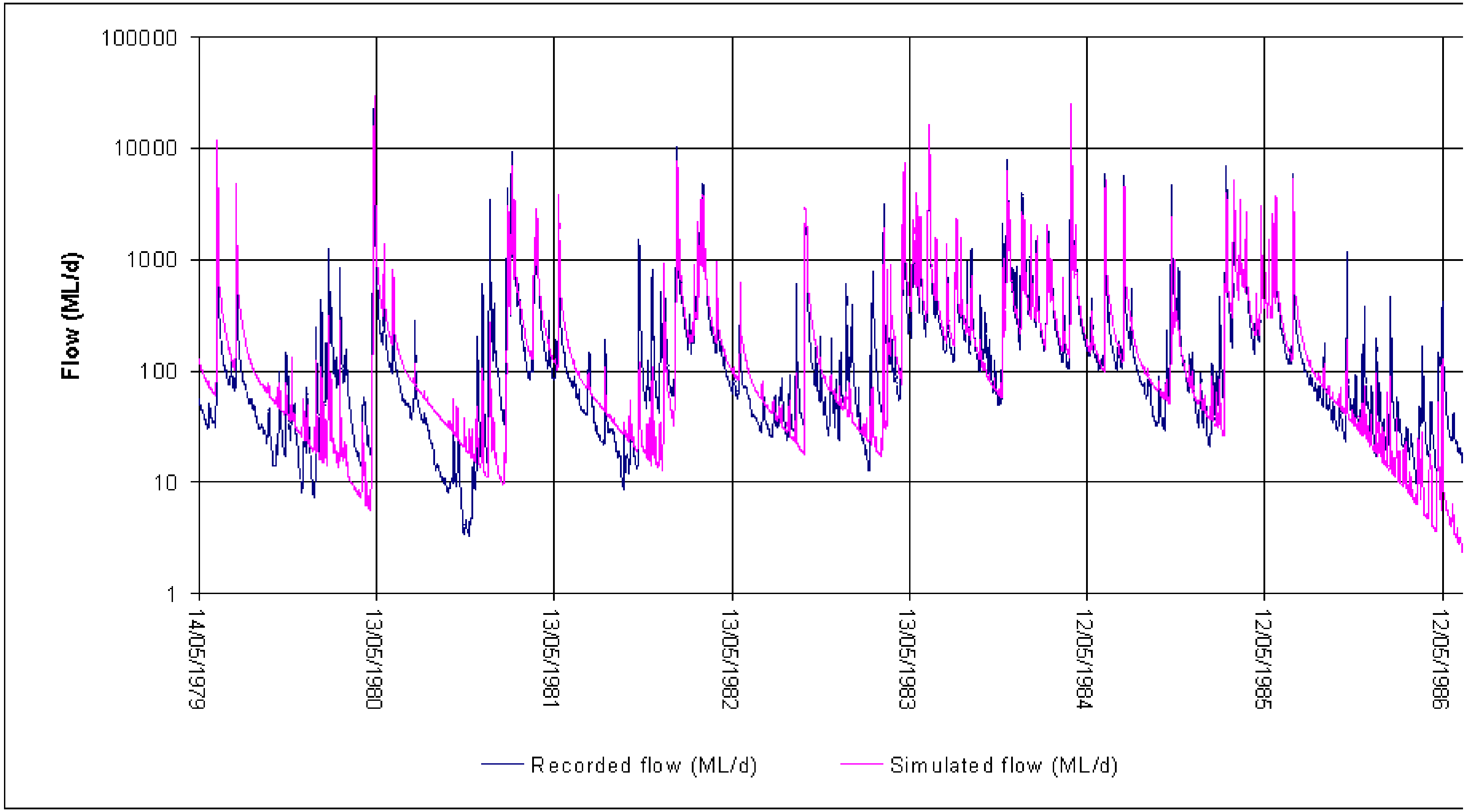


Figure B3-e: Simulated and Recorded Daily Flows for the Calibration Period of Eungella Gauge

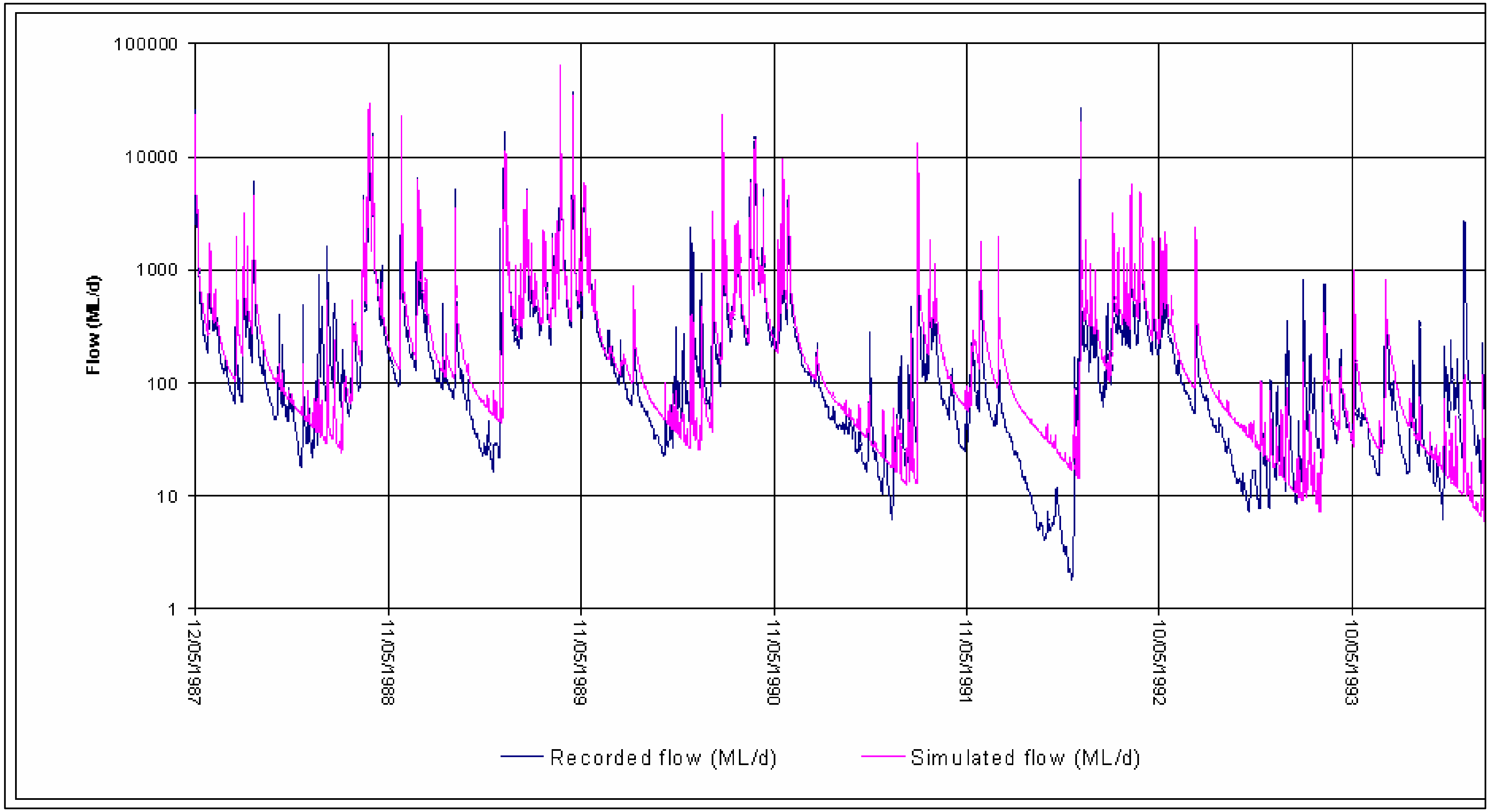


Figure B3-f: Simulated and Recorded Daily Flows for the Calibration Period of Eungella Gauge

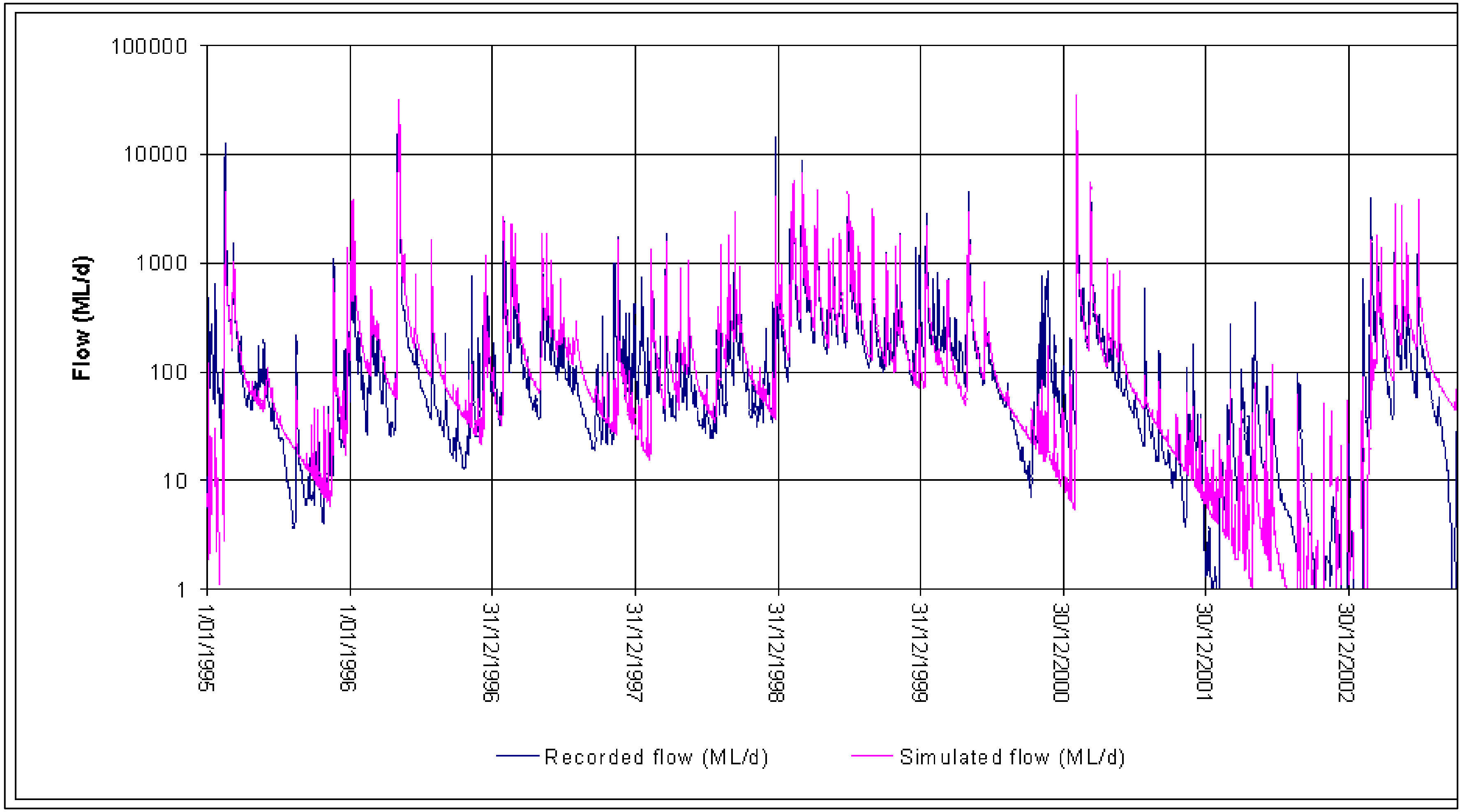


Figure B4: Simulated and Recorded Daily Flows for the Verification Period of Eungella Gauge

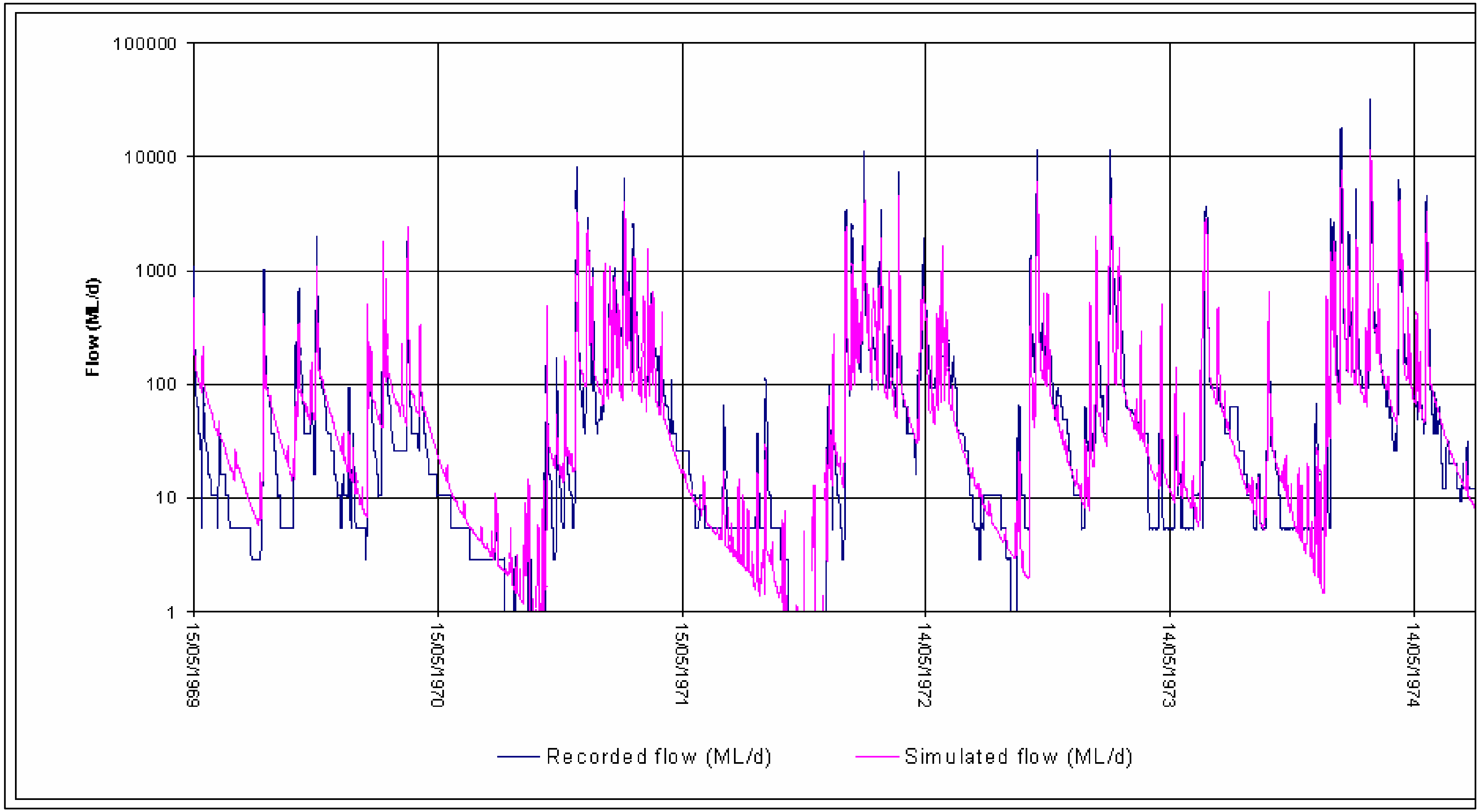


Figure B5-a: Simulated and Recorded Daily Flows for the Calibration Period of Doon Doon Gauge

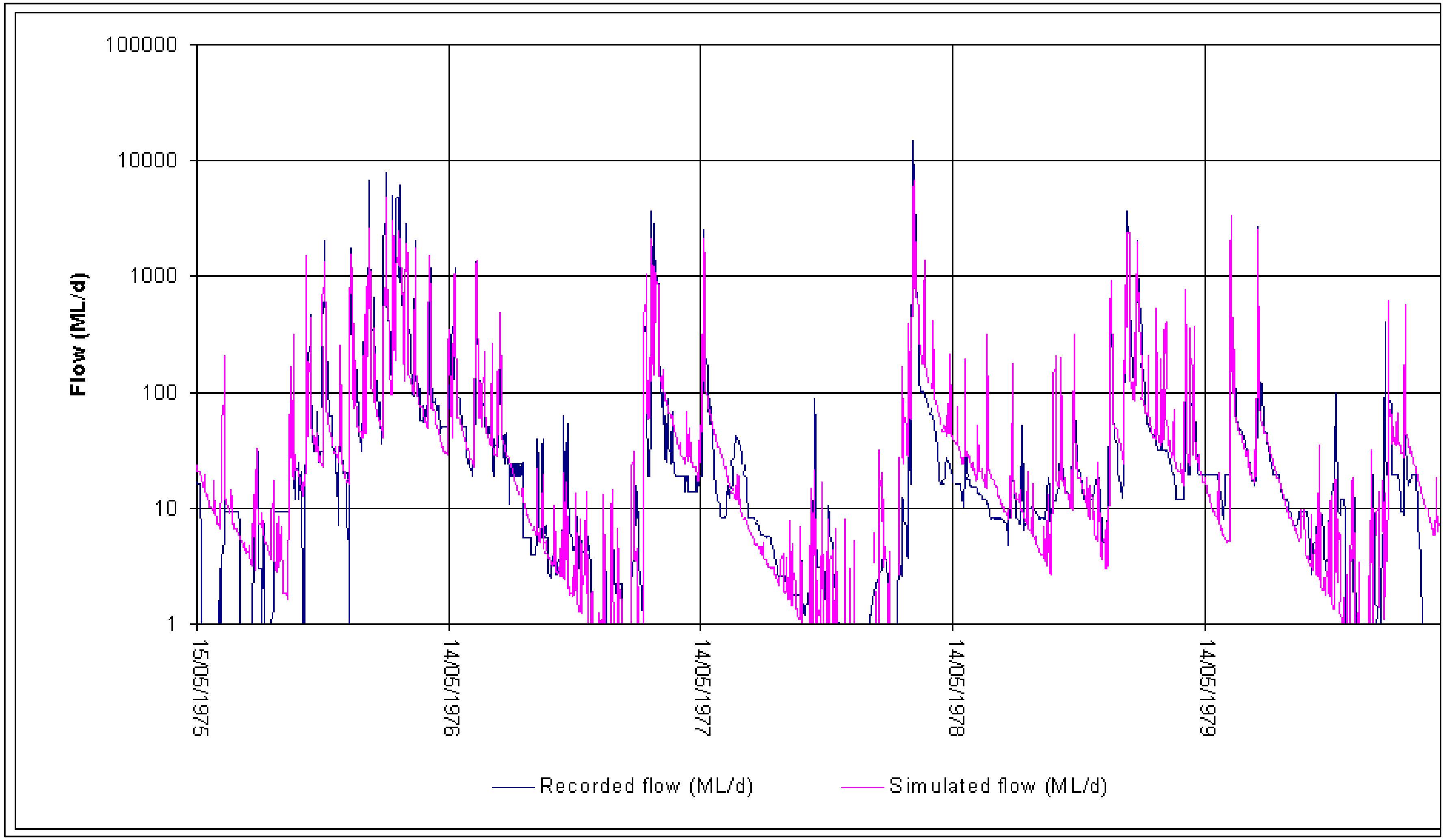


Figure B5-b: Simulated and Recorded Daily Flows for the Calibration Period of Doon Doon Gauge

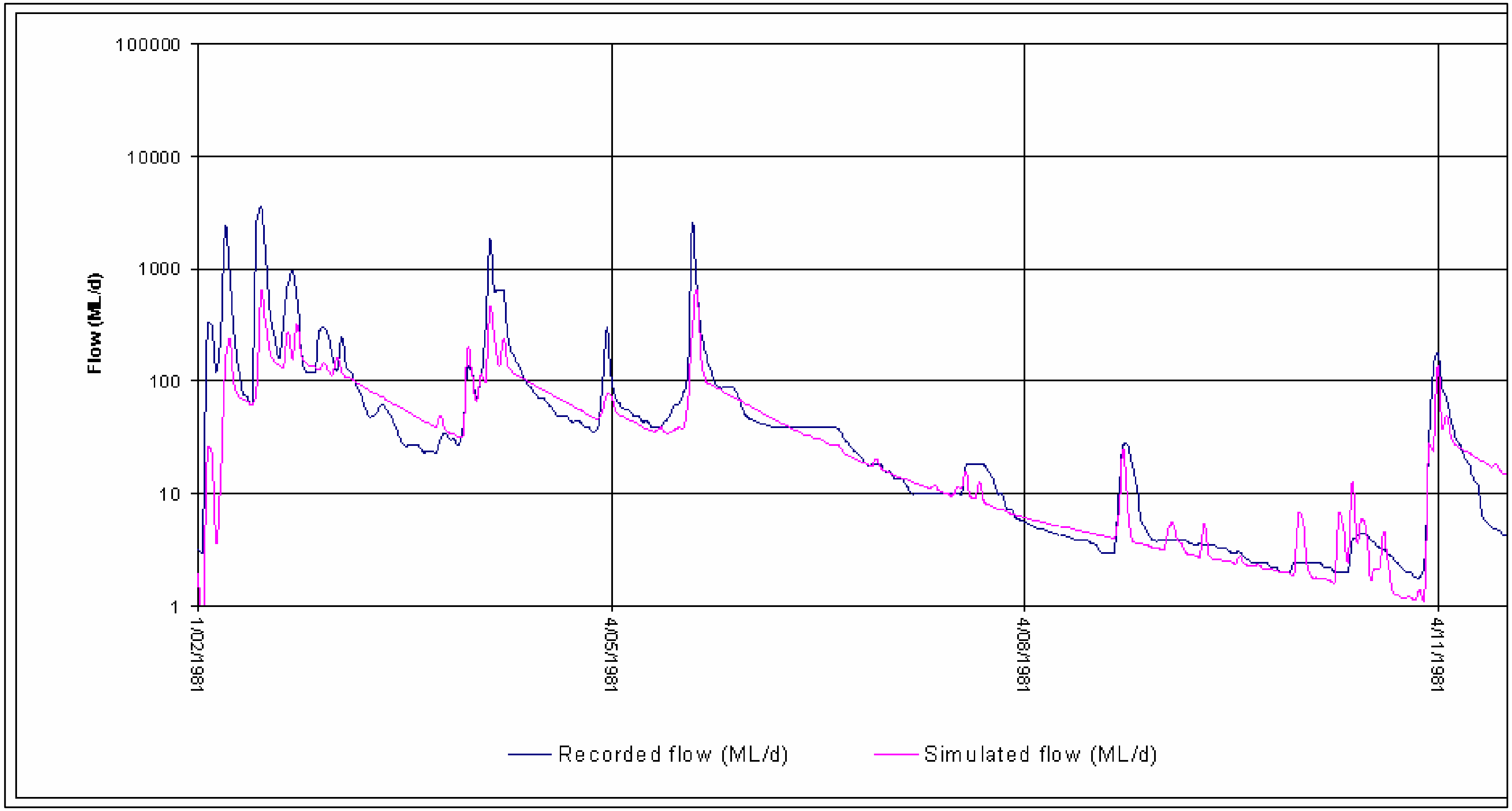


Figure B6: Simulated and Recorded Daily Flows for the Verification Period of Doon Doon Gauge

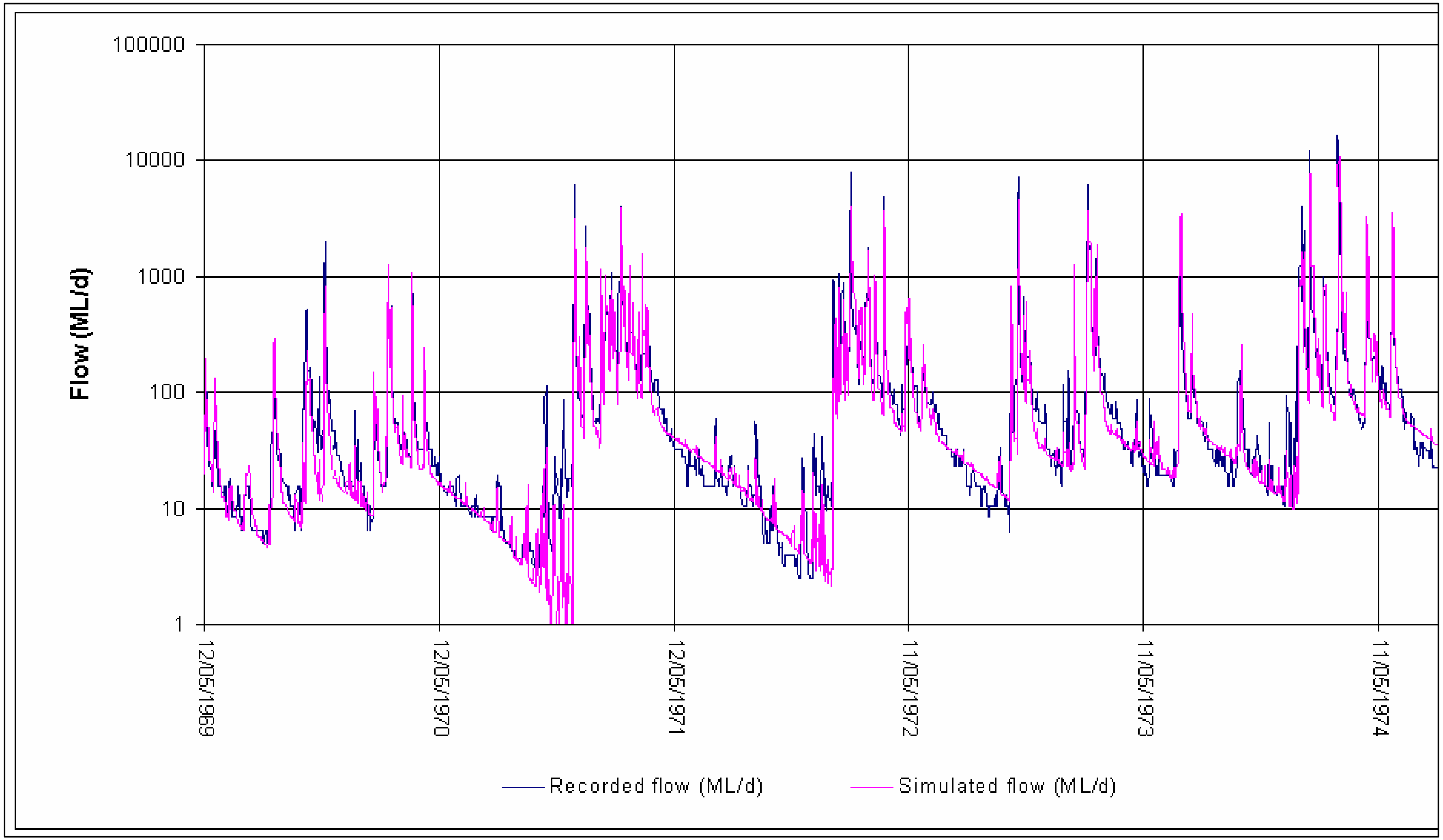


Figure B7-a: Simulated and Recorded Daily Flows for the Calibration Period of Byrrill Gauge

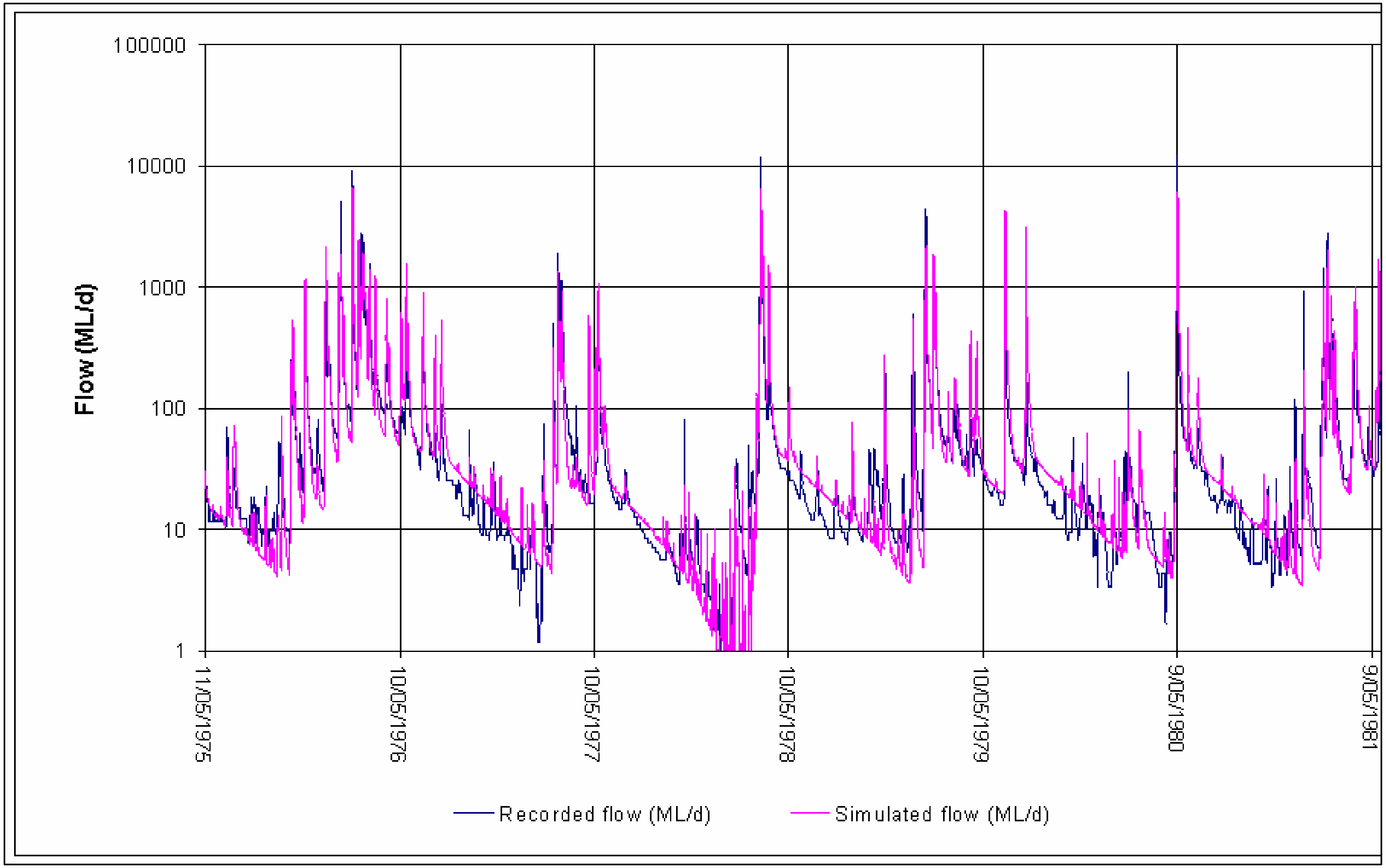
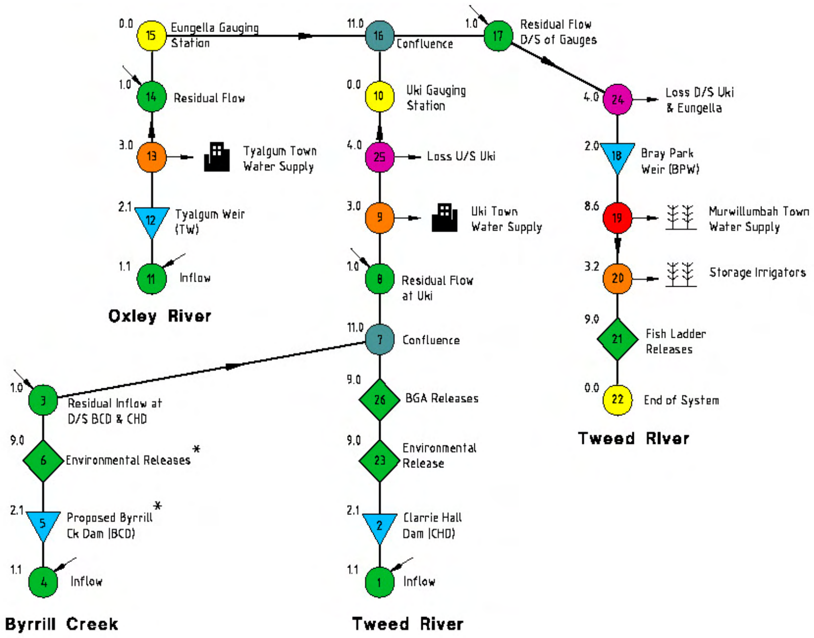


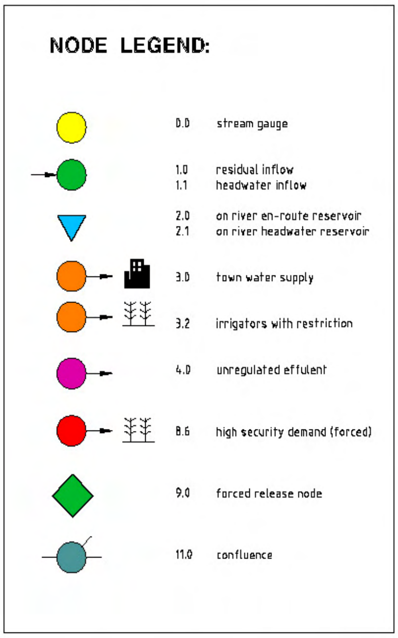
Figure B7-b: Simulated and Recorded Daily Flows for the Calibration Period of Byrrill Gauge

APPENDIX C

IQQM NODE DIAGRAM AND SYSTEM FILE FOR MODEL CALIBRATION



* Not considered in model calibration



P:\G Projects\G-81903_Tweed Shire Council\02_Tweed\03_Tweed River Study\03_Tweed Water Supply Security Review\Drafting\225612.dwg
16 Jan 2006 2:07 PM

DRAWN	DESIGNED	SunWater	TWEED RIVER IQQM CALIBRATION NODE DIAGRAM	CONTRACT NUMBER
RET	SD			
CHECKED	CHECKED			DRAWING NUMBER
APPROVED		Level 9, 120 Edward Street Brisbane Qld 4002 Tel: (07) 3120 0000		225612
N.Bartlett for PROJECT MANAGER WATER STUDIES				DATE JAN 2006

6.73.004
/
001/
'System file details:

++
++++++++

Project:	Tweed Water Supply Security Review
Basin:	201 - Tweed Catchment
Case Name:	Tweed_Calibration
Case for:	Calibration of the Tweed River Basin down to Castlehope
Requested by:	Tweed Shire Council
Modeling details:	
Modeled by:	Sunil Dayaratne
Date:	28 May 2006
Comments:	Corrected for BGA estimates as there appears to be discrepancies

Quality Assurance:
Checked by:
Date:
Comments: .

++
++++++++

details ends'

'C:\Sunil\SunWater\Tweed2\' / Input Path

'Tpatn.pat' / Pattern file name
'TS5Rain' / Time series precipitation data
'TS5Evapo' / Time series evaporation data
'TS5Flow' / Time series flow data
'Tusage' / Historical Diversion Data
' ' / No groundwater allocation data
' ' / No Maximum temperature Data
' ' / No Minimum temperature Data
' ' / Crop Factors

0 / flow output flag
6 24 / routing time step
0 / No of Const,

5 / No of river sections

3 / Number of links

001 002 / RVS: 1 I: 1
002 026 / RVS: 1 I: 2
026 007 / RVS: 1 I: 3

4 / Number of links

004 005 / RVS: 2 I: 1
005 006 / RVS: 2 I: 2
006 003 / RVS: 2 I: 3
003 007 / RVS: 2 I: 4

5 / Number of links

007 008 / RVS: 3 I: 1
008 009 / RVS: 3 I: 2
009 025 / RVS: 3 I: 3
025 010 / RVS: 3 I: 4
010 016 / RVS: 3 I: 5

5 / Number of links

011 012 / RVS: 4 I: 1
012 013 / RVS: 4 I: 2
013 014 / RVS: 4 I: 3
014 015 / RVS: 4 I: 4
015 016 / RVS: 4 I: 5

8 / Number of links

016 017 / RVS: 5 I: 1
017 024 8 8 0.25 1 1 1 / RVS: 5 I: 2
024 018 / RVS: 5 I: 3
018 019 / RVS: 5 I: 4
019 020 / RVS: 5 I: 5
020 021 / RVS: 5 I: 6
021 022 / RVS: 5 I: 7
022 027 / RVS: 5 I: 8

001
'US CHD' 1.1 0.0 0 0 1 / node-type, group,evap,rain,trace
10 1 0 1 0 0 / flwptr flwfact recfact state1shr minyr
0 0 0 0 0 0 0 0 0 0 0 0 0 / flow6med Jan..DEc and init median

002
'Clarrie Hall Dam' 2.1 0.0 1 2 1 / node-type, group,evap,rain,trace
15000 0 13880 0 6 0 0 10 9 0 0 / otime, reces. factor..

0 0 / Volume/Area
0 0 /
300 20 /
1000 32 /
2900 59 /
5000 93 /
8300 136 /
15700 224 /

```
32500 367               /
100.0E+06 1000          /

0 0                     / Volume/Valve Discharge
300 732                 /
2000 844                /
5000 937                /
11800 1029              /
23000 1109              /

15000 0                 / Volume/Spillway Discharge
15700 950               /
17000 2782              /
19200 5216              /
19400 8146              /
22000 15272             /
24600 23854             /
34000 56790             /
100.0E+06 100.0E+06     /

1                       / Number of states
1 1                     / State, number of groups
1                       /

026
'Blue Green Algae Releases' 9.0 1.1 0 0 1 / node-type, group,evap,rain,trace
0 0 -1 0 0 2            / Licvol pat dem ordtime no_fmit ordres
16                      / time series demand

004
'US Byrrill Creek Dam' 1.1 0.0 0 0 1      / node-type, group,evap,rain,trace
9 1 0 1 0 0             / flwptr flwfact recfact state1shr minyr
0 0 0 0 0 0 0 0 0 0 0 0 0  / flow6med Jan..DEc and init median

005
'Byrrill Creek Dam' 0.0 0.0 0 0 0

006
'Env Flow BCD' 0.0 0.0 0 0 0

003
'Residual BC & TR' 1.0 0.0 0 0 1 / node-type, group,evap,rain,trace
4 0.54 0 1 0 0    / flwptr flwfact recfact state1shr minyr

007
'Confluence' 11.0 0.0 0 0 1 / node-type, group,evap,rain,trace
1 0 0 0.0 0 0  0  / order1pass, trib1/or t to res.,orderpass2,trib2/or t to res.
002                     / ordresbr1

008
'Residual Flow at Uki' 1.0 0.0 0 0 1 / node-type, group,evap,rain,trace
4 0.46 0 1 0000 0       / flwptr flwfact recfact state1shr minyr

009
'Uki TWS' 3.0 1.1 0 0 1 / node-type, group,evap,rain,trace
```

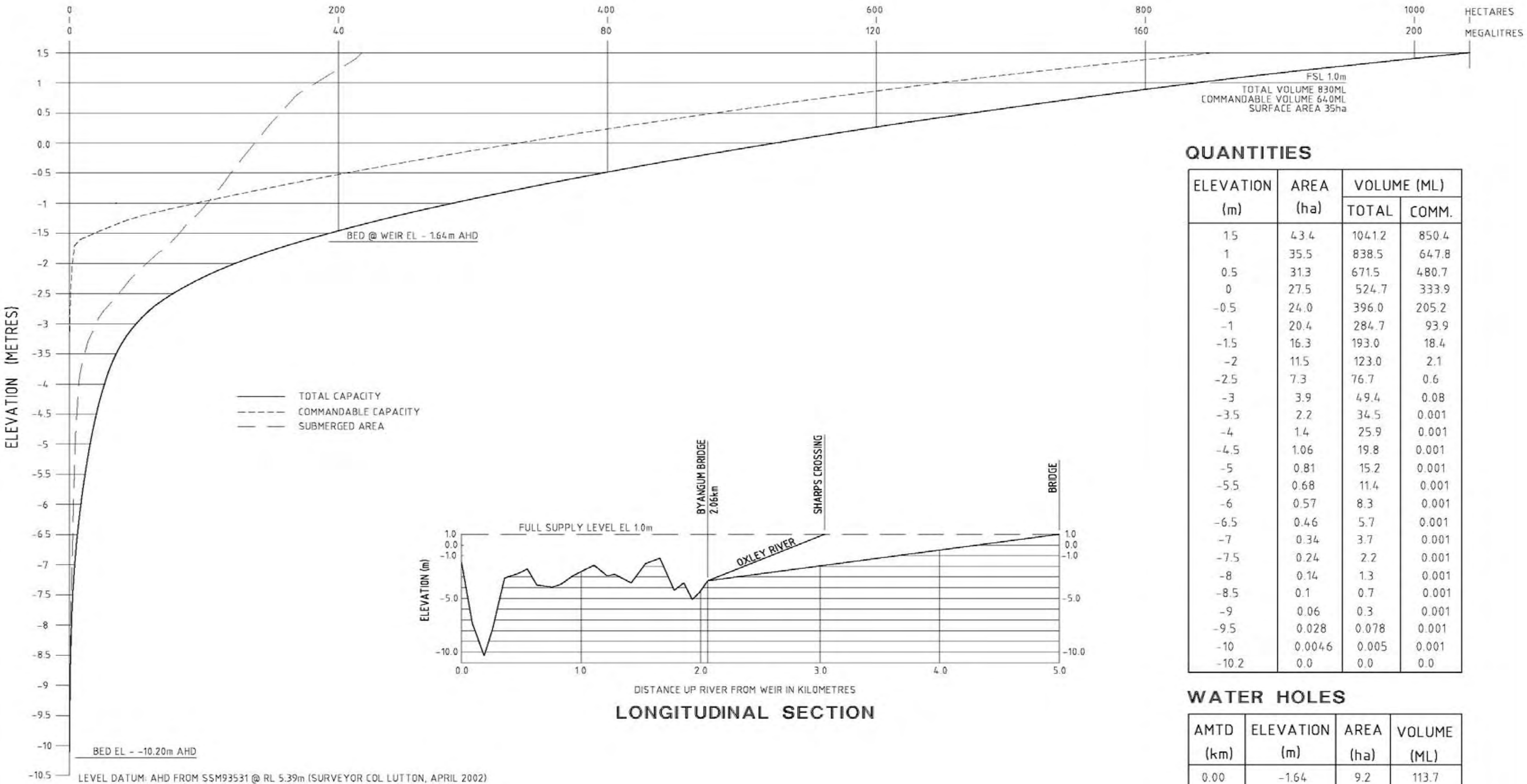
```
65 2 60 0 1 002              / Licvol pat dem ordtime ordfact ordres

025
'Loss u/s Uki' 4.0 0.0 0 0 1 / node-type, group,evap,rain,trace
0 0 0.0 6 0                  /  TS_file,dummy,dummy,Num_f_outf, ord_res
0.0     0.0                  / flow, eff
10.0    0.0                  /
42.0    10.0                 /
116.0   15.0                 /
530.0   100.0                /
10000.  100.0                /

010
'Uki GS' 0.0 0.0 0 0 1       / node-type, group,evap,rain,trace

011
'US Tyalgum Weir' 1.1 0.0 0 0 1           / node-type, group,evap,rain,trace
6 1 0 1 0 0                  / flwptr flwfact recfact state1shr minyr
0 0 0 0 0 0 0 0 0 0 0 0 0  / flow6med Jan..DEc and init median

012
'Tyalgum Weir' 2.1 0.0 1 3 1      / node-type, group,evap,rain,trace
9 1.48 0 0 3 0 0 12 2 0 0  / otime, reces. factor..

0 0                          / Volume/Area/level
1.48 0.31                    /
2.18 0.35                    /
3.09 0.51                    /
4.3 0.65                     /
5.74 0.76                    /
7.38 0.88                    /
9.03 0.95                    /
10.04 0.98                   /
12.06 1.04                   /
14.23 1.15                   /
100.0E+06 100.0E+06                /

1.48 0                       / Volume/Valve Discharge
9.03 10                      /
110 10                       /

9 0                          / Volume/Spillway Discharge
100.0E+06 100.0E+06  /

1                            / Number of states
1 1                          / State, number of groups
1                            /

013
'Tyalgum TWS' 3.0 1.1 0 0 1      / node-type, group,evap,rain,trace
55 2 50 0 1 012              / Licvol pat dem ordtime ordfact ordres

014
'Residual Flow' 1.0 0.0 0 0 1 / node-type, group,evap,rain,trace
5 1 0 1 0000 0   / flwptr flwfact recfact state1shr minyr
```

```
015
'Eungella GS' 0.0 0.0 0 0 1          / node-type, group,evap,rain,trace

016
'Confluence' 11.0 0.0 0 0 1 / node-type, group,evap,rain,trace
1 0 0 0.0 0 0 0               / order1pass, trib1/or t to res.,orderpass2,trib2/or t to res.
002                           / ordresbr1

017
'DS Eun & Uki' 1.0 0.0 0 0 1       / node-type, group,evap,rain,trace
7 0.13 0 1 0 0                / flwptr flwfact recfact state1shr minyr

024
'Loss d/s Uki & Eungella' 4.0 0.0 0 0 1 / node-type, group,evap,rain,trace
0 0 0.0 4 0                   / TS_file,dummy,dummy,Num_f_outf, ord_res
0.0      0.0                  / flow, eff
50.0     10.0                 /
100.0    20.0                 /
10000    30.0                 /

018
'Bray Park Weir' 2.0 0.0 1 1 1     / node-type, group,evap,rain,trace
839 191 839 0 2 0 0 0 10 7 0 1 0 002  / otime. owait,reces. factor..

0 0                           / Volume/Area
4 14.6                        /
29 17                         /
74 19.7                       /
280 26.1                      /
578 33.8                      /
648 35.5                      /
724 40.8                      /
850 43.4                      /
100.0E+06 200                 /

191 0                         / Volume/Valve Discharge
839 181                       /

839 0                         / Volume/Spillway Discharge
1041 2291                     /
1281 6480                     /
1481 11905                    /
1771 18328                    /
2000 25614                    /
100.0E+06 100.0E+06   /

1                             / Number of states
1 1                           / State, number of groups
1                             /

600 600 600 600 600 600 600 600 600 600 600 600 1  / vol
```

```
019
'Recorded TWS' 8.6 1.1 0 0 1 / node-type, group,evap,rain,trace
2                          /
18 0 0 1 0                 / ordres, resetbal,..
1000 1            / Pump capacity, efficiency
1.0e8                      /

020
'Irrigators' 3.2 1.1 0 0 1 / node-type, group,evap,rain,trace
760 1 2.05 0 1 018 018 000 000 4  / licvol pat dem ordtim ordfact ordres res1 res2 1.2nd Norst

0.0      0.0               / Vol Factor
390.0    0.0               /
391.0    100.0             /
900.0    100.0             /

021
'Fish Ladder' 9.0 1.1 0 0 1 / node-type, group,evap,rain,trace
0 -1 25 0 0 18             / Licvol pat dem ordtime no_fmit ordres
1                          / no of FCT tables
3 018 000 0 0 5 0 0 0      / Type, CNode1, CNode 2, Prim Const, Sec Const, No. Table
0.0      0.0               / X value, Y Value
405      0                 /
648      5                 /
839      25                /
1000000 25                 /

1                          / No. Levels
-1 0 1                     / Criteria, No. group, No. FCT
1                          /

022
'Dummy' 0.0 0.0 0 0 1 / node-type, group,evap,rain,trace

027
'EOS' 0.0 0.0 0 0 1         / node-type, group,evap,rain,trace

0                          / No risk function

1                          / No.of states
1 1                        / States of type

-1                         / No Resource Assessment
```

APPENDIX D

STORAGE CURVES



QUANTITIES

ELEVATION (m)	AREA (ha)	VOLUME (ML)	
		TOTAL	COMM.
1.5	43.4	1041.2	850.4
1	35.5	838.5	647.8
0.5	31.3	671.5	480.7
0	27.5	524.7	333.9
-0.5	24.0	396.0	205.2
-1	20.4	284.7	93.9
-1.5	16.3	193.0	18.4
-2	11.5	123.0	2.1
-2.5	7.3	76.7	0.6
-3	3.9	49.4	0.08
-3.5	2.2	34.5	0.001
-4	1.4	25.9	0.001
-4.5	1.06	19.8	0.001
-5	0.81	15.2	0.001
-5.5	0.68	11.4	0.001
-6	0.57	8.3	0.001
-6.5	0.46	5.7	0.001
-7	0.34	3.7	0.001
-7.5	0.24	2.2	0.001
-8	0.14	1.3	0.001
-8.5	0.1	0.7	0.001
-9	0.06	0.3	0.001
-9.5	0.028	0.078	0.001
-10	0.0046	0.005	0.001
-10.2	0.0	0.0	0.0

WATER HOLES

AMTD (km)	ELEVATION (m)	AREA (ha)	VOLUME (ML)
0.00	-1.64	9.2	113.7
1.66	-1.24	6.7	77.0

LEVEL DATUM: AHD FROM SSM93531 @ RL 5.39m (SURVEYOR COL LUTTON, APRIL 2002)
SECTIONS DIGITISED FROM PLAN A1-145-4 (PLAN DATUM - 0.24 = APPROX AHD)
SECTIONS FROM SOUNDINGS IN 1978 (EXTRAPOLATED ABOVE RL 0.0)
FOR SECTION LOCATIONS SEE PLANS A1-145-2 & 3
VOLUMES INCLUDE ESTIMATE FOR THE STORAGE IN THE TWEED RIVER ABOVE BYANGUM BRIDGE (NO SECTIONS IN 3km TO END OF STORAGE) OR THE OXLEY RIVER (2km) - DUMMY SECTIONS USED.
LATITUDE: 28°20'50" LONGITUDE: 153°22'30"

P:\E-02065_01\Clarrie_Hall_Yield_Study\StorageCurve\218541.dwg
07 May 2002 3:27 PM

REVISION | DATE | REMARKS | CKD | PSD | REFERENCE DRAWINGS

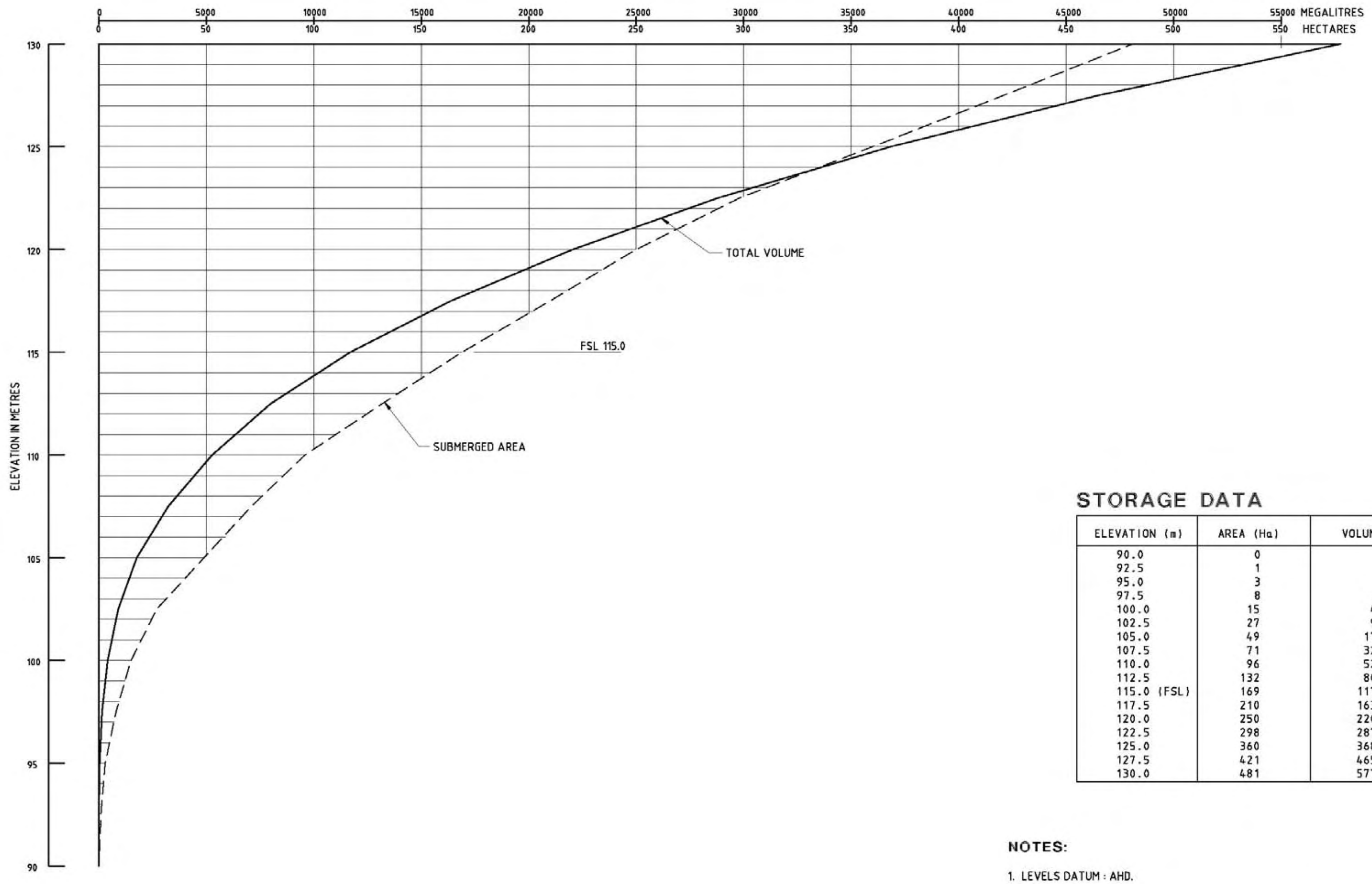
SCALES

DRAFTING TB | DESIGN
DRAFTING CHK | DESIGN CHK
APPROVED D. HOUSTON PRINCIPAL SURVEYOR

SunWater Engineering Services www.sunwater.com.au

TWEED SHIRE COUNCIL
BRAY PARK WEIR
STORAGE CURVE

CONTRACT NUMBER
DRAWING NUMBER 218541
DATE MAY 2002



STORAGE DATA

ELEVATION (m)	AREA (Ha)	VOLUME (ML)
90.0	0	0
92.5	1	2
95.0	3	43
97.5	8	153
100.0	15	414
102.5	27	904
105.0	49	1772
107.5	71	3235
110.0	96	5271
112.5	132	8009
115.0 (FSL)	169	11702
117.5	210	16379
120.0	250	22057
122.5	298	28793
125.0	360	36847
127.5	421	46515
130.0	481	57778

NOTES:

1. LEVELS DATUM : AHD.
2. STORAGE DATA DERIVED FROM DIGITAL 2.5m CONTOURS.

P:\G Projects\G-81903_Tweed Shire Council\02_Tweed\03_Tweed River Study\03_Tweed Water Supply Security Review\Drafting\224940A.dwg
06 Feb 2006 11:47 AM

DATE	REVISION	REMARKS	CKD	PSD
06.02.06	A	STORAGE CURVES TO EL130		SD

REFERENCE DRAWINGS

SCALES

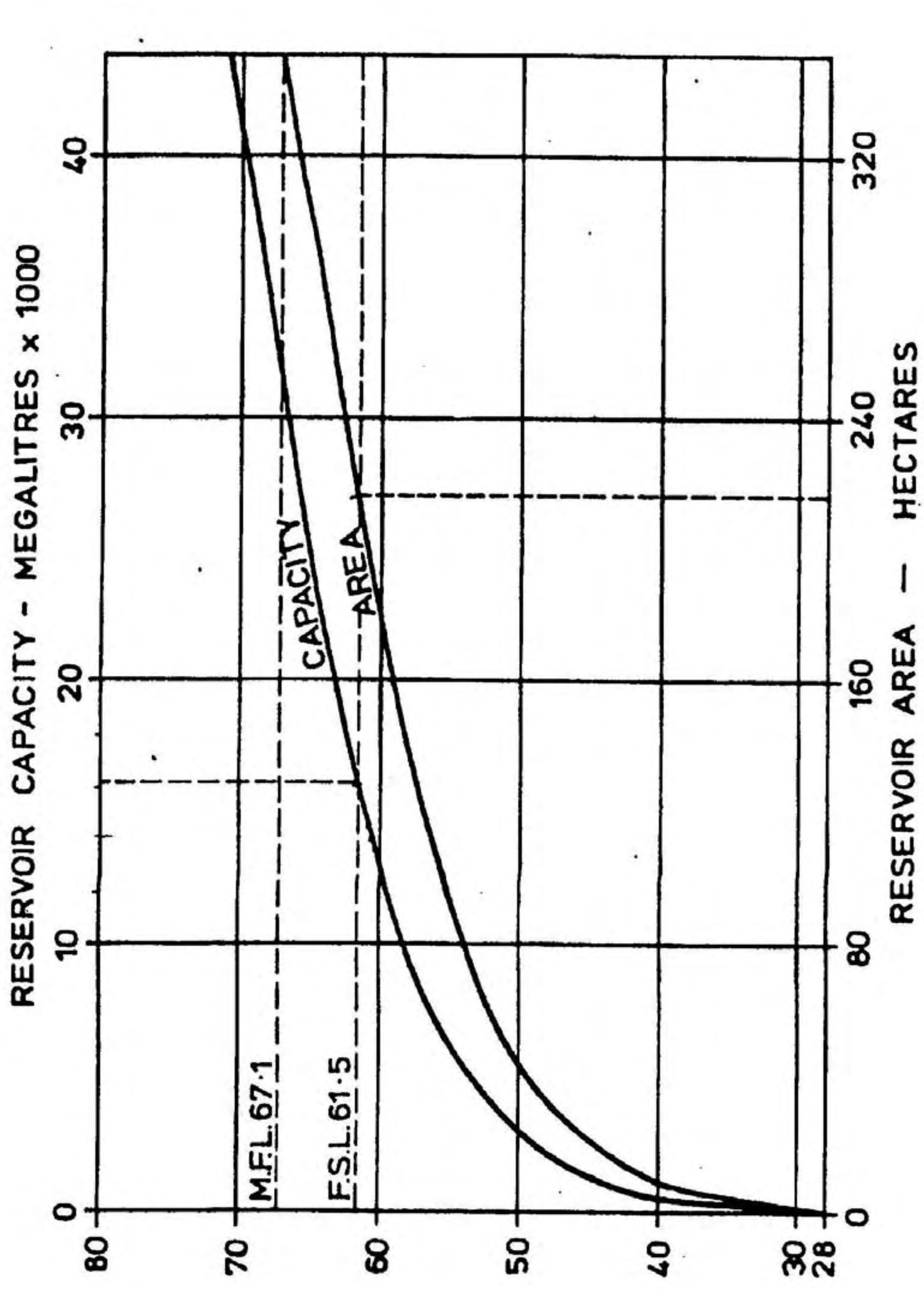
DRAWN: RET | DESIGNED: NB
CHECKED | CHECKED
APPROVED

SunWater
Level 9, 120 Edward Street
Brisbane Qld 4002
Tel: (07) 3120 0000

BYRRILL CREEK DAM SITE
BASIN 201
TWEED SHIRE COUNCIL
STORAGE CURVE

CONTRACT NUMBER
DRAWING NUMBER: 224940
DATE: SEP 2005
A

Clarrie Hall Dam Storage Curve



APPENDIX E

ANALYSES FOR CLIMATE DEMAND

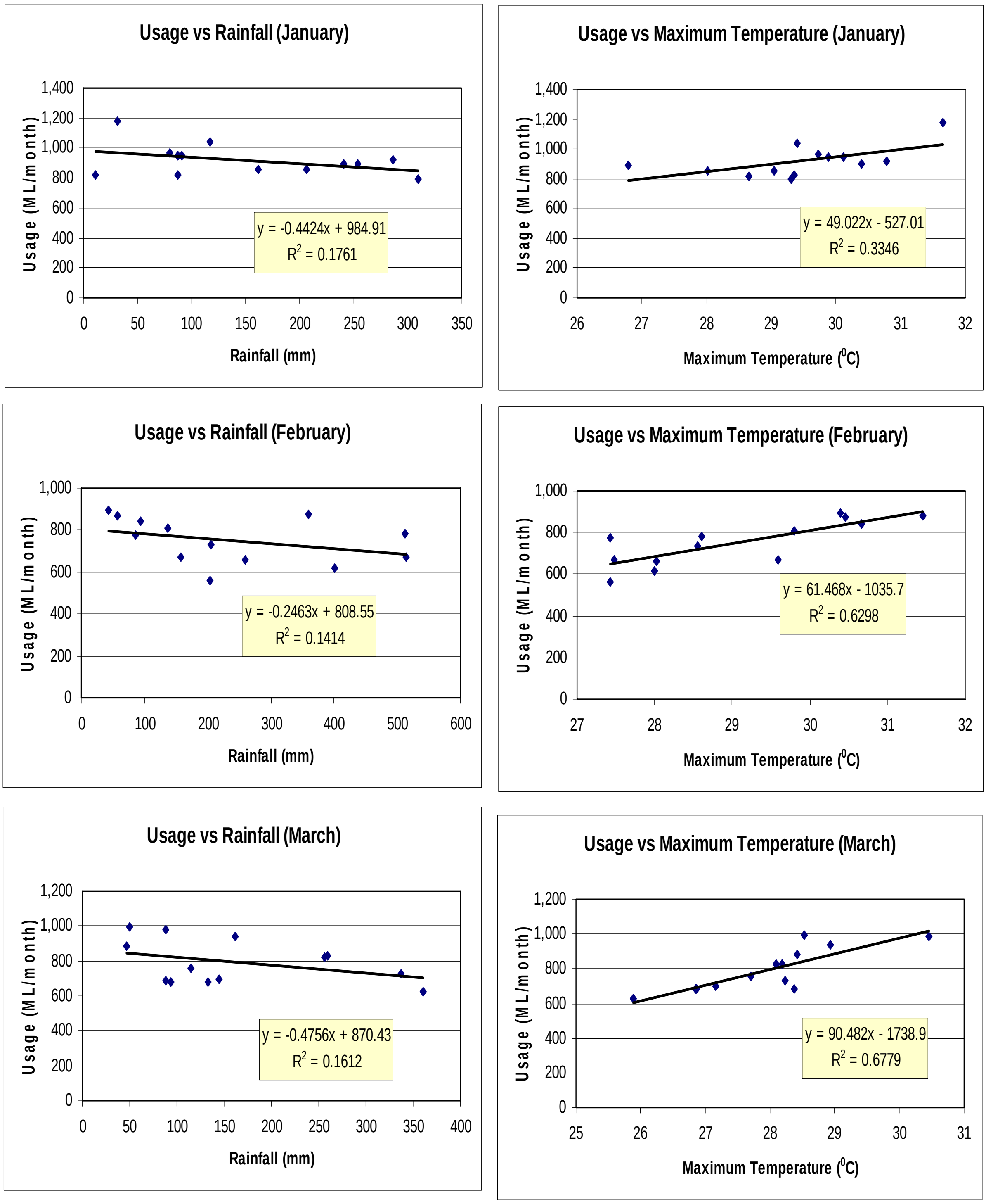


Figure E1: Regression Equation for Usage vs Rainfall or Temperature (Jan – Mar)

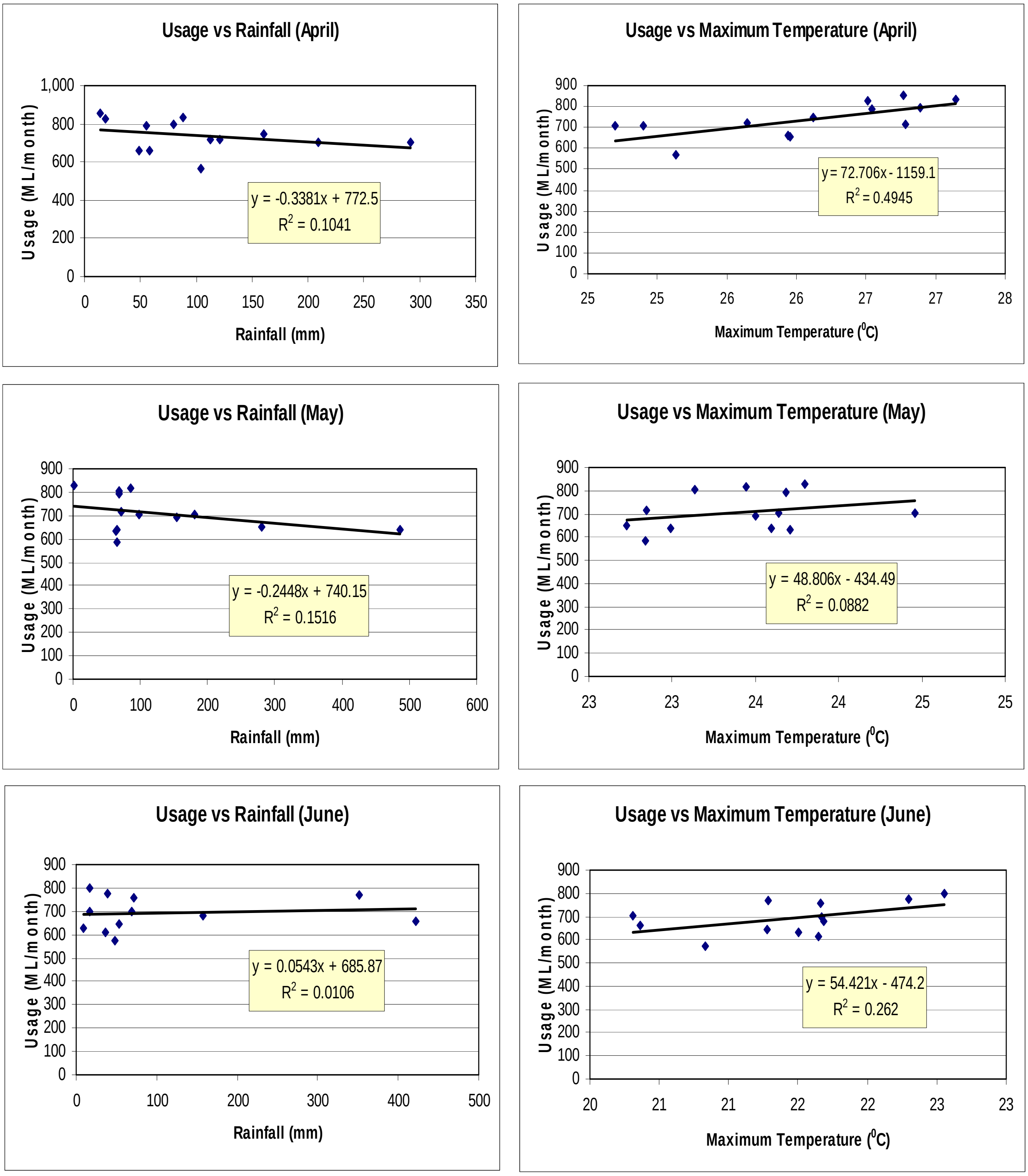


Figure E2: Regression Equation for Usage vs Rainfall or Temperature (Apr – Jun)

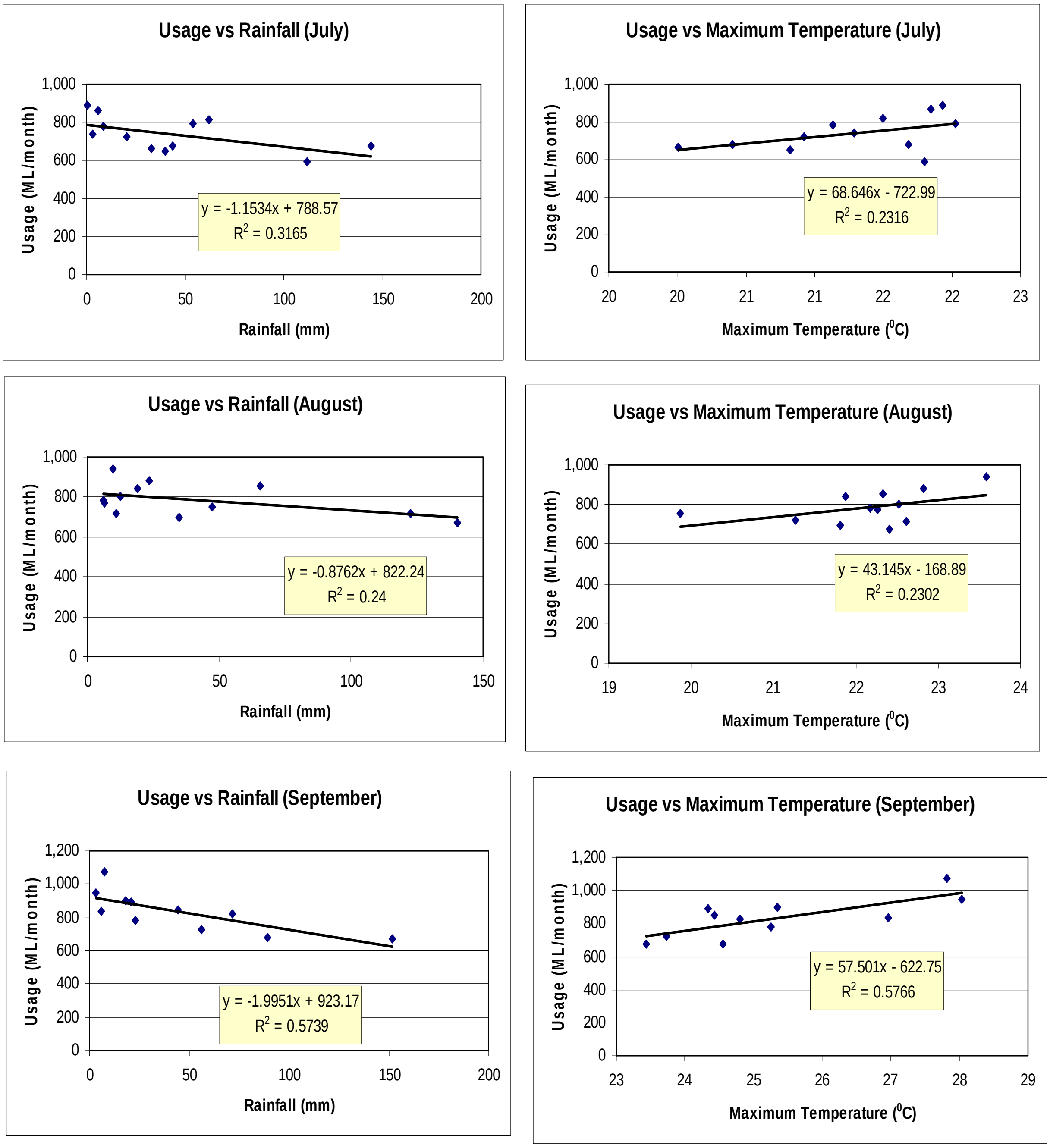


Figure E3: Regression Equation for Usage vs. Rainfall or Temperature (Jul – Sep)

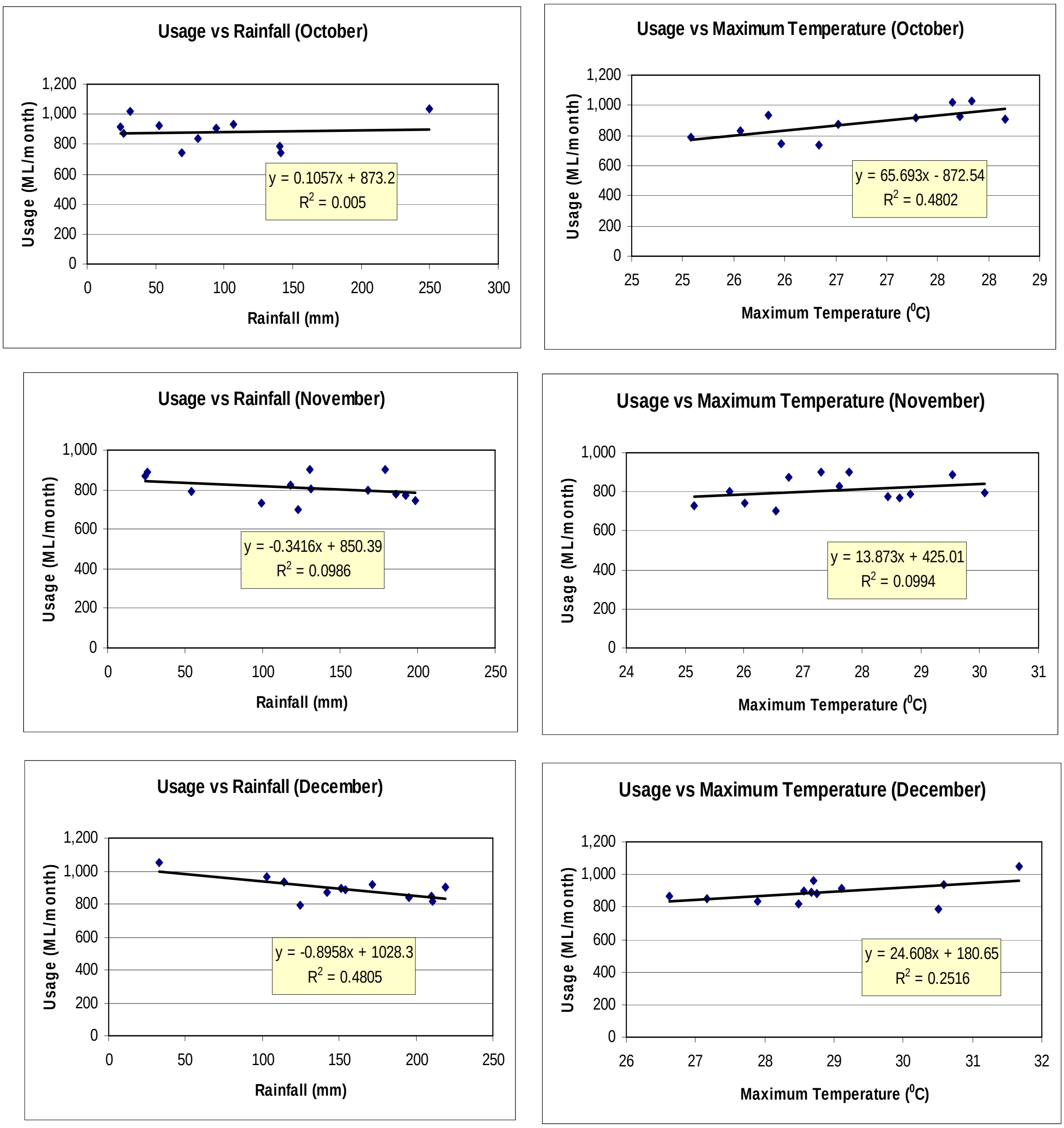
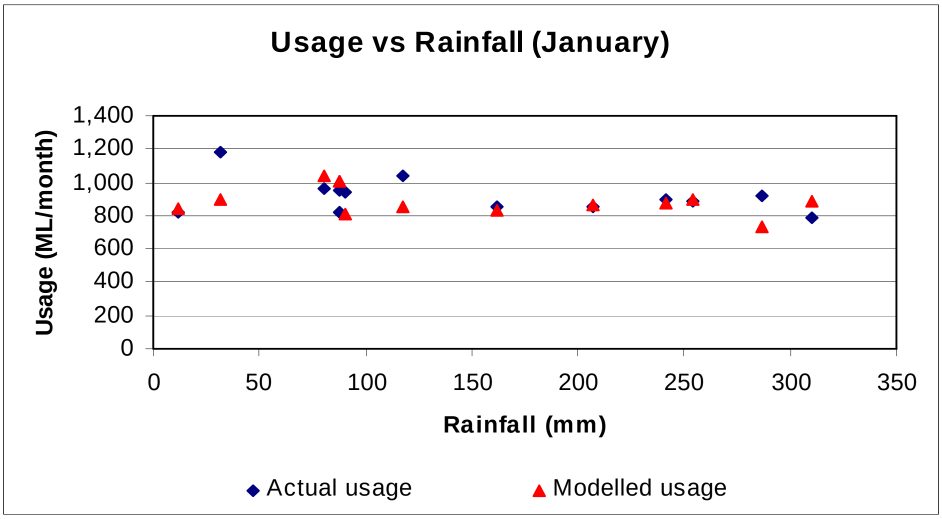
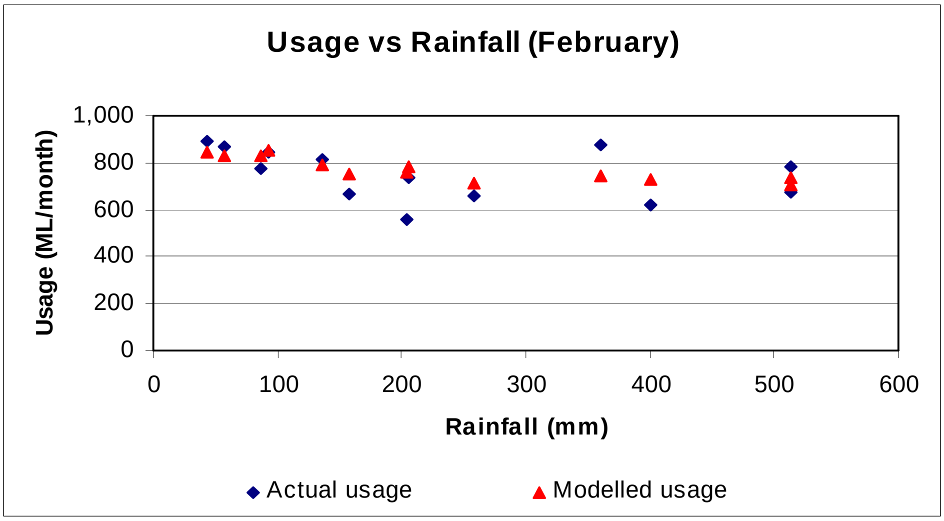


Figure E4: Regression Equation for Usage vs. Rainfall or Temperature (Oct – Dec)





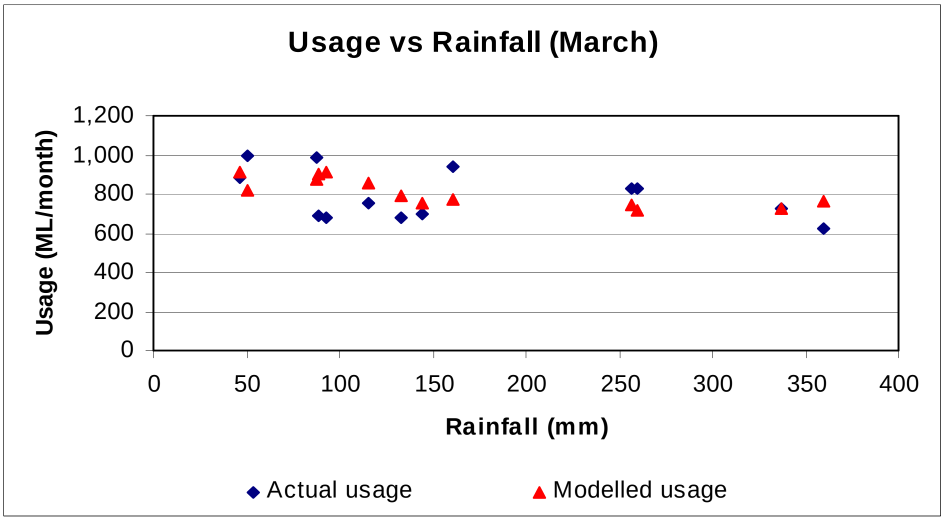
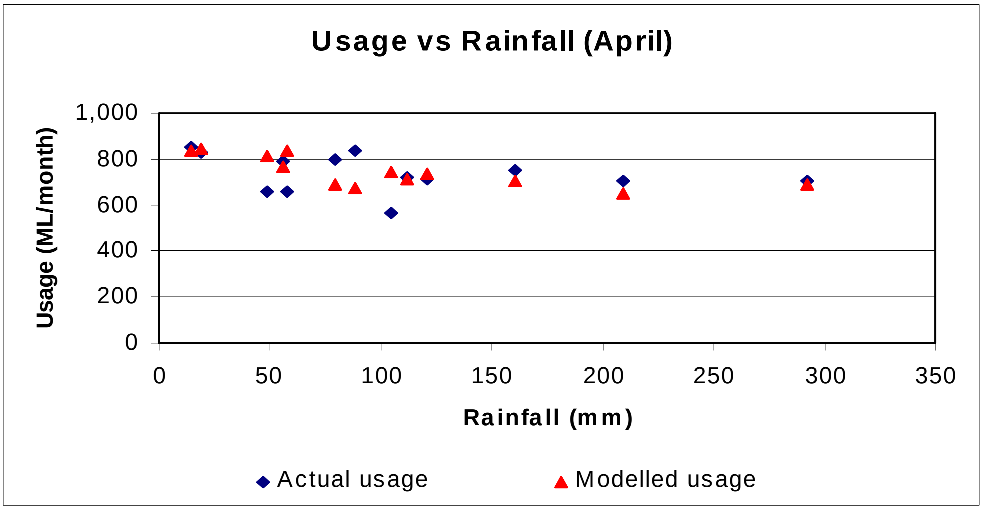
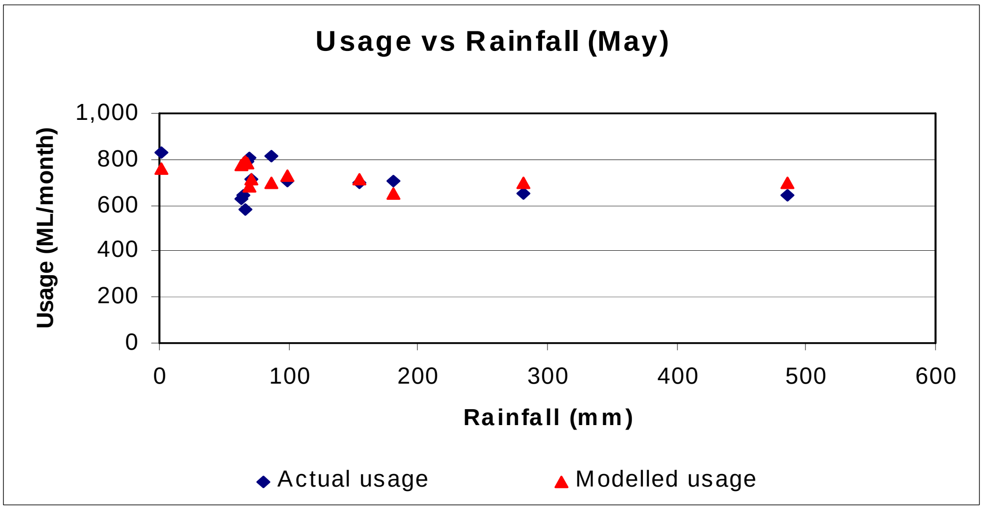


Figure E5: Modelled and Actual Usage (Jan – Mar)





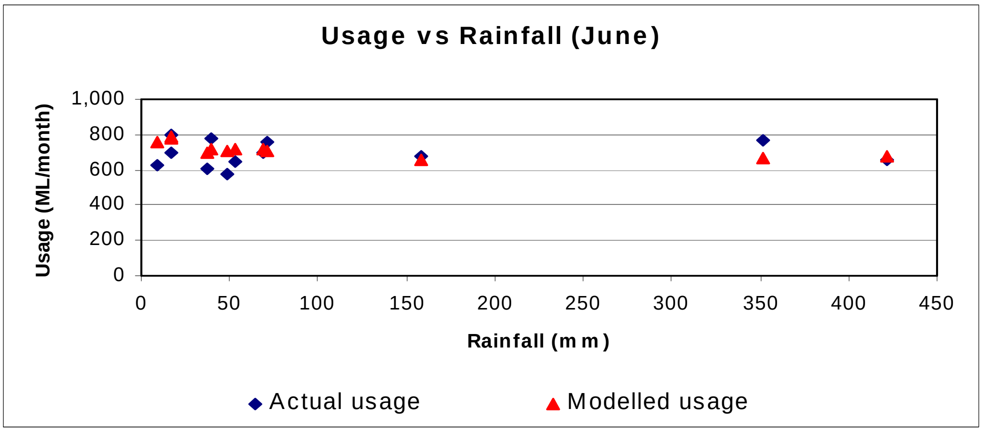
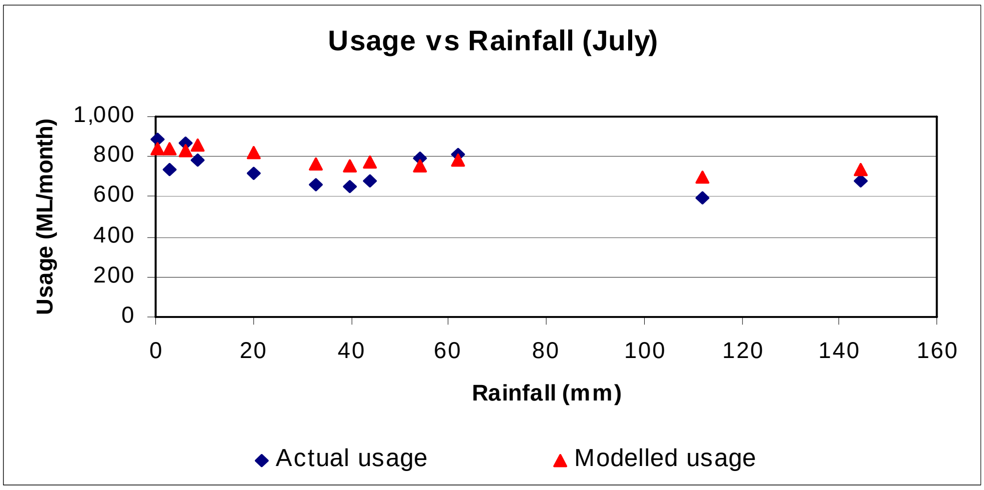
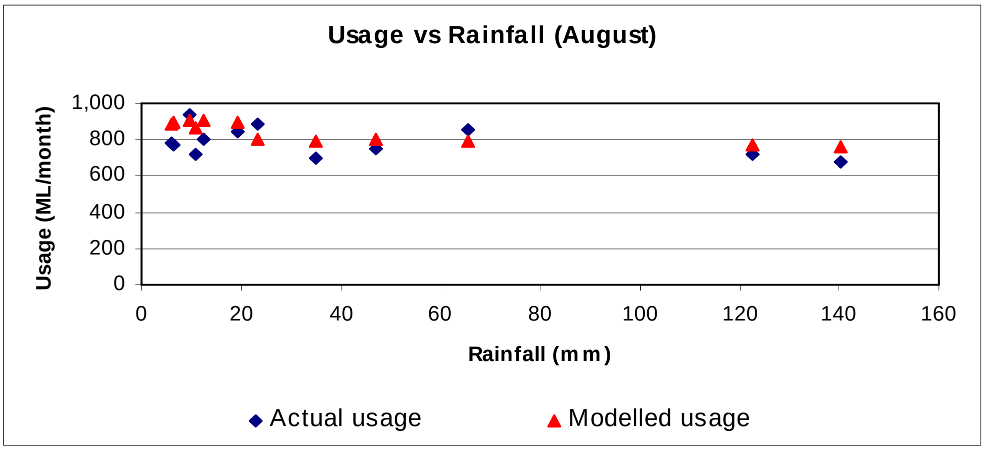


Figure E6: Modelled and Actual Usage (Apr – Jun)





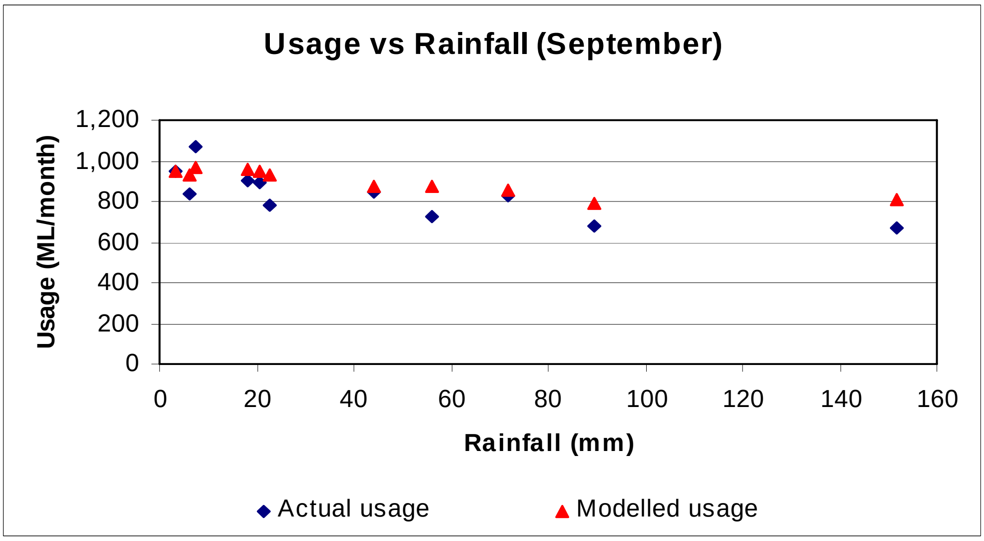
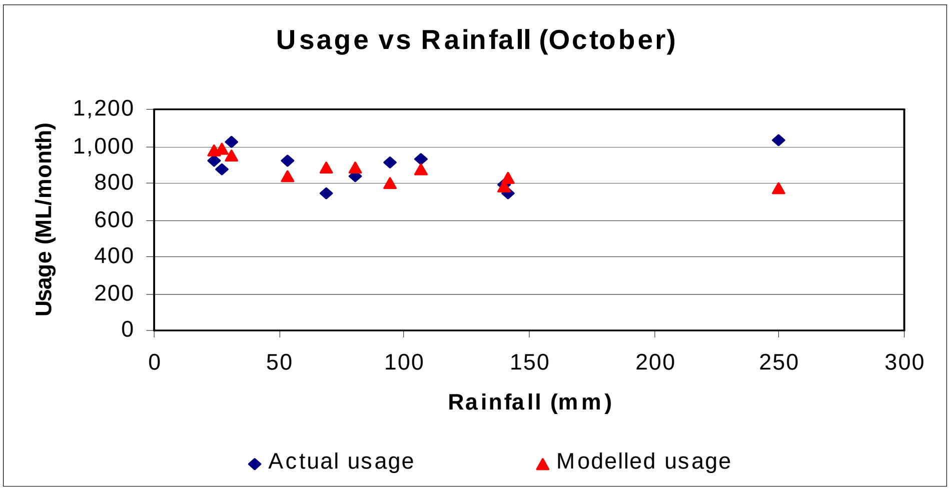
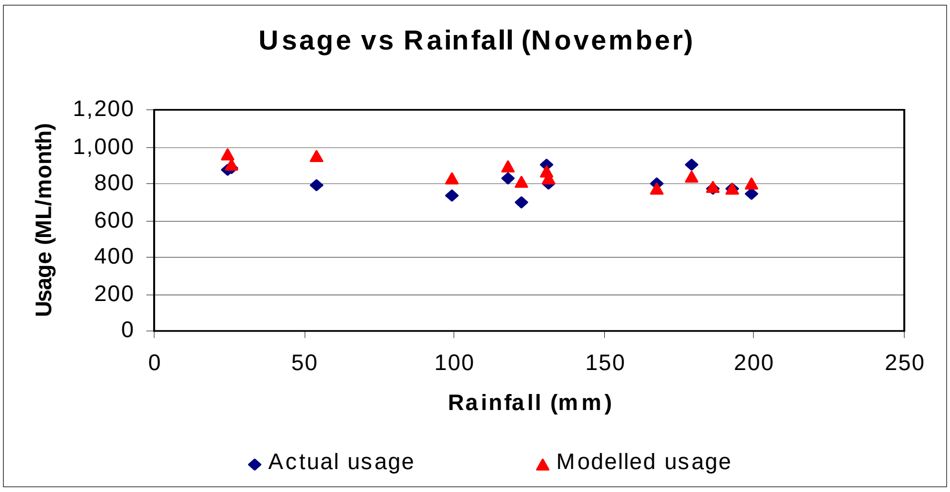


Figure E7: Modelled and Actual Usage (Jul – Sep)





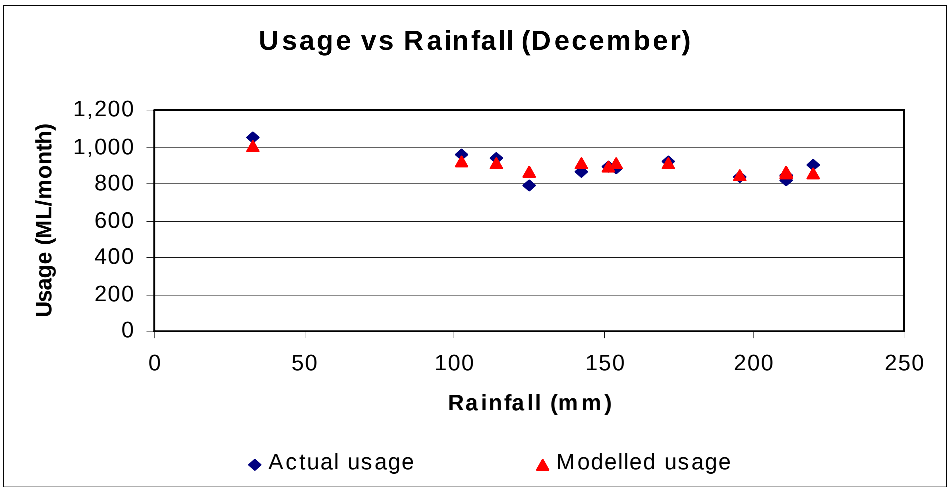


Figure E8: Modelled and Actual Usage (Oct – Dec)

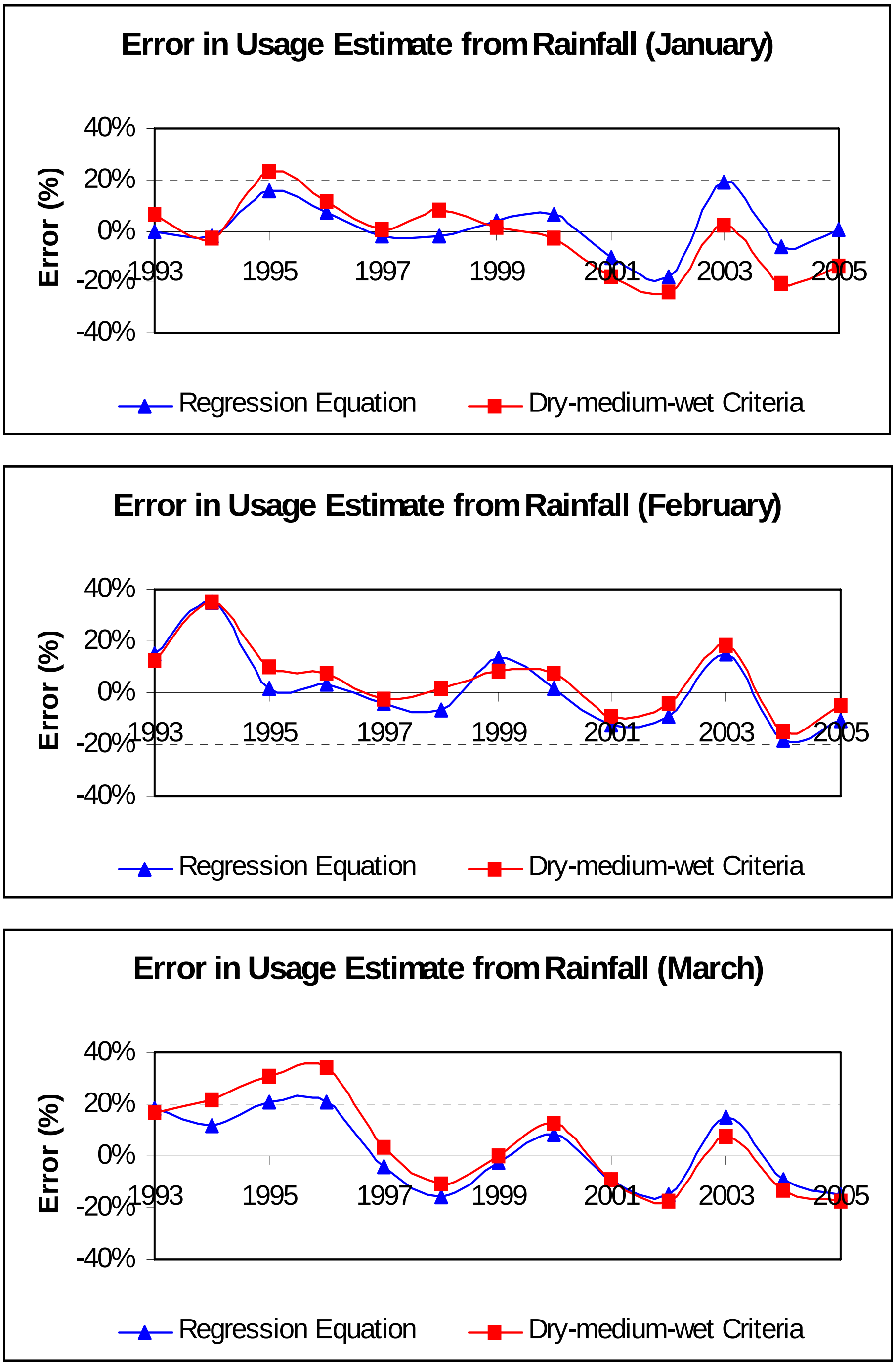
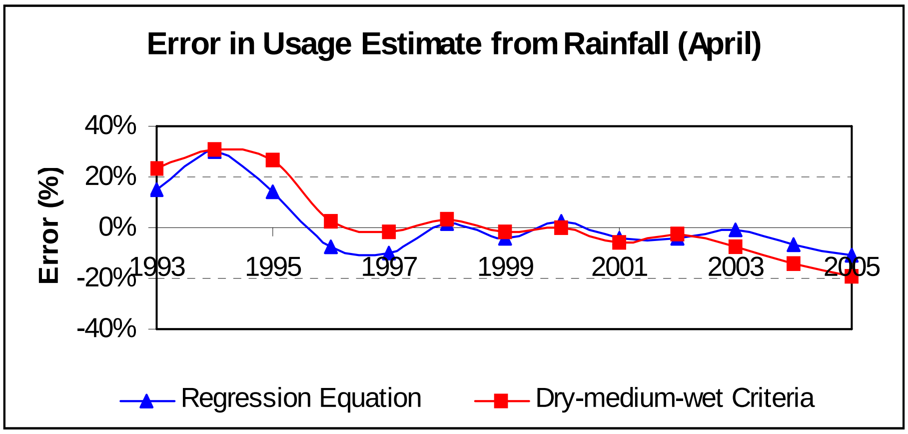
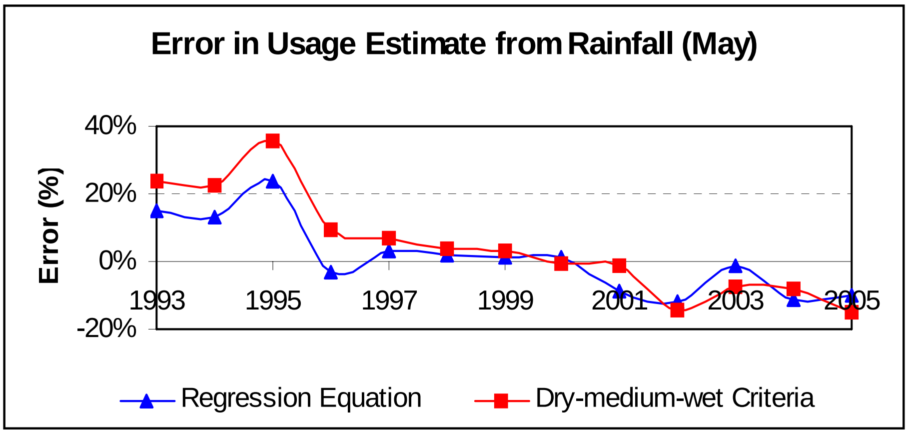


Figure E9: Error of Usage Estimation from the Two Methods (Jan – Mar)





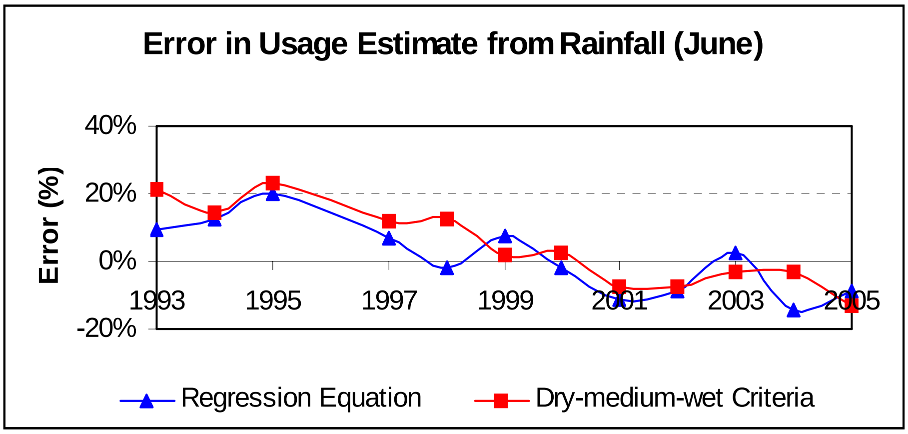
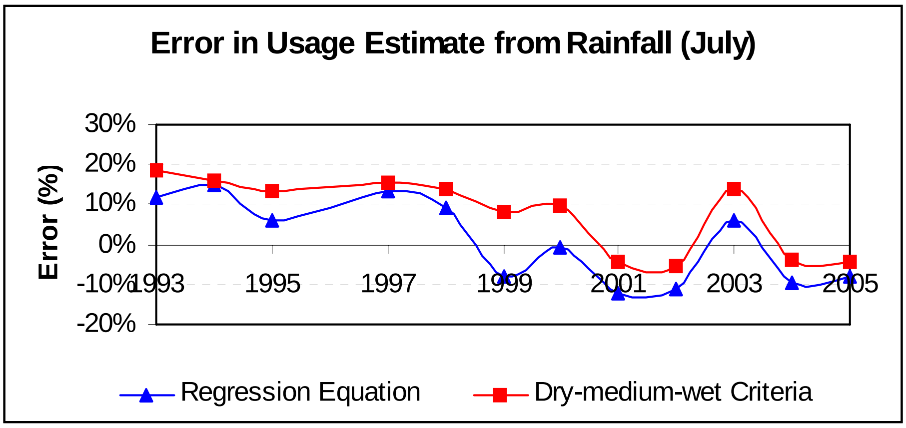
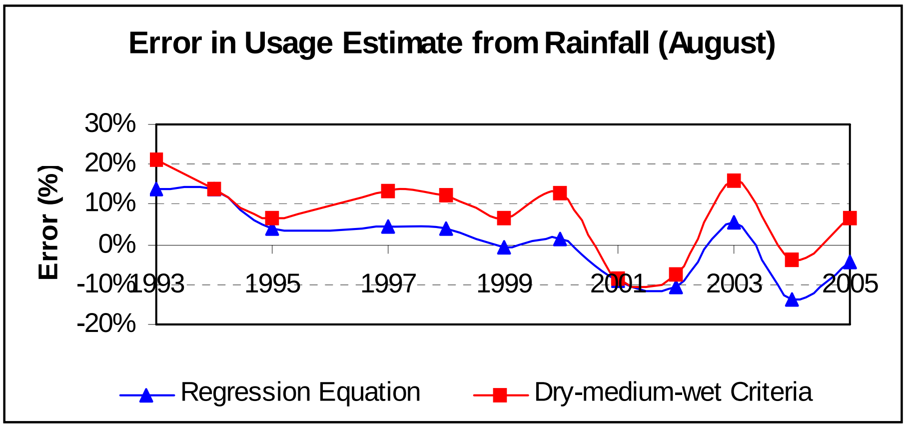


Figure E10: Error of Usage Estimation from the Two Methods (Apr – Jun)





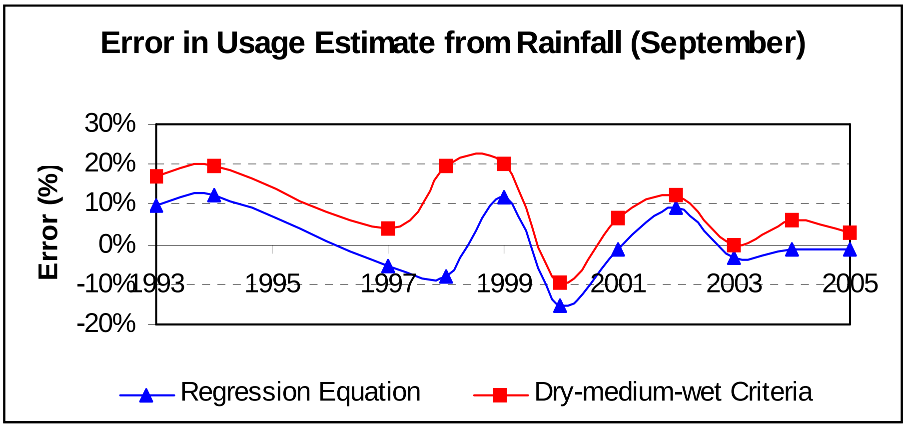
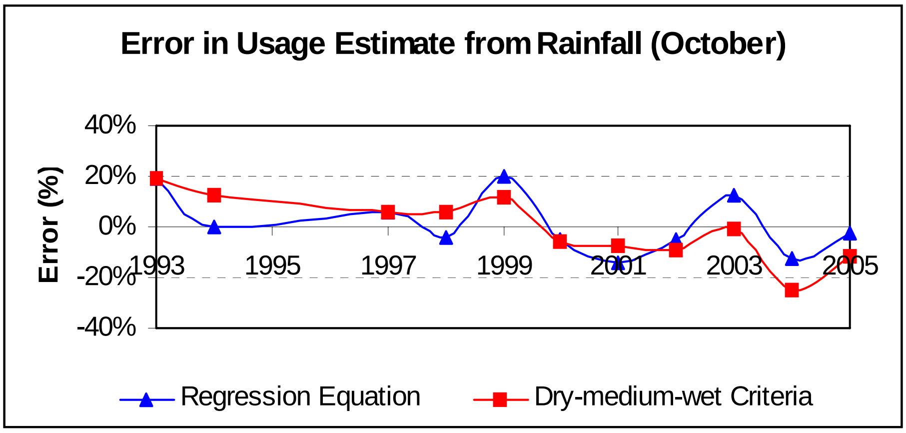
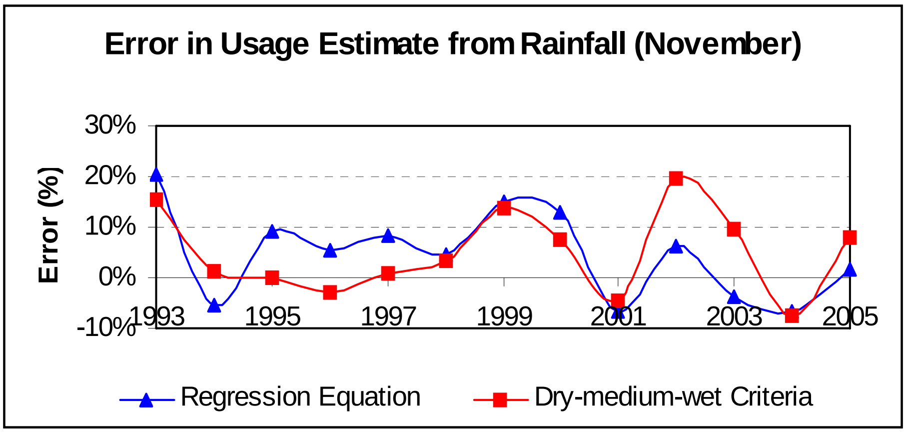


Figure E11: Error of Usage Estimation from the Two Methods (Jul – Sep)





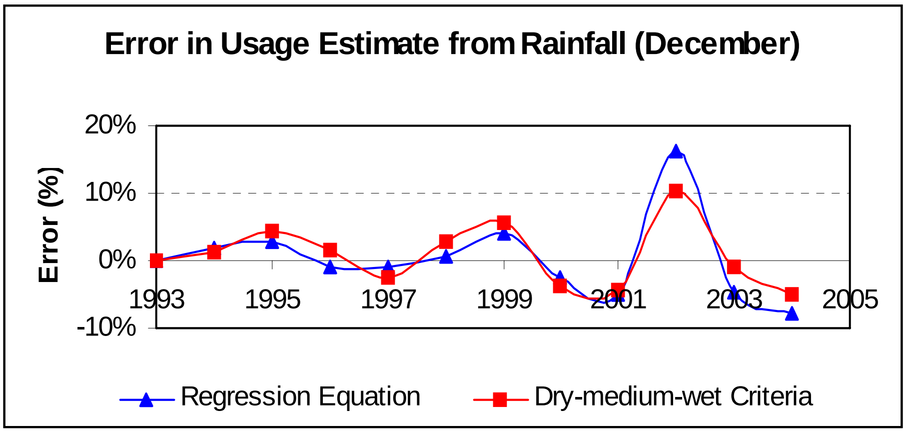
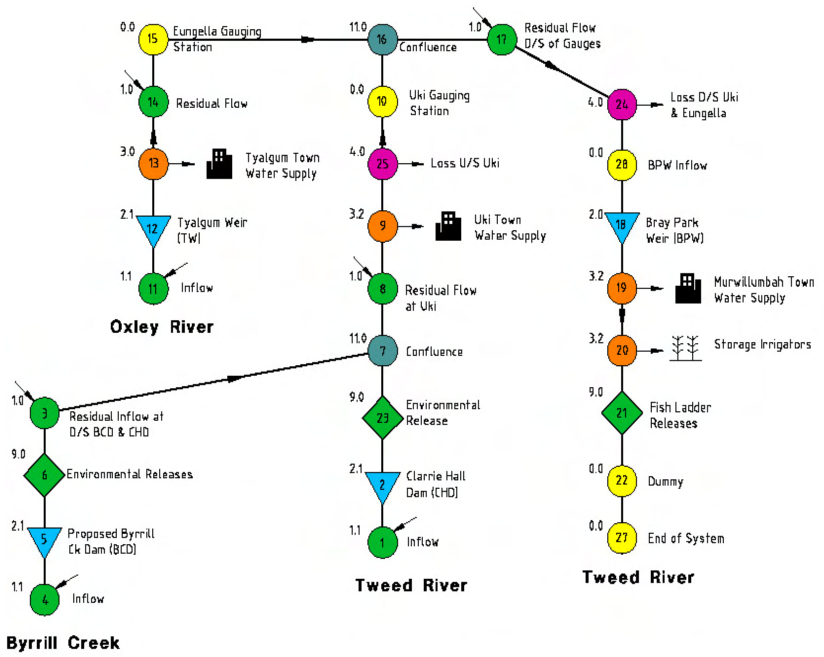


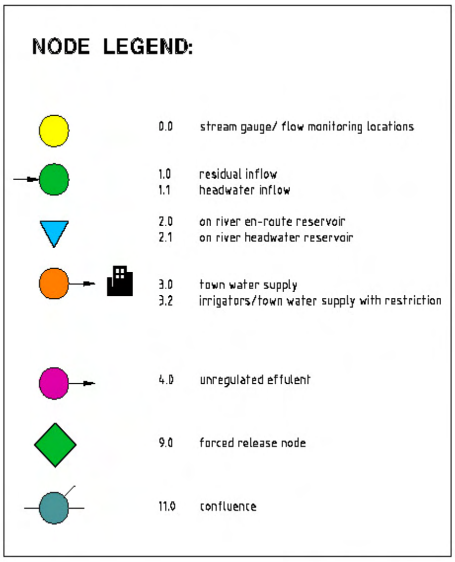
Figure E12: Error of Usage Estimation from the Two Methods (Oct – Dec)

APPENDIX F

IQQM NODE DIAGRAM AND SYSTEM FILE

FOR SCENARIO MODELLING





P:\G Projects\G-81903_Tweed Shire Council\02_Tweed\03_Tweed River Study\03_Tweed Water Supply Security Review\Drafting\225747.dwg

09 Mar 2006 9:33 AM

DRAWN	DESIGNED
RET	SD
CHECKED	CHECKED
	NGB

APPROVED
N.BARTLETT
FOR PROJECT MANAGER WATER STUDIES

SunWater
Level 9, 120 Edward Street
Brisbane Qld 4002
Tel: (07) 3120 0000

TWEED RIVER
IQQM SCENARIO MODELLING NODE DIAGRAM
(CASE 15C-5)

CONTRACT NUMBER

DRAWING NUMBER
225747

DATE MAR 2006

IQQM System File

6.73.004
/
001/
'System file details:

++

Project: Tweed Water Supply Security Review
Basin: 201 - Tweed Catchment
Case Name: Case 15C
Case for: CHD=15GL, EF=Existing, BCD=to be optimised (33 GL), TWS=24.5GL/a,
with Restrisction, BS=19.6GL, BPW=648ML, EF=95%
Requested by: Tweed Shire Council
Modeling details:
Modeled by: Sunil Dayaratne
Date: 04 April 2006
Comments:

Quality Assurance:
Checked by:
Date:
Comments: .

++

details ends'

'' / Input Path

'Tpatn2.pat' / Pattern file name
'TS5Rain' / Time series precipitation data
'TS5Evapo' / Time series evaporation data
'TS6Flow' / Time series flow data
' ' / Historical Diversion Data
' ' / No groundwater allocation data
' ' / No Maximum temperature Data
' ' / No Minimum temperature Data
' ' / Crop Factors

0 / flow output flag
6 24 / routing time step
0 / No of Const,

5 / No of river sections

4 / Number of links

001 002 / RVS: 1 I: 1
002 023 / RVS: 1 I: 2
023 029 / RVS: 1 I: 3
029 007 / RVS: 1 I: 4

4 / Number of links

004 005 / RVS: 2 I: 1
005 006 / RVS: 2 I: 2
006 003 / RVS: 2 I: 3
003 007 / RVS: 2 I: 4

5 / Number of links

007 008 / RVS: 3 I: 1
008 009 / RVS: 3 I: 2
009 025 / RVS: 3 I: 3
025 010 / RVS: 3 I: 4
010 016 / RVS: 3 I: 5

5 / Number of links

011 012 / RVS: 4 I: 1
012 013 / RVS: 4 I: 2
013 014 / RVS: 4 I: 3
014 015 / RVS: 4 I: 4
015 016 / RVS: 4 I: 5

9 / Number of links

016 017 / RVS: 5 I: 1
017 024 8 8 0.25 1 1 1 / RVS: 5 I: 2
024 028 /
028 018 / RVS: 5 I: 3
018 019 / RVS: 5 I: 4
019 020 / RVS: 5 I: 5
020 021 / RVS: 5 I: 6
021 022 / RVS: 5 I: 7
022 027 / RVS: 5 I: 8

001
'US CHD' 1.1 0.0 0 0 1 / node-type, group,evap,rain,trace
1 1 0 1 0 0 / flwptr flwfact recfact state1shr minyr
0 0 0 0 0 0 0 0 0 0 0 0 0 / flow6med Jan..DEc and init median

```
 002
'Clarrie Hall Dam' 2.1 0.0 1 2 1              / node-type, group,evap,rain,trace
15000 5880 15000 -1 4 0 0 10 9 0 0  / otime, reces. factor..

0 0                         / Volume/Area
300 20                      /
1000 32                     /
2900 59                     /
5000 93                     /
8300 136                    /
15700 224                   /
32500 367                   /
45000 450
100.0E+06 500               /

5880 0                      /Volume/Valve Discharge @8700 ML of buffer storage
11800 1029                  /
23000 1109
100.0E+06 100.0E+06



15000 0                     / Volume/Spillway Discharge
15700 950                   /
17000 2782                  /
19200 5216                  /
19400 8146                  /
22000 15272                 /
24600 23854                 /
34000 56790                 /
100.0E+06 100.0E+06   /

1                           / Number of states
1 1                         / State, number of groups
1                           /


 023
'Env Flow d/s CHD' 9.0 1.1 0 0 1 / node-type, group,evap,rain,trace
0 -1 10000 0 0 002                  / Licvol pat dem ordtime no_fmit ordres
2                                   / no of FCT tables
1 002 000 0 0 6                     / Type, CNode1, CNode 2, Prim Const, Sec Const, No. Table
 1   1.1  /
 121 1.1          / X value, Y Value
 122 0.8          /
 213 0.8          /
 214 1.1          /
 366 1.1          /

2 001 0 0 0 2
0.0       0.0               / X value, Y Value
1e6       1e6

1                           / No. Levels
-1  0  2                    / Criteria, No. group, No. FCT
```

```
1 2                           /

029
'd/s CHD Flow' 0.0 0.0 0 0 1       / node-type, group,evap,rain,trace


004
'US Byrrill Creek Dam' 1.1 0.0 0 0 1       / node-type, group,evap,rain,trace
2 1 0 1 0 0                   / flwptr flwfact recfact state1shr minyr
0 0 0 0 0 0 0 0 0 0 0 0 0  / flow6med Jan..DEc and init median

005
'Byrrill Creek Dam' 2.1 1.1 1 4 1                 /   node-type,   group,evap,rain,trace   'Byrrill
Creek Dam' 0.0 0.0 0 0 0           /
35000 13720 35000 -1 4 0 0 18 4 0 0  / otime, reces. factor..

0 0                           / Volume/Area
2 1                           /
43 3                          /
153 8                         /
414 15                        /
904 27                        /
1772 49                       /
3235 71                       /
5271 96                       /
8009 132                      /
11702 169                     /
16379 210                     /
22057 250                     /
28793 298                     /
36847 360                     /
46515 421                     /
57778 481                     /
100.0E+06 1000                /


13720 0                       /  Volume/Valve Discharge
23000 1109                    /
45000 1250
1.0e06 1.0e06                 /

35000 0                       / Volume/Spillway Discharge
55600 23854                   /
70000 56790                   /
100.0E+06 100.0E+06   /

1                             / Number of states
1 1                           / State, number of groups
1.0                           /

006
'Env Flow d/s BCD' 9.0 1.1 0 0 1 / node-type, group,evap,rain,trace
 'Env Flow BCD' 0.0 0.0 0 0 0    /
0 -1 10000 0 0 005                 / Licvol pat dem ordtime no_fmit ordres
2                                  / no of FCT tables
```

```
1 004 000 0 0 24                    / Type, CNode1, CNode 2, Prim Const, Sec Const, No. Table

 1   1.0  /
 31  1.0
 32  4.0 / X value, Y Value
 60  4.0
 61  3.0 /
 91  3.0
 92  4.0 /
 121 4.0
 122 7.0/
 152 7.0
 153 6.0/
 182 6.0
 183 6.0/
 213 6.0
 214 5.0/
 244 5.0
 245 4.0/
 274 4.0
 275 3.0/
 305 3.0
 306 2.0/
 335 2.0
 336 1.0/
 366 1.0

2 004 0 0 0 2

0.0      0.0              / X value, Y Value
1e6      1e6              /


1                         / No. Levels
-1  0  2                  / Criteria, No. group, No. FCT
1 2                       /


003
'Residual BC & TR' 1.0 0.0 0 0 1 / node-type, group,evap,rain,trace
3 0.54 0 1 0 0    / flwptr flwfact recfact state1shr minyr


007
'Confluence' 11.0 0.0 0 0 1 / node-type, group,evap,rain,trace
1 0 1 0.0 0 0  0  / order1pass, trib1/or t to res.,orderpass2,trib2/or t to res.
002                       / ordresbr1
005                       / ordresbr2


008
'Residual Flow at Uki' 1.0 0.0 0 0 1 / node-type, group,evap,rain,trace
3 0.46 0 1 0000 0         / flwptr flwfact recfact state1shr minyr
```

009
'Uki TWS' 3.2 1.1 0 0 1 / node-type, group,evap,rain,trace
65 3 60 0 1 002 002 005 0 8 / Licvol pat dem ordtime ordfact ordres

0 80 /Restriction up to 80% imposed
10640 80
10641 85
13680 85
13681 90
15200 90
15201 100
30400 100

025
'Loss u/s Uki' 4.0 0.0 0 0 1 / node-type, group,evap,rain,trace
0 0 0.0 6 0 / TS_file,dummy,dummy,Num_f_outf, ord_res

0.0 0.0 / flow, eff
10.0 0.0 /
42.0 10.0 /
116.0 15.0 /
530.0 100.0 /
10000. 100.0 /

010
'Uki GS' 0.0 0.0 0 0 1 / node-type, group,evap,rain,trace

011
'US Tyalgum Weir' 1.1 0.0 0 0 1 / node-type, group,evap,rain,trace
4 1 0 1 0 0 / flwptr flwfact recfact state1shr minyr
0 0 0 0 0 0 0 0 0 0 0 0 0 / flow6med Jan..DEc and init median

012
'Tyalgum Weir' 2.1 0.0 1 3 1 / node-type, group,evap,rain,trace
9 1.48 9 -1 4 0 0 12 2 0 0 / otime, reces. factor..

0 0 / Volume/Area/level
1.48 0.31 /
2.18 0.35 /
3.09 0.51 /
4.3 0.65 /
5.74 0.76 /
7.38 0.88 /
9.00 0.95 /
10.04 0.98 /
12.06 1.04 /
14.23 1.15 /
100.0E+06 100.0E+06 /

1.48 0 / Volume/Valve Discharge
9.0 10 /
110 10 /
1e6 15

```
9 0                         / Volume/Spillway Discharge
100.0E+06 100.0E+06   /

1                           / Number of states
1 1                         / State, number of groups
1                           /

013
'Tyalgum TWS' 3.0 1.1 0 0 1      / node-type, group,evap,rain,trace
55 3 50 0 1 012             / Licvol pat dem ordtime ordfact ordres

014
'Residual Flow' 1.0 0.0 0 0 1 / node-type, group,evap,rain,trace
5 1 0 1 0000 0   / flwptr flwfact recfact state1shr minyr

015
'Eungella GS' 0.0 0.0 0 0 1        / node-type, group,evap,rain,trace

016
'Confluence' 11.0 0.0 0 0 1 / node-type, group,evap,rain,trace
1 0 0 0.0 0 0 0   / order1pass, trib1/or t to res.,orderpass2,trib2/or t to res.
007                         / ordresbr1

017
'DS Eun & Uki' 1.0 0.0 0 0 1      / node-type, group,evap,rain,trace
6 0.13 0 1 0 0    / flwptr flwfact recfact state1shr minyr

024
'Loss d/s Uki & Eungella' 4.0 0.0 0 0 1 / node-type, group,evap,rain,trace
0 0 0.0 4 0                 / TS_file,dummy,dummy,Num_f_outf, ord_res

0.0       0.0               / flow, eff
50.0      10.0              /
100.0     20.0              /
10000     30.0              /

028
'BPW inflow' 0.0 0.0 0 0 1         / node-type, group,evap,rain,trace

018
'Bray Park Weir' 2.0 0.0 1 3 1     / node-type, group,evap,rain,trace
648 0 648 -1 5 0 0 0 10 7 0 1 0 007  / otime. owait,reces. factor..

0 0                         / Volume/Area
4 14.6             /
29 17              /
74 19.7                     /
280 26.1                    /
578 33.8                    /
648 35.5                    /
724 40.8                    /
850 43.4                    /
100.0E+06 200               /
```

```
0 0                     / Volume/Valve Discharge
648 181                 /
720 200
976 250
1e6 300

648 0                   / Volume/Spillway Discharge
850 2291                /
1090 6480               /
1290 11905              /
1580 18328              /
1810 25614              /
100.0E+06 100.0E+06     /

1                       / Number of states
1 1                     / State, number of groups
1                       /

378 378 378 378 378 378 378 378 378 378 378 378  1  /Dead storage Rule curve at 10cm below FL invert


019
'Murwillumbah HP Demand' 3.2 1.1 0 0 1       / node-type, group,evap,rain,trace
150000 3 24500 0 1 018 002 005 0 8    / Licvol pat dem ordtime ordfact ordres

0       80      /Restriction up to 80% imposed
10640   80
10641   85
13680   85
13681   90
15200   90
15201   100
30400   100


020
'Irrigators' 3.2 1.1 0 0 1 / node-type, group,evap,rain,trace
750 2 730 0 1 018 018 000 000 4  / licvol pat dem ordtim ordfact ordres res1 res2 1.2nd Norst

0.0     0.0             / Vol Factor
390.0   0.0             /
391.0   100.0           /
900.0   100.0           /


021
'Fish Ladder' 9.0 1.1 0 0 1 / node-type, group,evap,rain,trace
0 -1 1.0e8 0 0 018      / Licvol pat dem ordtime no_fmit ordres
3                       / no of FCT tables
1 018 0 0 0 24   / Type, CNode1, CNode 2, Prim Const, Sec Const, No. Table

1   11.5        /
31  11.5
32  20.0        / X value, Y Value
```

```
60  20.0
61  35.0          /
91  35.0
92  40.0          /
121 40.0
122 55.0          /
152 55.0
153 48.0          /
182 48.0
183 38.0          /
213 38.0
214 30.0          /
244 30.0
245 17.0          /
274 17.0
275 15.0          /
305 15.0
306 12.0          /
336 12.0
336 13.0          /
366 13.0

2 028 0 0 0 2               /

0.0      0.0                / X value, Y Value
1e6      1e6                /
2 029 0 0 0 2               /

0.0      0.0                / X value, Y Value
1e6      1e6                /

2                           / No. Levels
-1 1 1                      / Criteria, No. group, No. FCT
1
3 0 2                       /
2 3


022
'Dummy' 0.0 0.0 0 0 1 / node-type, group,evap,rain,trace


027
'EOS' 0.0 0.0 0 0 1 / node-type, group,evap,rain,trace


0                     / No risk function

1                     / No.of states
1 1                    / States of type

-1                    / No Resource Assessment
```

APPENDIX G

HUNTER WATER AUSTRALIA

COMMENTS ON PERFORMANCE CRITERIA

Hunter Water Australia Pty. Limited
ACN 080 869905

HUNTER WATER AUSTRALIA

8 – 10 Kings Road, Broadmeadow NSW 2292

PO Box 5007 Hunter Region MC NSW 2310 Phone (02) 4941 5888 Fax (02) 4941 5801

Wednesday, 16 August 2006

General Manager
Tweed Shire Council
PO Box 816
MURWILLUMBAH NSW 2484

ATTENTION: ANTHONY BURNHAM

Dear Anthony

TWEED SUPPLY SECURITY REVIEW –
COMMENTS ON PERFORMANCE CRITERIA

I refer to the workshop on 18 May 2006 and the subsequent teleconference on 22 June 2006 regarding the Tweed Supply Security Review project currently being undertaken by Sunwater for Tweed Shire Council. An action arising from the workshop and teleconference was for Hunter Water Australia to provide some comments on various performance criteria for inclusion in the Final Report currently being prepared by Sunwater.

The following comments are offered for inclusion in the report:

Water Supply Performance Criteria

Ideally, town water security (and associated water supply system yields) should be assessed using established performance criteria, as is becoming increasingly common in most major cities around Australia. Performance criteria should include both a *security of supply* component and a *level of service* component.

The security of supply (or reliability of supply) component would typically define the minimum total storage volume acceptable during the most severe drought of a particular climatic sequence (generally either a long term historical sequence, say 100 years, or a generated stochastic sequence, say 10,000 years). Typical security of supply criteria include:

- Total storage should not fall below a minimum total storage limit of say 30% during a repeat of the worst drought on record – which offers a buffer storage in the case of a more severe drought.

- Total storage should not fall below a minimum total storage of say 5% during an estimate of the worst possible drought - estimated using say a 10,000 year stochastic sequence.

Security of supply criteria will vary between authorities, depending on the type of catchment, climate and extent of drought contingency planning. At present, there is no generally accepted scientific method of determining optimum security of supply criteria. Generally speaking, an authority with high confidence in its ability to call on new or alternative sources of water in an extreme drought should be able to adopt lower values for security of supply criteria.

The level of service criteria would typically define the frequency and proportion of time in restrictions over a particular climatic sequence. Typical level of service criteria include:

- Restrictions occur no more than once in 10 years, on average.

- Restrictions are in place for no more than 5% of the time, on average.

Level of service criteria will also vary between authorities, depending on the values and expectations of the communities they service and their historical experience with drought periods and associated restrictions.

By adopting a combination of the above performance criteria, a water supply system can be designed with the primary objective of not running out of water and at the same time achieve an acceptable level of service, with restrictions not being imposed too often. This is in line with the recent urban water resource planning framework outlined by the Water Services Association of Australia (WSAA) and published in June 2005 (WSAA, 2005).

Historic No Failure Yield (HNFY)

The previous estimate of yield for the Tweed Water Supply System (Sunwater, 2002) was based on the HNFY, which is defined as the annual volume of water that can be supplied without failure (ie without applying restrictions and without running out of water) for every year of the analysis. The HNFY is basically a security of supply criteria that requires the system to not run out of water through a repeat of the historic climate sequence. By not including restrictions in the modelling of the historic climate sequence, an undefined ‘buffer storage’ is included as an additional performance criteria and is equivalent to the water saved by imposing restrictions during the worst case drought sequence. The extent of this buffer storage is dependent on the length of the worst case drought sequence and the effectiveness of restriction regimes and will therefore vary from system to system. In most cases, the volume of buffer storage that is effectively included in an assessment of HNFY is insufficient to guard against more severe climate conditions and/or to cater for the uncertainty in the modelling (including demand assumptions).

Assessing a water supply system on the basis of HNFY effectively ignores the consideration of levels of service criteria, such as the frequency and length of time in restrictions.

HNFY is no longer considered an adequate measure for assessing water supply system performance and as such, should not be relied upon for defining the yield of a water supply system.

DEUS Performance Criteria

The Department of Energy, Utilities and Sustainability (DEUS) defines level of service standards for NSW town water supplies. The DEUS level of service criteria are:

- Restrictions imposed no more than 5% of the time [5% rule]

- Restriction imposed no more frequently than every 10 years on average [10% rule]

In addition, DEUS also specifies a security of supply criteria, viz:

- The system should be able to supply 80% of normal demand (20% reduction) through a repeat of the worst drought on record (starting at the storage level at which restrictions should be first applied to satisfy the 5% and 10% rule) [20% rule]

The 20% rule effectively includes a buffer storage allowance in the assessment of system yields. The buffer storage is equivalent to the difference in system storage between full supply capacity and the storage level at which restrictions are introduced. However, similar to the buffer storage included in an assessment using HNFY, the actual extent of the buffer storage is not defined and will vary from system to system. In addition, the assumed average demand reduction of 20% is generally too optimistic for most systems and consequently has the effect of reducing the effective buffer storage included in the assessment.

An assessment of existing Tweed water supply system using the DEUS criteria results in a system yield higher than the yield that was determined using the HNFY approach. This suggests that the effective buffer storage included in the DEUS criteria assessment is actually less than the buffer storage included in the HNFY approach.

Therefore, although the DEUS criteria approach does include consideration of appropriate level of service criteria, the effective buffer storage allowance is still not defined and is not considered to be sufficient for the Tweed water supply system.

State Water Performance Criteria

Town water security is not explicitly defined in a river regulated by DNR and State Water. However, State Water generally uses a security of supply criteria only, with town water supply (along with other 'high security' water supply) being nominally guaranteed through a repeat of the worst drought on record plus up to an additional full year of restricted supply. This is similar to saying that total system storage should not fall below a minimum total storage equivalent to one year restricted supply (plus any expected inflows and losses) during a repeat of the worst drought on record.

This minimum total storage volume is referred to as the carry over reserve (COR) and is used in the resource assessment for the river. The COR is used in the calculation of the irrigation allocation for any given month. It is added to the town water requirements for the remainder of the water year and forms part of the essential storage requirements for the dam that must be satisfied before water is made available for irrigators.

The State Water performance criteria include a more specific buffer storage allowance of one year restricted supply (plus consideration of inflows/losses). The buffer storage or COR has to be specified as it is used in the resource assessment for the regulated river and directly impacts on the volume of water available for general security irrigators. However, the State Water performance criteria do not include level of service criteria and unrealistically assume that restrictions are not applied unless a drought sequence more severe than the worst on record is experienced.

Proposed Interim Performance Criteria

It is suggested that a hybrid water resource planning approach be adopted for assessing town water security (and associated water supply system yields) for the Tweed water supply system. The proposed approach is in line with the urban water resource planning framework outlined by WSAA (WSAA, 2005), and is effectively a hybrid of the DEUS criteria and the State Water criteria.

The proposed interim performance criteria include a security of supply component (including a defined buffer or contingency storage) and a level of service component (refer to Table A below).

Table A Proposed Interim System Performance Criteria – Tweed Water Supply System

Security of Supply	Total storage should not fall below a minimum total storage (buffer or contingency storage) - equivalent to one year restricted supply (plus any expected inflows and losses) during a repeat of the worst drought on record.
Level of Service	➢ Restrictions imposed no more than 5% of the time ➢ Restriction imposed no more frequently than every 10 years on average

The level of service criteria are in line with many other major population centres across Australia. In the absence of stochastic modelling (ie the use of synthetically generated climate sequences of around 10,000 years) a contingency storage criteria is considered to be the preferred approach for assessing security of supply.
The contingency storage is effectively the volume of water reserved in storage to take into account future uncertainties, such as:

- Unprecedented climatic fluctuations / variability
- Long term climate change
- Higher than anticipated demand / population growth
- Modelling uncertainties

The size of the contingency storage should also depend on other factors, such as:

- The consequence of a community running out of water
- The additional cost associated with reserving the contingency volume
- The time required to put in place emergency supply options

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In the absence of a more detailed assessment, it is suggested that a contingency storage allowance of one year restricted supply (plus any expected inflows and losses) be adopted for the Tweed water supply system. The desired long term security of supply and level of service standards should be determined in association with Tweed community and with reference to a more detailed assessment of the consequences of restrictions and supply shortfalls.

If you have any queries, please ring me on 02 4941 5816 or send an email to cameron.smith@hwa.com.au.

Yours faithfully

CAMERON SMITH
Senior Civil Engineer

APPENDIX H

DEUS SUMMARY

Explanatory Notes for DEUS Criteria

The Department of Energy, Utilities and Sustainability (DEUS) criteria specify that the yield must be such that the restricted yield can still be obtainable if the worst drought is in action. Therefore, to satisfy the DEUS criteria, four conditions should be satisfied. They are:

1. restrictions no more than 5% of the time

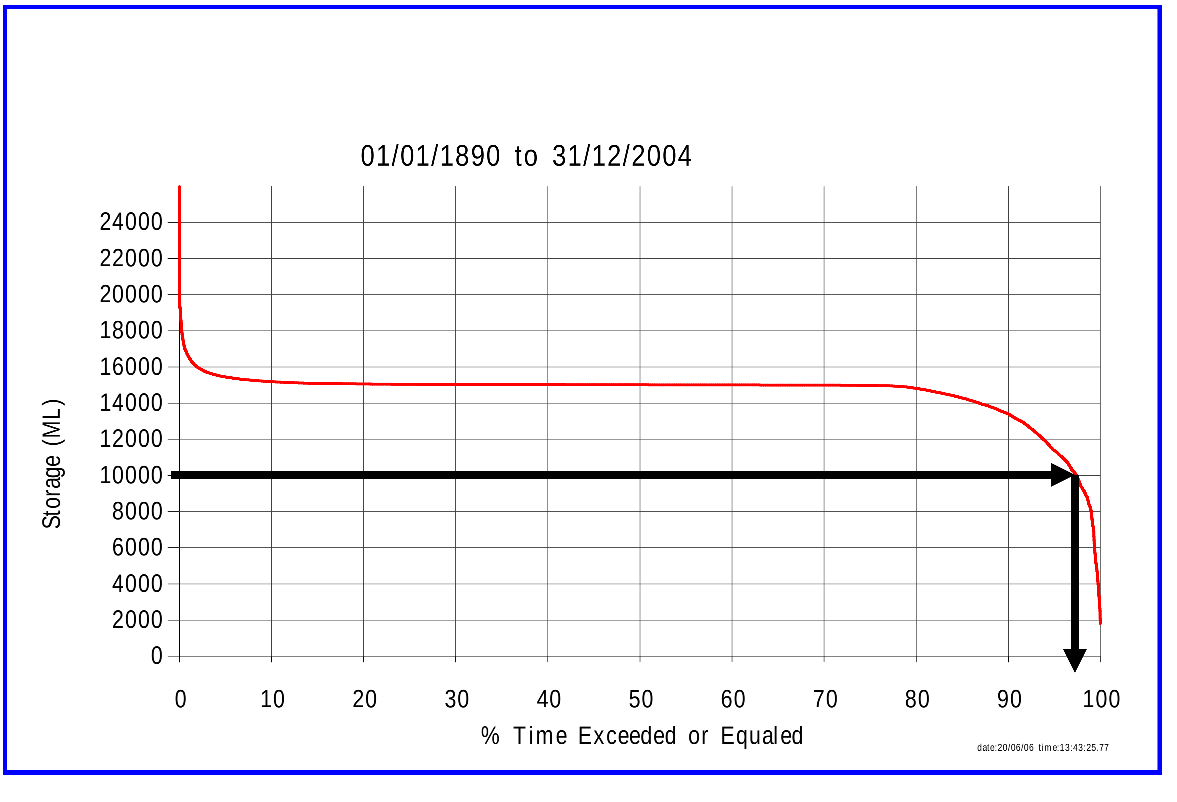
2. restrictions to have a frequency of no more than 1 in 10 years, on average

3. a 20% reduction in consumption to be assumed

4. must not run out of restricted water in the storage in the worst drought, with the storage starting at the restriction trigger level.

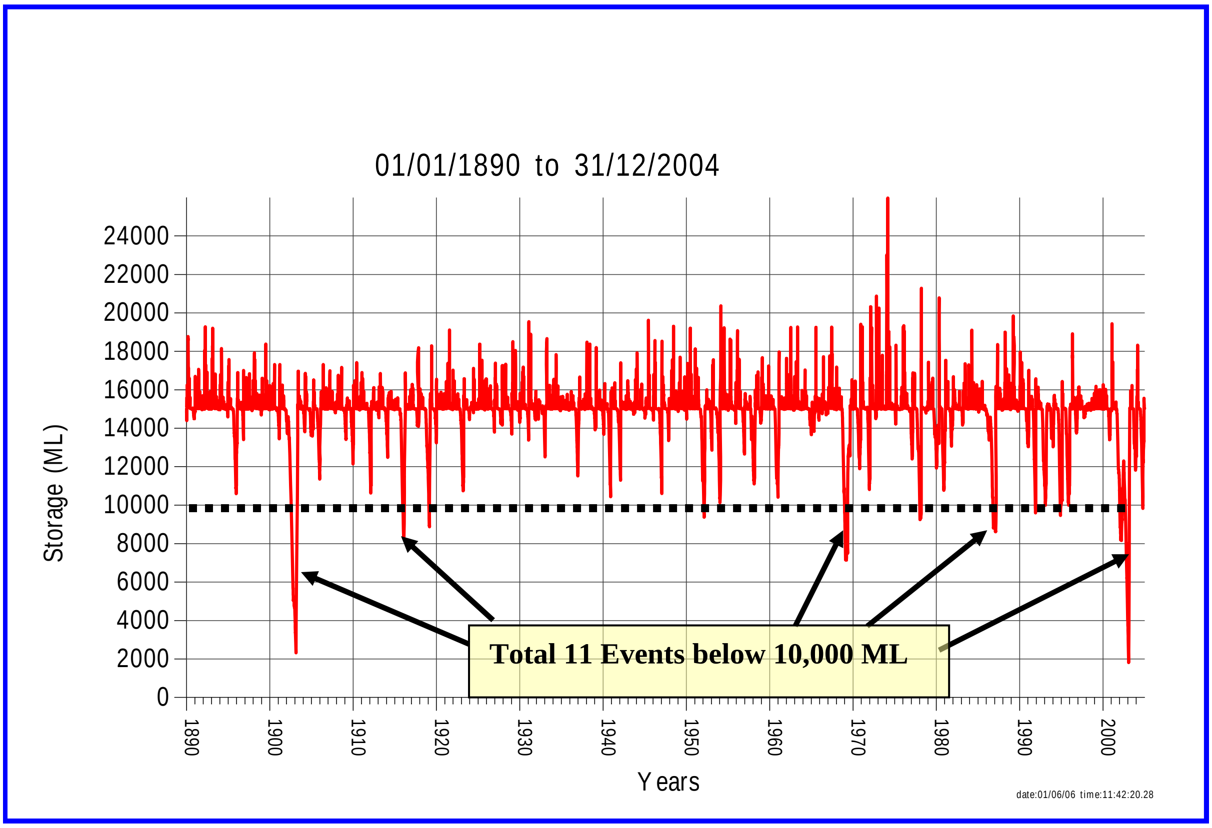
<u>Checking for Condition 1</u>

Restrictions should be less than 5% of the total simulation period. This can easily be tested from the ranked plot of storage levels. Following example is for Case 4B (i.e. the restriction level is at 10,000 ML). According the plot, volume of CHD is less than the 5% of the time below 10,000 ML.



Checking for Condition 2

To test the condition 2, count the number of event below the restriction level (eg. Below 10,000 ML) continuous storage plot of CHD.

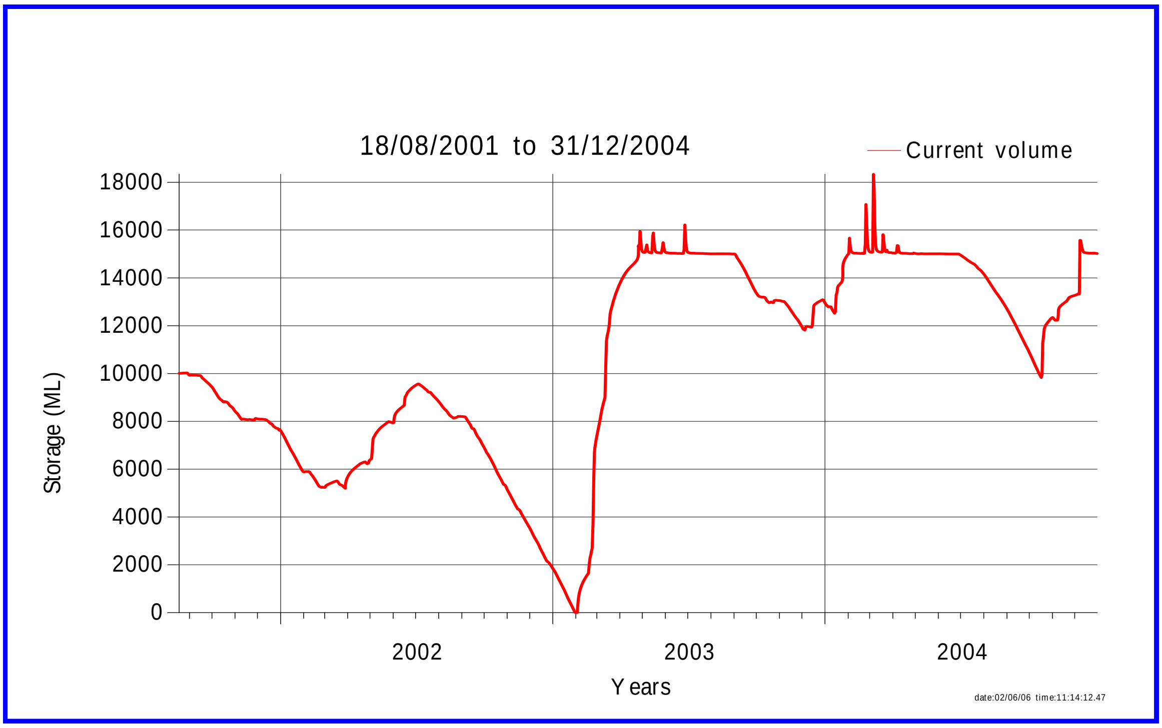


Condition 3

In the model, 80% reduction in the demand of town water supply when storage level of CHD below 10,000 ML were incorporated.

Condition 4

Check whether 80% demand can be supplied if the worst drought (2001/03 flow sequence) occurs when the storage is at the restriction trigger level (10,000 ML). Following figure shows the condition.



This testing process is an iterative one. First restriction level should be determined and then other conditions should be tested.

APPENDIX I

SCENARIO RESULTS

TABLE I1: SCENARIO RUNS AND RESULTS

Case	Description	Evaluation for	System Variables										Additional Comments	Results: Murwillumbah TWS				
			CHD		BCD		Bray Park Weir		Demand		Restriction Levels	Contingency Storage						
			Volume (ML)	EF	Volume (ML)	EF	EF	Fish Ladder Operation	TWS	Irrigation				Yield (ML/a)		Monthly Reliability	No of Restrictions	Other
1	System HNFY	For comparison with previous studies	15,000	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	vary	Existing (730 ML/a)	No restriction for TWS	Dead storage	For comparison to May 2002 report. HNFY (2002) = 18,000 ML/a	16,200		100	n/a	
1A1	System HNFY with 80% EF d/s of both CHD & BPW, with no contingency storage	To see the effect of different EF conditions	15,000	80%	n/a	n/a	80%	-	vary	Existing (730 ML/a)	No restriction for TWS	Dead storage	To assess impact	9,900		100	n/a	
1A1b	System HNFY with 80% EF only d/s of BPW, contingency storage	To see the effect of different EF conditions	15,000	Existing	n/a	n/a	80%	-	vary	Existing (730 ML/a)	TSC start at 10,300	5,600 ML	To assess impact	7,000		100	36	
1A2	System HNFY with 95% EF d/s of both CHD & BPW, with no contingency storage	To see the effect of different EF conditions	15,000	95%	n/a	n/a	95%	-	vary	Existing (730 ML/a)	No restriction for TWS	Dead storage	To assess impact	13,990		100	n/a	
1A3	System HNFY with 95% EF only at BPW, with no contingency storage & no restriction	To see the effect of different EF conditions	15,000	Existing	n/a	n/a	95%	-	vary	Existing (730 ML/a)	No restriction for TWS	Dead storage	For comparison to May 2002 report. HNFY (2002) = 14900 ML/a	14,000		100	n/a	
1A4	System HNFY with 95% EF only at BPW, with no contingency storage but with restriction	To see the effect of different EF conditions	15,000	Existing	n/a	n/a	95%	-	vary	Existing (730 ML/a)	TSC, start at 7,500 ML	Dead storage	For comparison to May 2002 report. HNFY (2002) = 16700 ML/a	15,000		100	5	
1A4b	System HNFY with 95% EF only at BPW, with contingency storage and restriction	To see the effect of different EF conditions	15,000	Existing	n/a	n/a	95%	-	vary	Existing (730 ML/a)	TSC, start at 11,540 ML	8,080 ML	C.S. = 80% x 10,100	10,100		100	9	
1B	Identical to case 1, utilising the new data series up to 2001	For comparison with 2002 study	15,000	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	vary	Existing (730 ML/a)	n/a	Dead storage	Includes the new data up to 2001. removes impact of 2002/03 drought	16,600		100	n/a	
1C	New case according to AB's email on 01/02/07	HNFY (system)	15,000	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	vary	Existing (730 ML/a)	n/a	Dead storage	Include 2002 data series in new model (required some modification to allow it to be used in 2006 Model). Result was 16600 ML/a	Two different models and results cannot be compared		100	n/a	
2	System yield with TSC restriction, no contingency storage & existing EF d/s CHD & BPW	To see the effect of different EF conditions	15,000	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	vary	Existing (730 ML/a)	TSC, start at 7,500 ML	Dead storage	For comparison to July 2002 report, in the 2002 study 18500 ML/a	17,150		100	5	
3	System yield with restriction & a contingency storage	For comparison	15,000	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	vary	Existing (730 ML/a)	TSC, start at 11,700 ML	8,400 ML	contingency storage = 80 % of current demand (i.e. 10900ML) =8700 ML	10,500		100	4	
4B	System yield under DEUS 5/10/20 rule with existing EFs	To check the current operating regime	15,000	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	vary	Existing (730 ML/a)	10,000 ML	Dead storage	Restriction should be a 20% reduction of average demand with the restriction.	16,900		100	11	
4C	System yield under DEUS 5/10/20 rule with existing EF d/s of CHD & 95% d/s of BPW	For comparison with Case 4	15,000	Existing	n/a	n/a	95%	-	vary	Existing (730 ML/a)	9,000 ML	Dead storage	Restriction should be a 20% reduction of average demand with the restriction.	13,750		100	7	
5	HNFY of Stand alone CHD for varying Capacities	HNFY (CHD Stand-Alone) - Development of storage-yield curve	vary	n/a	n/a	n/a	n/a	n/a	vary	n/a	n/a	Dead storage	The 2002 study a 15,000 ML capacity of CHD provided a stand alone HNFY yield of 10800 ML/a	CHD Capacity (ML)	Yield (ML/a)			
														5,000	5,250	100	n/a	
														10,000	8,400	100	n/a	
														15,000	11,500	100	n/a	
														20,000	14,600	100	n/a	
														25,000	17,700	100	n/a	
														35,000	23,800	100	n/a	
														45,000	27,500	100	n/a	
6	Pipeline from CHD												Not proceed with, see Section 6.3.5 of the report					
7	HNFY of Stand alone of proposed BCD for varying Capacities	HNFY (BCD Stand-Alone)- Development of storage-yield curve	n/a	n/a	vary	n/a	n/a	n/a	vary	n/a	n/a	Dead storage	To assess potential	BCD Capacity (ML)	Yield (ML/a)			
														5,000	5,000	100	n/a	
														15,000	11,500	100	n/a	
														20,000	14,400	100	n/a	
														25,000	16,600	100	n/a	
														45,000	23,600	100	n/a	
														58,000	25,500	100	n/a	
8A	System HNFY for varying CHD capacities with existing Efs	HNFY (system)	vary	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	vary	Existing (730 ML/a)	n/a	Dead storage	To assess potential	CHD Capacity (ML)	Yield (ML/a)			
														5,000	8,400	100	n/a	
														15,000	16,200	100	n/a	
														20,000	18,700	100	n/a	
														25,000	21,200	100	n/a	
														35,000	26,300	100	n/a	
														45,000	31,700	100	n/a	
8A_1	System yield with various CHD capacities for existing EF d/s CHD & 95% EF d/s of BPW and contingency storage	System yield	15000	Existing	n/a	n/a	95%	-	vary	Existing (730 ML/a)	11,540	8,080	contingency storage = 80 % of current demand	10,100		100	9	
8A_2			20000								14,800	9,600	"	12,000		100	7	
8A_3			25000								18,100	11,200	"	14,000		100	9	
8A_4			35000								24,700	14,400	"	18,000		100	7	
8A_5			45000								31,300	17,600	"	22,000		100	7	

Case	Description	Evaluation for	System Variables										Additional Comments	Results: Murwillumbah TWS				
			CHD		BCD		Bray Park Weir		Demand		Restriction Levels	Contingency Storage		Yield (ML/a)		Monthly Reliability	No of Restrictions	Other
			Volume (ML)	EF	Volume (ML)	EF	EF	Fish Ladder Operation	TWS	Irrigation								
8B	System HNFY for existing 15,000 ML at CHD & additional varying storage at the proposed BCD, existing Efs	System yield	15000	Existing	vary	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	vary	Existing (730 ML/a)	n/a	Dead storage	To assess potential	15 GL of CHD + BCD Capacity (ML)	Yield (ML/a)			
														5,000	19,300	100	n/a	
														15,000	24,300	100	n/a	
														20,000	26,900	100	n/a	
														25,000	29,500	100	n/a	
														45,000	38,400	100	n/a	
														58,000	42,600	100	n/a	
8B_1	System yield with existing CHD & various BCD capacities for existing EF d/s CHD, 95% EF d/s of BCD & BPW and contingency storage	System yield	15000	Existing	20000	95%	95%	-	vary	Existing (730 ML/a)	TSC	15,200 ML		19,000		100	13	
8B_2					25000						TSC	16,800 ML		21,000		100	12	
9	Additional existing System investigations to determine storage behaviour with existing EFs , no contingency or restrictions	System performance	15,000	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	Existing (10,900 ML/a)	Existing (730 ML/a)	n/a	Dead storage		10,900		100	n/a	
10		System performance	15,000	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	75,000 people (11,250 ML/a)	Existing (730 ML/a)	n/a	Dead storage		11,250		100	n/a	
11		System performance	15,000	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	125,000 people (18,125 ML/a)	Existing (730 ML/a)	n/a	Dead storage		18,125		99.78	n/a	2 failures
12		System performance	15,000	Existing	n/a	n/a	n/a	Current rule of 0 - 25 ML/d when storage > 405 ML	175,000 people (24,500 ML/a)	Existing (730 ML/a)	n/a	Dead storage		24,500		98.91	n/a	4 failures
12B	Additional existing System investigations to determine contingency storage impacts with existing EF d/s of CHD, 95% EF d/s BPW & contingency storage	System performance	15,000	Existing	n/a	n/a	95%	-	Existing (10,900 ML/a)	Existing (730 ML/a)	TSC, start at 11,860 ML	8,720 ML		10,900		98.7	17	
12C		System performance	15,000	Existing	n/a	n/a	95%	-	75,000 people (11,250 ML/a)	Existing (730 ML/a)	TSC, start at 12,000 ML	9,000 ML		11,250		98.68	18	
12D		System performance	15,000	Existing	n/a	n/a	95%	-	125,000 people (18,125 ML/a)	Existing (730 ML/a)	TSC, start at 14,750 ML	14,500 ML		18,125		5	110	
12E		System performance	15,000	Existing	n/a	n/a	95%	-	175,000 people (24,500 ML/a)	Existing (730 ML/a)	-	19,600 ML	contingency storage > FS volume of the dam according to 80% demand rule	-				
12F	Yield without failure	System performance	15,000	Existing	n/a	n/a	95%	-	67,300 people	Existing (730 ML/a)	TSC, start at 11,540 ML	8,080 ML		10,100		100	9	
13	System performance with CHD 45,000 ML, contingency storage, 175,000 persons, EF 95% only at BPW	System performance	45,000	Existing	n/a	n/a	95%	Cease to pump when inflow < 95% flow	175,000 people (24,500 ML/a)	Existing (730 ML/a)	TSC, start at 32,300 ML	19,600 ML		24,500		99.70	10	
14	System performance with CHD 45,000 ML, Proposed BCD 15,000 ML, contingency storage, 175,000 persons, EF 95% at BCD & BPW	System performance	45,000	Existing	15,000	95%	95%	Cease to pump when inflow < 95% flow	175,000 people (24,500 ML/a)	Existing (730 ML/a)	TSC	19,600 ML		24,500		100	3	
15A	Determine Capacity of Proposed BCD for CHD 35,000 ML, contingency storage, 175,000 persons, EF 95% at BCD & BPW	Optimised BCD storage (13 GL)	35,000	Existing	to be optimised	95%	95%	Cease to pump when inflow < 95% flow	175,000 people (24,500 ML/a)	Existing (730 ML/a)	TSC	19,600 ML	contingency storage = 80 % of annual demand = 0.8 * 24,500 = 19600 ML	24,500		100	8	13,000 ML of BCD capacity
15B	Determine Capacity of Proposed BCD for CHD 15,000 ML, contingency storage, 125,000 persons, EF 95% at BCD & BPW	Optimised BCD storage	15,000	Existing	to be optimised	95%	95%	Cease to pump when inflow < 95% flow	125,000 people (18,125 ML/a)	Existing (730 ML/a)	TSC	14,500 ML	contingency storage = 80 % of annual demand = 0.8 * 18,125 = 14,500 ML	18,125		100	24	15,000 ML of BCD capacity
15B_2	Determine Capacity of CHD with contingency storage, 125,000 persons, EF 95% at BPW	Optimised CHD storage (35 GL)	to be optimised	Existing	n/a	n/a	95%	Cease to pump when inflow < 95% flow	125,000 people (18,125 ML/a)	Existing (730 ML/a)	TSC, start at 24,750 ML	14,500 ML	contingency storage = 80 % of annual demand = 0.8 * 18,125 = 14,500 ML	18,125		100	7	35,000 ML of CHD capacity
15C	Determine Capacity of Proposed BCD for CHD 15,000 ML, contingency storage, 175,000 persons, EF 95% at BCD & BPW	Optimised BCD storage	15,000	Existing	to be optimised	95%	95%	Cease to pump when inflow < 95% flow	175,000 people (24,500 ML/a)	Existing (730 ML/a)	TSC	19,600 ML (5880 & 13720)	contingency storage = 80 % of annual demand = 0.8 * 24,500 = 19600 ML	24,500		100	7	35,000 ML of BCD capacity
16	Determine the population can be supplied from CHD 45,000 ML, contingency storage, EF 95% only at BPW	Population that can be supplied	45,000	Existing	n/a	n/a	95%	Cease to pump when inflow < 95% flow	vary	Existing (730 ML/a)	TSC, start at 31,300 ML	17,600 ML	Demand and therefore contingency storage will be variables	22,000		100	5	155,000 of population
17	Determine the impact of Raising BPW by 200mm for CHD 45,000 ML, contingency storage, 175,000 persons, EF 95% only at BPW	Rerun Case 13 with increased BPW volume (720 ML)	45,000	Existing	n/a	n/a	95%	Cease to pump when inflow < 95% flow	175,000 people (24,500 ML/a)	Existing (730 ML/a)	TSC, start at 32,300 ML	19,600 ML	contingency storage = 80 % of annual demand = 0.8 * 24,500 = 19600 ML	24,500		99.71	8	

APPENDIX J

TRANSMISSION LOSS

INVESTIGATIONS

Loss Estimates from Clarrie Hall Dam to Bray Park Weir

Clarrie Hall Dam to Uki Gauge

Estimated releases from CHD, recorded flows at Uki and Eungella, and recorded storage levels at BPW were used to estimate the losses between CHD and BPW. Estimated releases from CHD, based on either recorded valve openings or on a basic water balance, are compared with recorded flows at Uki, as shown in Figure I.1.

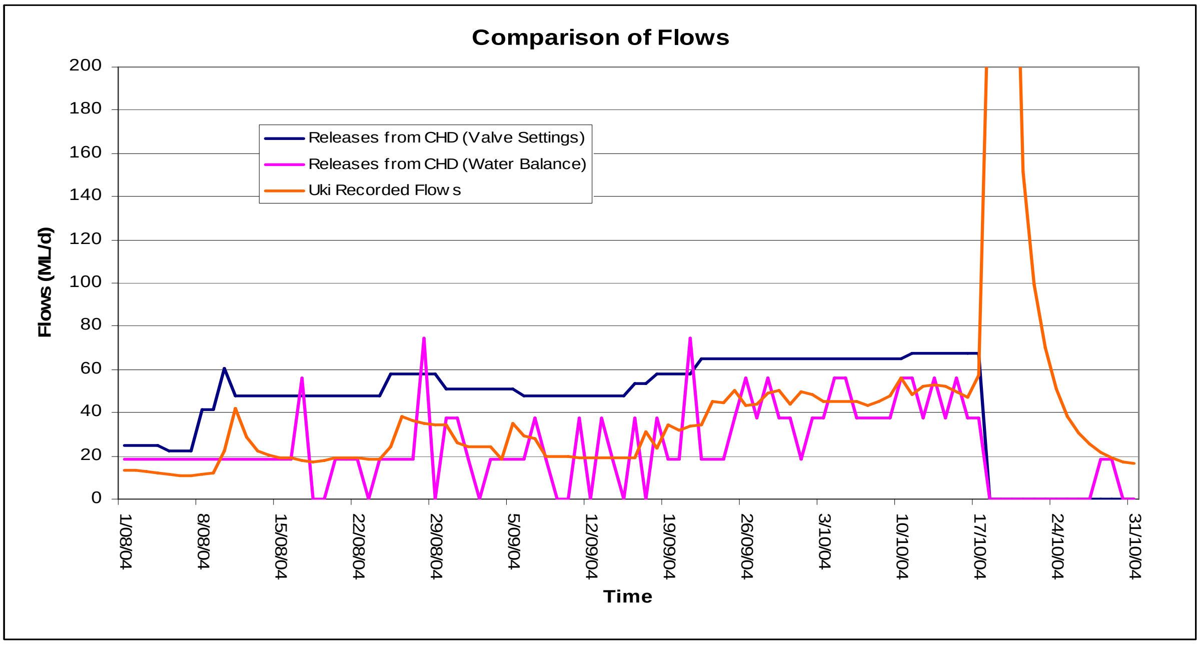


Figure I.1: Comparison of Flows at Uki

As can be seen from the graph, for all of the time, the recorded Uki flow was less than the estimated releases from CHD based on valve opening. However, the releases based on the water balance are of the same magnitude as Uki flows. Therefore, there is considerable doubt about the accuracies of the releases based on valve ratings.

Although the water balance contains some variations in flow, overall the pattern matches the recorded Uki flows and the volumes are very similar for the period. From this data, there does not appear to be significant indication of losses experienced in this reach of the river.

A factor was then applied to the CHD releases to see if a reduction on valve releases could achieve a more acceptable fit. The factor of 0.4 gave a somewhat acceptable match as shown in Figure I.2.

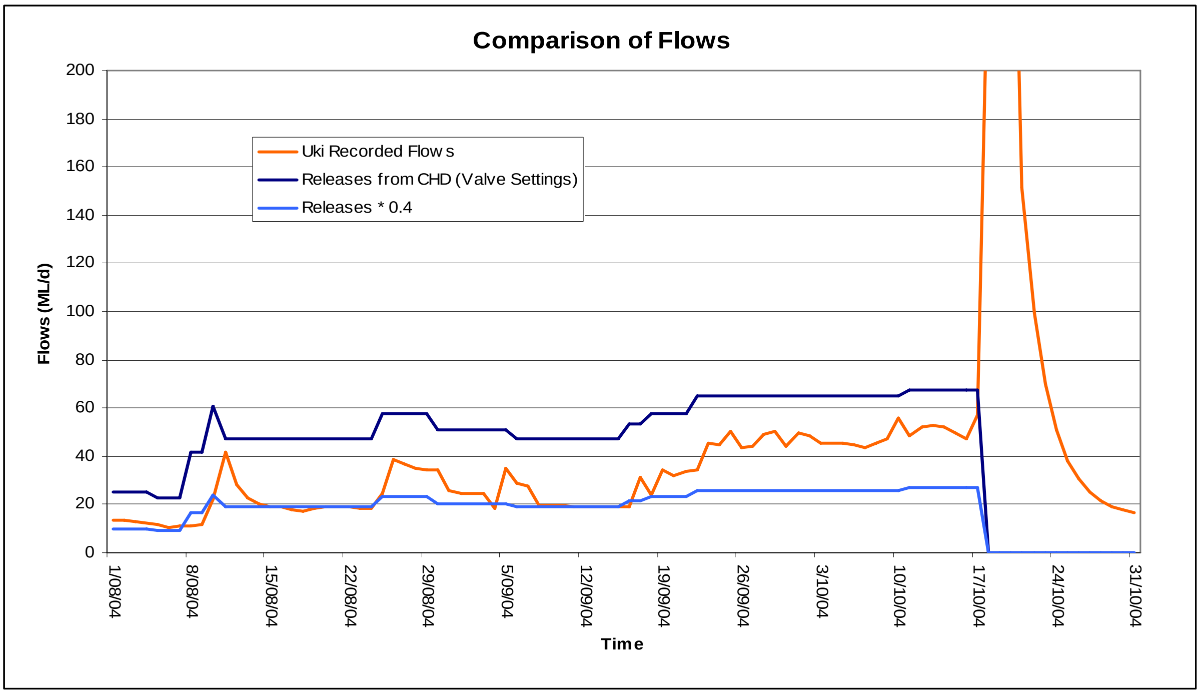


Figure I.2: Valve Reduction Factor Application

Based on this set of data, either the loss between CHD and Uki is about 60%, or there is serious doubt about the accuracy of these estimates of CHD releases. Possible diversions of the reach were not considered and that might also cause an error.

Due to the number of inaccuracies highlighted by this data, it was not possible to determine any type of relationship between releases from Clarrie Hall dam and transmission losses in the stream down to Uki. It is essential that the exact volumes of water released from Clarrie Hall Dam be determined before any further analyses can be undertaken.

Uki Gauge to Bray Park Weir

Although the estimated storage volumes from the recorded stage at BPW were available, there was no available record of fish ladder releases. BPW volumes for the considered period (1/08/2004 – 17/10/2004) were above the fish ladder invert and therefore, continuous outflow would have happened.

Without considering any possible fish ladder releases, the combined flows of Uki and Eungella were plotted against the daily volume change of BPW as shown in Figure I.3. No allowance was made for inflows downstream of the two gauges. The daily extraction by Murwillumbah for the town water supply was then included with the change in volume.

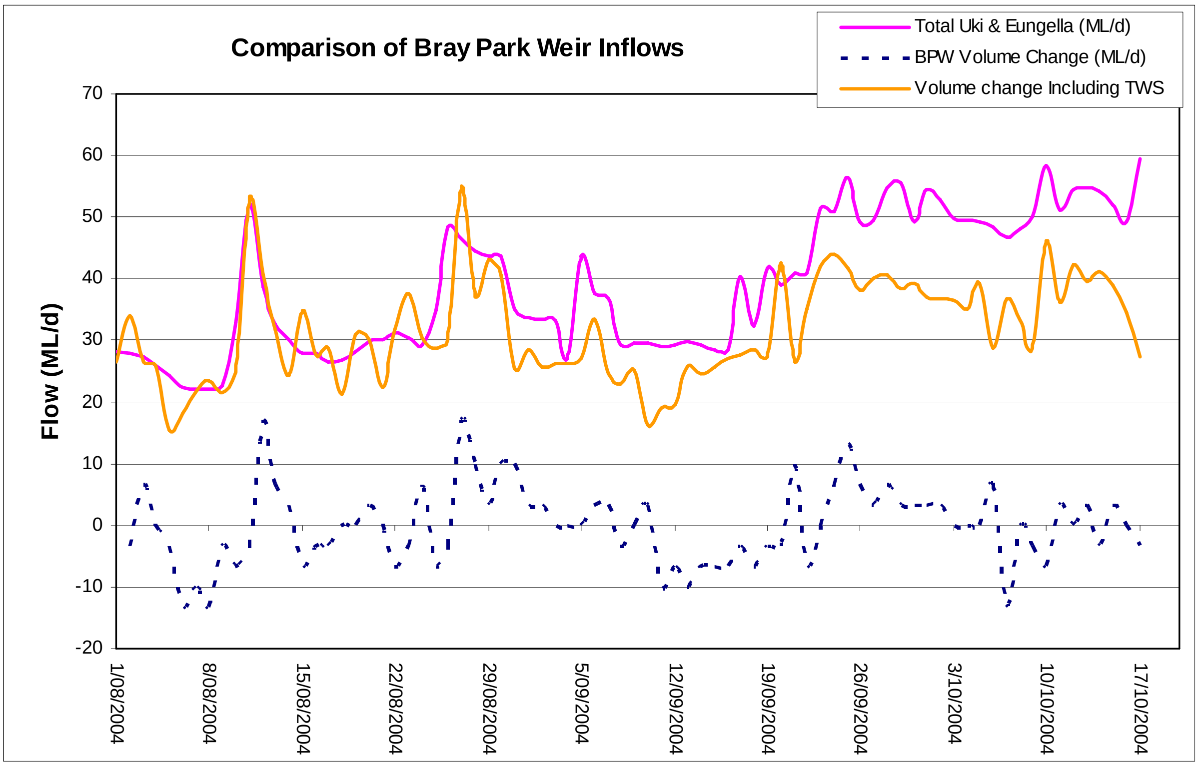


Figure I.3: Bray Park Weir Inflows

Figure I.3 shows a reasonable correlation between inflows and change in volumes, particularly in the early portion. However, the differences do not show any discernable pattern. However, there is no record of residual inflows downstream of the gauges to explain the differences, and so the water balance between Uki and BPW could not be performed.

Based on this dearth of factual information, the loss calculation between Clarrie Hall Dam and Bray Park Weir could not be performed accurately. There is no advantage to analysing this data further in an attempt to estimate the losses using the water balance method.

Therefore, a field measurement method is strongly recommended for the assessment of losses, as well as confirmation of the exact releases from Clarrie Hall Dam with respect to valve openings.

STAND-ALONE AND SYSTEM YIELDS OF CLARRIE HALL AND BYRRILL CREEK DAMS

Stand-alone Clarrie Hall Dam

A HNFY analysis was carried out for Clarrie Hall Dam to determine the storage-yield curve for the dam as a stand-alone entity. A simplified version of the IQQM was set up for Clarrie Hall Dam. The model was run for a range of storage volumes. For each case, the same spillway characterises were assumed. The HNFYs for different Clarrie Hall Dam volumes are given in Table H2.

System Yields with Clarrie Hall Dam

The total system was analysed with different Clarrie Hall Dam capacities. Operational conditions were the same as for the existing system. Neither restrictions nor a contingency storage was included. The system HNFYs for different Clarrie Hall Dam volumes are given in Table I2.

Table I2: HNFY for Clarrie Hall Dam Stand-alone and the System

Clarrie Hall Dam Capacity (ML)	Clarrie Hall Dam Stand-alone HNFY (ML/a)	System HNFY (ML/a)
5,000	5,200	8,400
15,000	11,500	16,200
20,000	14,600	18,700
25,000	17,700	21,200
35,000	23,800	26,300
45,000	27,500	31,700

Stand-alone Byrrill Creek Dam

The storage-yields for the single storage, HNFY for a range of the Byrrill Creek Dam capacities were calculated. A simple IQQM model with an inflow node representing the flow upstream of Byrrill Creek Dam and a demand node was set up with the simulated inflow and evaporation time series of Byrrill Creek Dam. The spillway and valve characteristics of

Clarrie Hall Dam were assumed for Byrrill Creek Dam. The model was run for a range of storage volumes and the maximum demand supplied without failure was determined. The HNFYs for different Byrrill Creek Dam volumes are given in Table H3.

System Yields with Byrrill Creek Dam

The system yields were also determined for a range of capacities of Byrrill Creek Dam (BCD) with Clarrie Hall Dam (CHD) at its present capacity (15,000 ML of commandable capacity). The fish ladder was operated to release up to 25 ML/d of flow when Bray Park Weir storage was greater than 405 ML. It was assumed that 730 ML/a irrigation demand was supplied from Bray Park Weir when its storage was greater than 405 ML. Both Clarrie Hall Dam and Byrrill Creek Dam storages were allowed to drop down to the minimum operating volume to supply the demand. The system HNFYs for different Byrrill Creek Dam volumes with 15,000 ML capacity of Clarrie Hall Dam are given in Table I3.

Table I3: HNFY for Byrrill Creek Dam Stand-alone and the System

Byrrill Creek Dam Capacity (ML)	Byrrill Creek Dam Stand-alone HNFY (ML/a)	System HNFY (ML/a)
5,000	5,000	19,300
15,000	11,500	24,300
20,000	14,400	26,900
25,000	16,600	29,500
45,000	23,600	38,400
58,000	25,500	42,600